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Localization and driving behavior classification using smartphone sensors in the direct absence of GNSS

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INTRODUCTION

The objective of this research is to present a framework for the vehicle localization and monitoring and modeling of driving behavior in indoor facilities, or –more generally– facilities where GNSS information is not available.
Several broad sources of information can be considered:

- Point measurements of vehicle crossings
- Point-to-point measurements
- Localization of vehicles equipped with some other type of sensor, interacting with an access-point or other type of infrastructure; and
- Sensors (such as accelerometers and gyroscopes) available on-board the vehicle or on nomadic devices (such as smartphones)

LOCALIZATION TECHNOLOGIES, NEEDS AND METHODOLOGY ADOPTED

- **3D Positioning and Navigation of Vehicles for ITS**

In indoor parking garages the navigation solution may involve GNSS to get initial location information near the entrance, which is then propagated in time using other navigation sources. An overview of the most commonly used positioning sensor technologies and their typical accuracy metrics in given in Table 1.

	Sensor / technique	Navigation information	Typical accuracy
Radio frequency (RF)	GPS position GPS velocity	X, Y, Z v_x, v_y, v_z	~10 m (DGPS 1-3 m) ~0.05 m/s, ~0.05 m/s, ~0.2 m/s
	pseudolites	X, Y, Z v_x, v_y, v_z	comparable to GNSS
	UWB	X, Y, Z	dm-level
	IEEE 802.11 fingerprinting	X, Y	3-5 m
	Bluetooth (e.g. BLE)	X, Y	1-2 m
	RFID cell-based RFID fingerprinting	X, Y X, Y	depends on cell size 1-3 m
INS	accelerometer	a_{tan}, a_{rad}, a_z	<0.03 m/s²
	gyroscope	heading ϕ	0.5°-3°
Optical systems	Image-based	X, Y, Z	few meters
	optical sensor network	X, Y, (Z optional)	few meters
	laser	X, Y, Z	cm to dm
Others	digital compass/ magnetometer	heading ϕ	0.5°-3°
	barometric pressure sensor	Z	1-3 m
	temperature sensor	T	0.2°-0.5° C

Table 1: Commonly used sensor types for navigation support in ITS applications

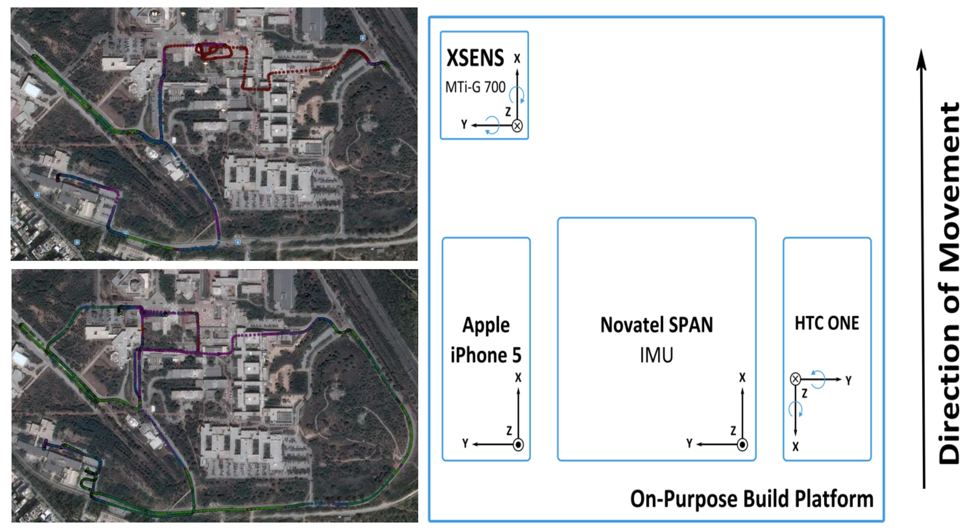
- **Wireless Sensor Networks-Aided Indoor Positioning**

The dynamic nature of the radio environment makes the employment of fingerprinting algorithms infeasible, and therefore triangulation algorithms are recommended. Range-based positioning algorithms may use: (i) Mobile Terminal-based indoor positioning systems, (ii) Mobile Terminal-assisted indoor positioning system designs, (iii) Indoor Positioning with beacons and (iv) Indoor Positioning with moving beacons.

- **Positioning Requirements in Parking Facilities and Monitoring Approach Adopted**

This study concentrates on testing the capabilities and potential of sensors found in common smart mobile phones. Particularly, it attempts an initial sensor capability characterization and driving behavior classification through studying patterns in the raw data distributions. Testing focuses on acceleration and gyroscope observations.

CASE STUDIES SET UP AND DATA ACQUISITION



(a) (b)
Figure 1 (a-b): (a) Field test trajectories (b) sensor colocation diagram

Data collection was implemented in a small indoor parking facility and segments with open spaces. Driving speed range was constrained to normal city driving speeds, whereas higher acceleration / deceleration values were pursued at straight segments. The traveled trajectory included discrete scenarios, simulation of aggressive and stressful conditions and driving a ramp inside a parking garage upwards and downwards.

ASSESMENT OF NAVIGATION SOLUTION

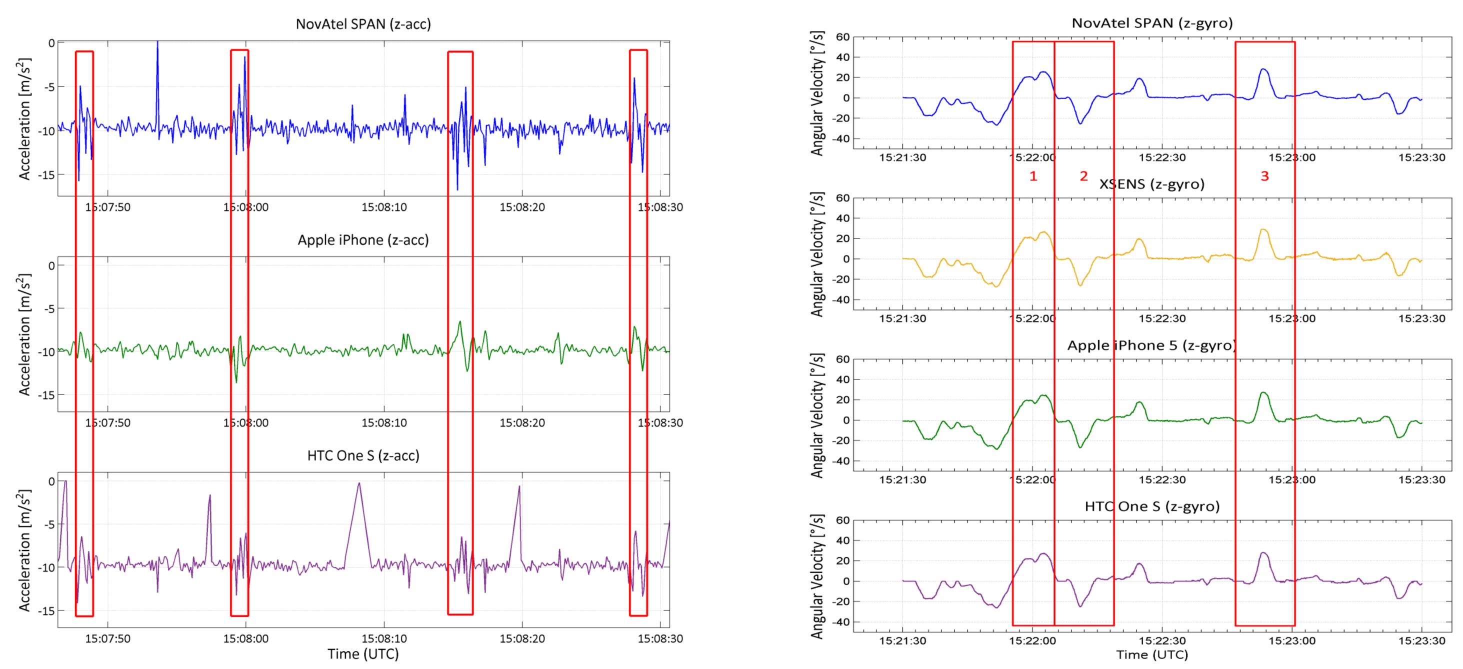


Figure 2 : Interpretation of sensor data

All devices involved in the test successfully detected all events. Visible changes of acceleration values of an abrupt character are observed for all recording devices and for all four speed hump locations. Notably, the excessive noise in the SPAN data is due to unsmoothed observables

DRIVER BEHAVIOR CLASSIFICATION ANALYSIS

A more macroscopic analysis of the driver behavior includes the defining of the **optimal number of clusters** with the package "ClusterCrit", within the R software for statistical computing. The K-means algorithm was used. Internal indices provide insight supporting the choice of the optimal number of clusters. External indices measure the similarity between two partitions, mainly two clustering alternatives, taking into account only the distribution of the data in the different clusters.

Internal Index	Optimal number of clusters		
	NTUA-1	NTUA-2 (no gyros)	NTUA-2
Ratkowsky_Lance (rule: max)	3	3	3
Dunn (rule: max)	5	5	3
Calinski_Harabasz (rule: max)	5*	2*	5 / 3
Log_det_ratio (rule: max diff)	4	5	3

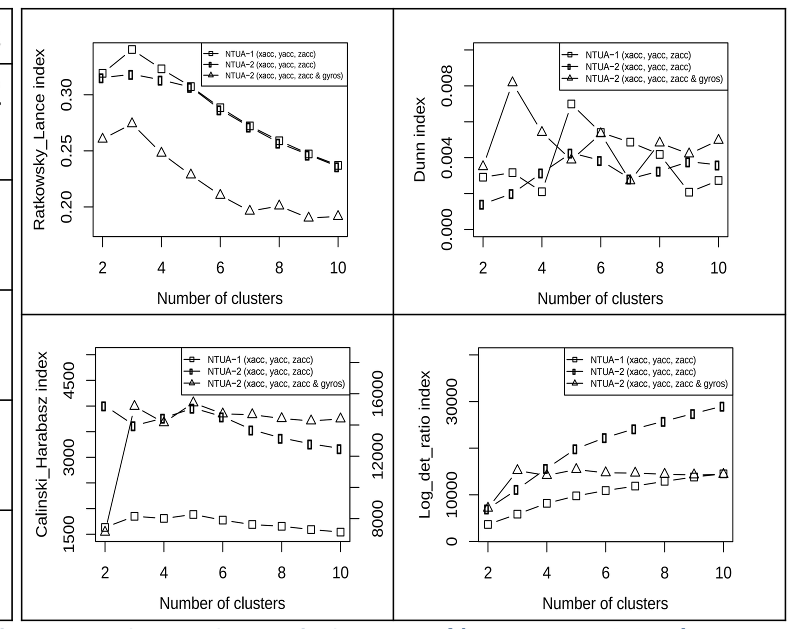


Figure 3 : Internal indices for determination of optimal number of clusters (not sensitive)*

The Calinski Harabasz is the least sensitive of the indices considered. The decision rule "max" corresponds to the greatest index value, while the decision rule called "max diff" corresponds to the greatest difference between two successive slopes, i.e. to the "elbow" in the curve.

External Index	Comparison of partitions		
	NTUA-1	NTUA-2 (no gyros)	NTUA-2
czekanowski_dice	0.48	0.59	0.85
fowlkes_mallows	0.49	0.60	0.86
jaccard	0.32	0.42	0.74
kulczynski	0.52	0.60	0.87
precision	0.64	0.69	0.98
rand	0.67	0.75	0.83
recall	0.39	0.52	0.75
rogers_tanimoto	0.41	0.53	0.57
russel_rao	0.15	0.18	0.49
sokal_sneath1	0.14	0.21	0.43
sokal_sneath2	0.74	0.82	0.84

Table 3 : External indices for determination of optimal number of clusters

Clustering results

- Clusters that overlap in terms of x-acc, are differentiated by y-acc (and vice versa);
- Gyros help distinguish the clusters in terms of x-acc, but lead to more overlap in y-acc;
- Clustering with 5 clusters is crisper than with 3 clusters;
- NTUA-2 results in a better clustering in y-acc. This is due to the fact that NTUA-1 includes essentially only left turns.

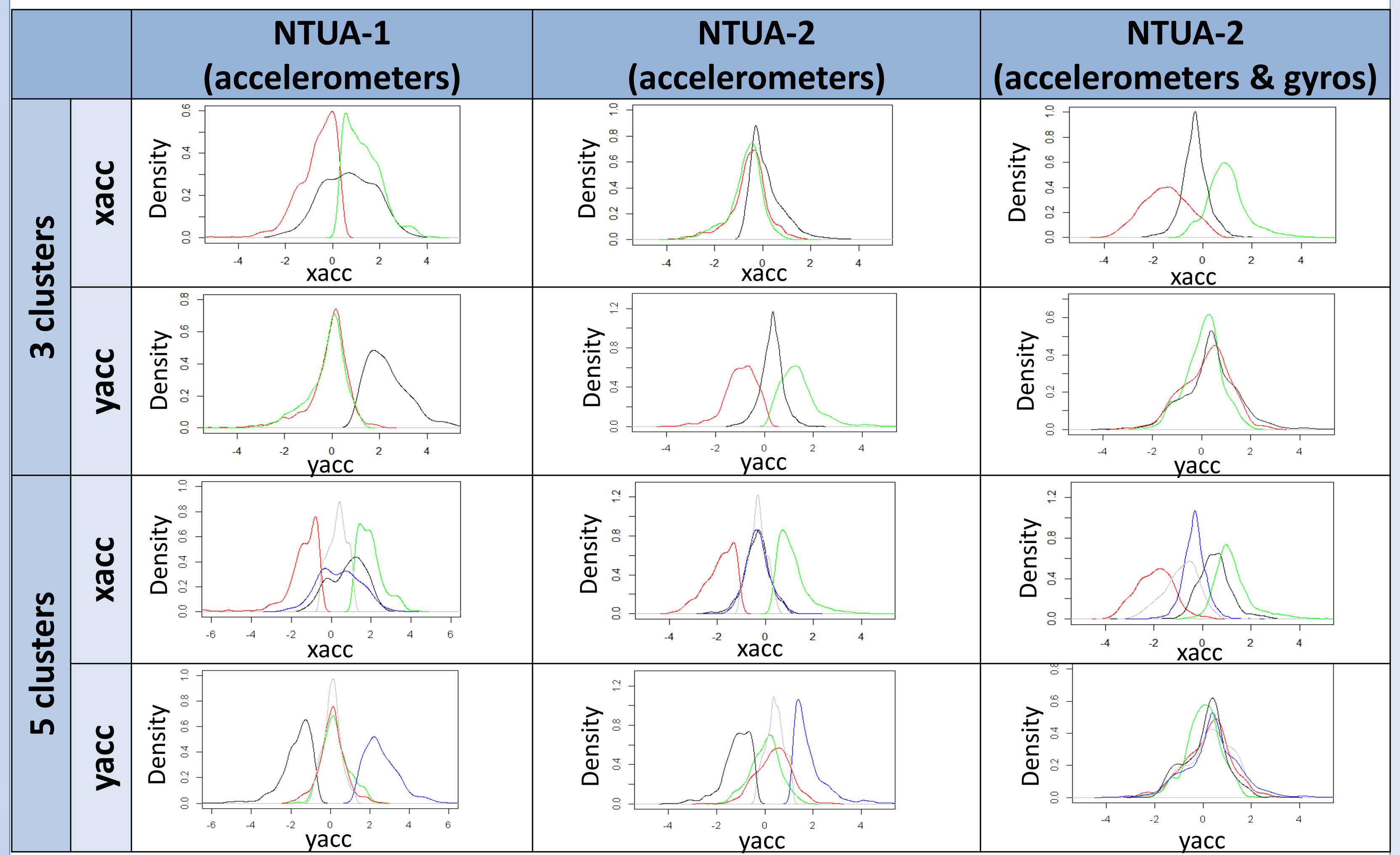


Figure 4 : Clustering results for 3 and 5 clusters

DISCUSSION AND FUTURE WORK

Simulation of indoor environments, such as those considered in this research, requires challenging aspects of modeling vehicle operation at a microscopic scale in parking facilities. Behavioral aspects and the impact of stressful driving conditions are also of interest in this context. The absence of direct GNSS coverage in these applications, means that innovative approaches may be employed to the localization of the vehicles. Combinations of certain events can increase the confidence with which the localization of the vehicles; furthermore, low speeds within the facilities of interest in this research reduce the problem complexity. Finally, exploiting radio sensors is another interesting direction for localization under these conditions.
There are many practical challenges that need to be addressed:

- Mobile terminal related measurements
- Wireless-link related measurements
- Different frequency bands of the wireless technologies
- Optimum placement of the access points
- Usage of multiple antennas and multi-node technologies