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Autonomous vehicles: get necessary redundancy in positioning with enhanced GNSS and maps

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Abstract

GNSS are everywhere in Intelligent Transportation Systems and mobility in general. Satellite positioning has enabled many solutions, applications, innovations to be deployed for the benefit of the road transport sector, after being natively targeted and developed for the need of civil aviation and maritime navigation. Today, despite significant progress have been made in vehicle positioning, research efforts are still needed. Mapping, in addition to GNSS, will also be considered as a necessary complement of the former, in order to get relative location of one's vehicle with respect to the environment. This is redundant with perception systems embedded, like camera vision measuring distance to lane marking, but this redundancy is actually sought for reliability purpose. This article will give an overview of what has been obtained so far in terms of positioning and mapping performance, and will outline the next steps toward reliable performance for advanced ITS applications, among which autonomous vehicles.

KEYWORDS:

Positioning, Mapping, Redundancy

Introduction

The best positioning performance obtained today for autonomous vehicles relies on perception, and this makes use of camera, lidar, radar, all techniques for local environment sensing processed altogether with computer vision algorithms. The paradigm below this is in fact the same as how us human beings behave in similar and usual driving situation: open your eyes, brain-process what you see to get a full context awareness, then plan your trajectory and decide on the corresponding driving command.

All this process is made locally, without using any landmark or even less any satellite. This process is local, it is not global.

Despite these techniques are efficient and occasionally may be complementary in some degraded situations, particularly in difficult whether conditions, at present there is not too much redundancy in the loop and any additional technique will be welcome, all the more if its cost meets the automotive usual requirement regarding this economic aspect. This is why GNSS antennas and receivers are so interesting [1].

There are two issues on which researchers have to work with respect to GNSS and autonomous vehicles:

- First get GNSS solutions decimeter accurate, reliable and affordable.
- Second elaborate enhanced maps where to match these solutions.

Let us discuss these two issues.

GNSS positioning

The question is: what performance can one get today?

A large survey has been made recently in the frame of the European COST action SaPPART (www.sappart.net). This survey has been made with the aim of classifying performance of GNSS-based systems using metrics for accuracy, availability and integrity [2]. The final objective is to standardize, with respect to classes of performance, the GNSS-based systems (among which simple antenna-plus-receiver pairs, but also GNSS-hybridized inertial units, or more complex systems using e.g. additional computer vision).

An interesting production of this action consists in a large data set of measurements, in different environments, and for different GNSS equipment. Let us focus on accuracy.

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SaPPART data set and accuracy analysis

The purpose of the experiment was a survey of a variety of GNSS devices, from professional grade receivers to low-cost chipsets, all set up on-board the Ifsttar VERT vehicle (Vehicle for Experimental Research on Trajectories, figure 1), the ground truth being provided by the hybridization of an iXSea IMU with a Novatel dual frequency receiver using differential data from several local static base stations (figure 1). The data set itself consists of a selection of equipment on-board the vehicle and listed in Tables 1, 2 and 3, and the choice of 4 categories of GNSS reference environments around the city of Nantes, France:

- Peripheric (city ring road with typical underpasses and parts below surroundings)
- Highway (mostly clear sky conditions on the highways between neighboring cities)
- Urban (obstructed sky conditions in inner city)
- Rural (a combination of clear sky, semi-urban and tree-lined).



Figure 1: the Ifsttar Vehicle for Experimental Research on Trajectories and the iXSea IMU

Table 1: describing the professional roof antenna-plus-receiver pairs

Manufacturer	Chipset /Model	Rate (Hz)	Constellation	INS	NMEA	RAW
Novatel	DL-V3		GPS+GLONASS	iXSea LandINS	No	Yes
Septentrio	AsteRX3		GPS+GLONASS	No	Yes	Yes

Table 1 professional receivers require the placement of larger multipath rejection antenna, real-time or post-processing procedures and clear sky visibility in order to preserve phase measurement continuity and to avoid GNSS cycle-slips. Although these receivers achieve least positioning errors, their availability is lower than from less accurate smartphones. Two professional receivers were used during the data collection, both already onboard the Ifsttar VERT: Novatel DL-V3 receiver and Septentrio AsteRX3. Two streams of data were recorded – raw data (.SBF) for Post Processed Kinematic (PPK) and standalone solution providing NMEA sentences. The antennas NOV702GGL for Novatel and G5Ant-52AT1 for Septentrio on the roof were placed on standard pre-measured consoles. DL-V3 PPK solutions are loosely coupled with the iXSea LandINS integrated measurements.

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Table 2 outlines automotive receivers, whose antenna was patched on the roof of the car. Different generations of equipment are listed, being either exclusively GPS tracking or multi-constellation with SBAS. Note that one receiver in particular is internally IMU coupled.

Table 2: describing the roof antenna-plus-receiver pairs

Manufacturer	Chipset /Model	Rate (Hz)	Constellation	INS	NMEA	RAW
uBlox	LEA-4T	1	GPS	No	Yes	No
uBlox	LEA-5H	1	GPS	No	Yes	No
uBlox	LEA-6T	5	GPS+EGNOS	No	Yes	Yes
uBlox	NEO-M8N	1	GPS+GLONASS+EGNOS	No	Yes	Yes (1)
uBlox	NEO-M8N	5	GPS+EGNOS	No	Yes	No
uBlox	NEO-M8U	1	GPS+GLONASS+EGNOS	Yes (2)	Yes	Yes
uBlox	NEO-M8T	1	GPS+GLONASS+EGNOS	No	Yes	Yes
SiRF IV	BU-353-S4	1	GPS	No	Yes (3)	No

(1) uBlox NEO-M8N does not provide RAW data using documented information. The firmware FW2.01 supports additional undocumented binary packets TRK-MEAS (03-0F) and TRK-SRFBX (03-10);

(2) uBlox evaluation kit EVK-M8U with NEO-M8U introduces u-Blox’s Untethered Dead Reckoning (UDR) technology with onboard accelerometer and gyroscope, without dependency on external odometer;

(3) SiRF IV module inside USGlobalSat’s BU-353-S4 USB receiver has default settings of only 4800 bit/s providing GGA/RMC/GSA, so GSV data is given only every 5 seconds.

Table 3 outlines the last group of GNSS devices placed on the dashboard of the car. Here some degradation of positioning performance could be expected due to the metal body of the vehicle, as researched in [4].

Table 3: describing the smart phones placed on the dashboard

Manufacturer	Chipset /Model	Constellation (1)	NMEA	Sensors (2)
Samsung	S4 mini	GPS+GLONASS	Yes	Accelerometer, Gyro, Compass
Huawei	P8	GPS+GLONASS	Yes	Accelerometer, Gyro, Compass
Acer	Liquid Jade	GPS	Yes	Accelerometer, Compass
Wiko	Fever	GPS	Yes	Accelerometer, Gyro
Samsung	Gal. Note 4	GPS+GLONASS	Yes	Accelerometer, Gyro, Compass, Barometer
WinTec (3)	WBT-202G	GPS+EGNOS	Yes	Bluetooth module w/ uBlox 5

(1) None of the smartphones supported EGNOS.

(2) These sensors are not integrated into the position using sensor fusion, still some data was obtained separately for possible further study.

(3) The WinTec WBT-202G module is not a smartphone and uses uBlox 5 core, Bluetooth connected to a smartphone. Due to its dashboard placement it was placed to the smartphones group.

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The following figures 2.1 to 2.4 give the cumulative density function of the plane error for the 4 different environments where one travelled, each for an approximate duration of 6 hours.

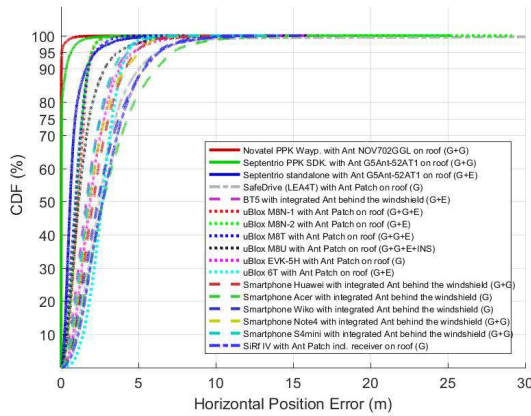


Figure 2.1: CDF peripheric

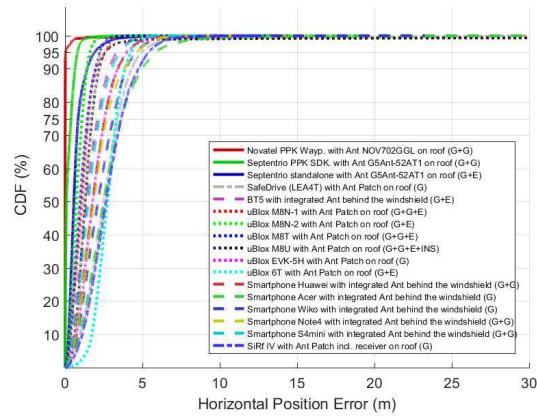


Figure 2.2: CDF highway

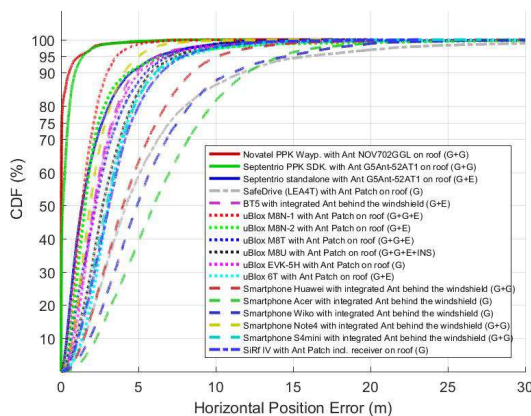


Figure 2.3: CDF urban

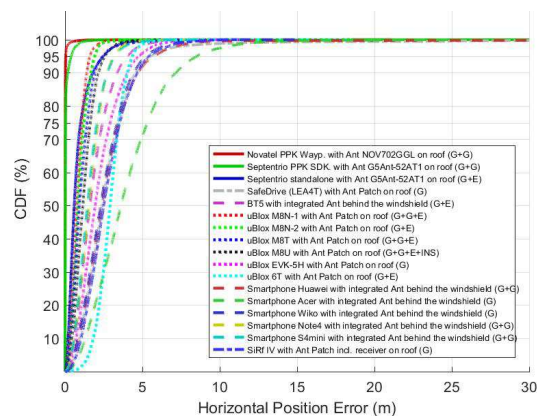


Figure 2.4: CDF rural

Comparing all four scenarios some preliminary conclusions can be made. Most different scenarios are the highway with the majority of clear sky conditions, and urban with many obstructed epochs.

Classes of horizontal accuracy

A suggestion of clustering 3 classes in this data set is made hereafter, based on technical criteria applicable to the devices under test:

Class 1 receivers Novatel and Septentrio in PPK mode always show an advantage over other devices. The CDF is very steep and they reach 95% under 0.04 m and 0.81 m on highway, and urban worst case 1.17 m and 1.44 m.

Class 2 was expected to be chosen among the low-cost receivers with roof mounted antenna (Table 2). It can be observed that they take place over a much wider area, but consistently from the newest generation of uBlox receivers (gen. 8) down to the oldest (gen. 4) reaching 95% from 1.62 m down to 4.95 m on highway and 3.62 m to 16.37 m in urban environment.

Class 3 should belong to smartphones and bluetooth receiver inside the vehicle, with partially obstructed sky visibility. It is obvious that the average horizontal error among smartphones is higher than for Class 2 (95% from 3.34 m to 5.91 m on highway, 5.02 m to 14.63 m in urban). Still there is no distinct limit among Class 2/3 as in case of Class 1/2, since some of the smartphones (e.g. Huawei and Samsung) could easily belong to Class 2.

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Last, but not least, it is noticeable (figures 3.1 to 3.4) that the newer devices benefit from updates with improved accuracy.

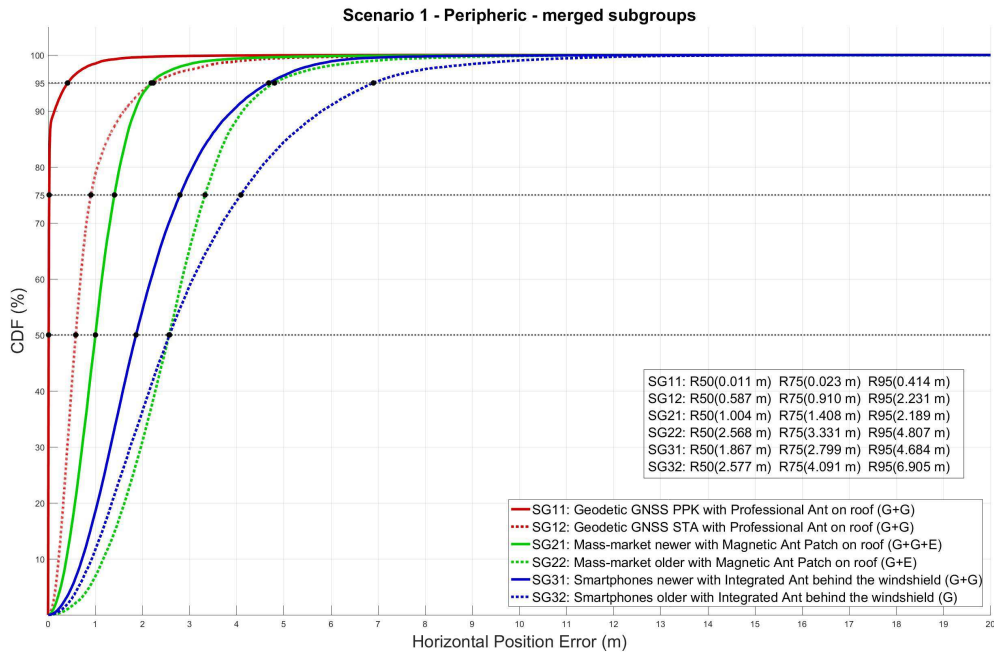


Figure 3.1: CDF peripheric after clustering

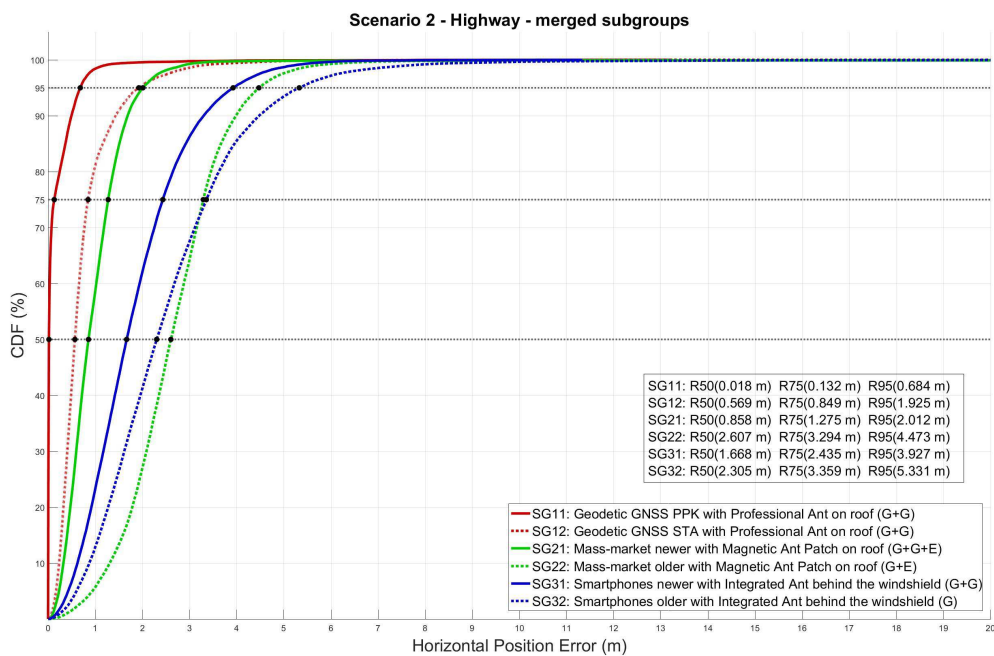


Figure 3.2: CDF highway after clustering

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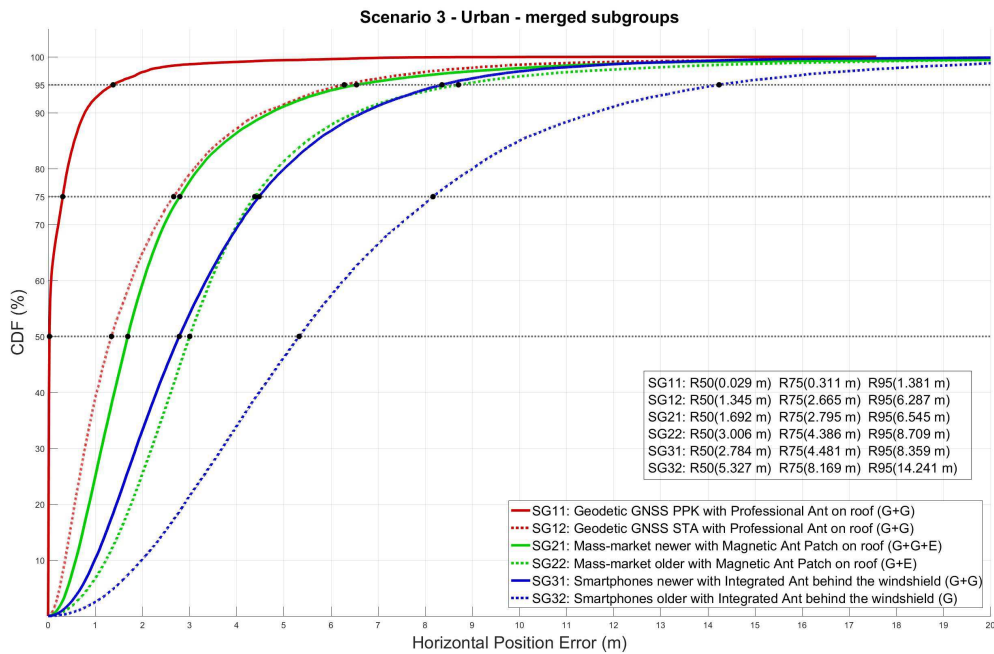


Figure 3.3: CDF urban after clustering

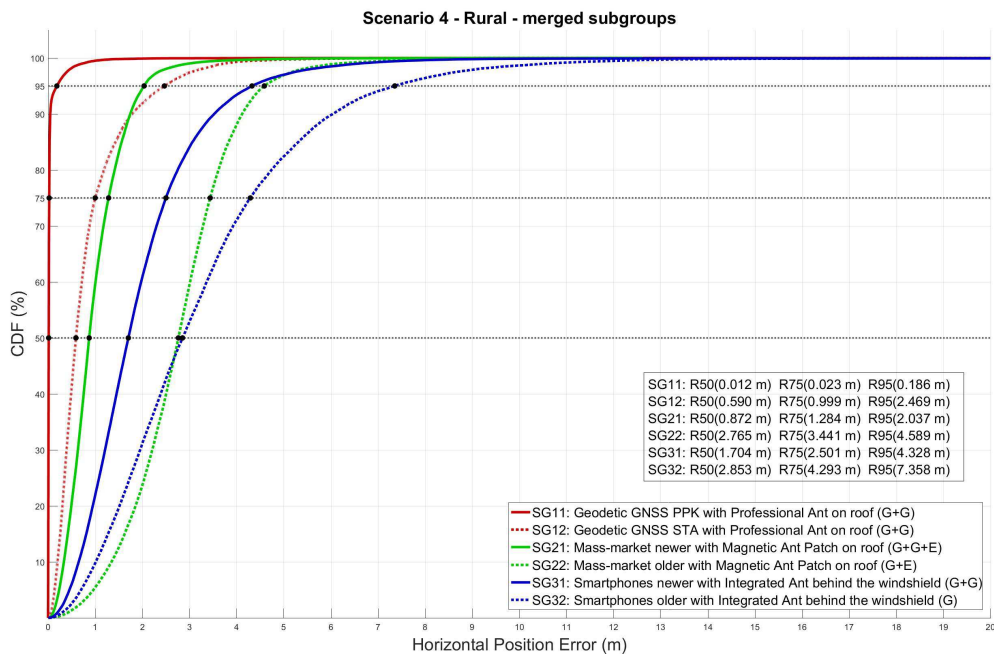
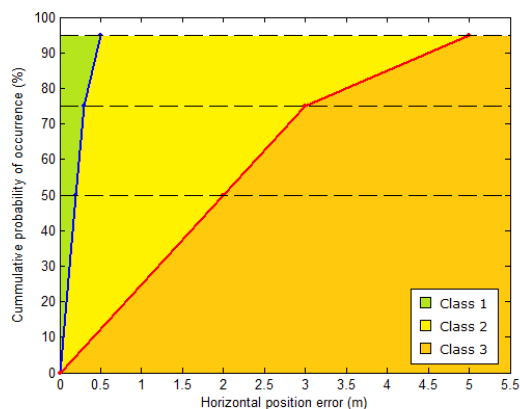


Figure 3.4: CDF rural after clustering

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This classification approach is clearly based on technologies used inside GNSS receivers, and leads to the following table:

Class ID	Horizontal accuracy		
	50%	75%	95%
1	0.2 m	0.3 m	0.5 m
2	2 m	3 m	5 m
3	>2 m	>3 m	>5 m



This classification is one of the two imagined by CEN TC5-WG1 for elaborating its norm EN16803 [10]. But another approach is also considered today: classification from the point of view of road applications. The main idea is based on the different needs of these applications: from the most challenging to the less demanding. Among applications which need high accuracy, we find autonomous guidance systems. Such systems need a sub lane level accuracy. For “public transportation - signal priority” a lane level should be achieved. For applications like “route guidance & navigation” or “fleet management”, accuracy at carriage-way could be enough. This analysis leads to exploring the following classification table:

Class ID	Class name	Horizontal accuracy		
		50%	75%	95%
1	In-lane	0.1 m	0.15 m	0.25 m
2	Lane	0.4 m	0.6 m	1 m
3	Carriageway	4 m	6 m	10 m
4	Area	40 m	60 m	100m
5	No specific	>40 m	>60 m	>100 m

Today these two approaches are still discussed and preliminary evaluation tests are currently on going.

Enhanced GNSS on-going development

SBAS (like WAAS or EGNOS) was designed for civil aviation need, particularly in terms of integrity. If one focuses on accuracy, the improvement SBAS achieved is still far from being sufficient with respect to the positioning requirement of autonomous vehicles. A recent study [3], based on the Finnish DGNSS network, has shown that the 95th percentile of the horizontal error was close to 0.5 m on a typical road test drive of 30 km, with permanent stations farer than 10 km. In conclusion this paper says: “DGNSS solutions offer better accuracy and availability in almost all the test environments as compared to SBAS. In kinematic mode in good environments, the DGNSS accuracy (– contrary to the SBAS one –) was almost as good as in static tests.” This really makes it decisive the evaluation of a differential solution based on a road side dedicated DGNSS network.

PPP, Precise Point Positioning is, contrary to DGNSS, a positioning mode using phase (and not only code) from observation raw data. PPP is trying to make pseudo-distance phase ambiguities converge, which requires ionosphere local modelling and precise ephemeris, in order to potentially get to decimeter accuracy. PPP has also been evaluated in the frame of the SaPPART COST action [4], with automotive receivers and smart phones. PPP is promising but still difficult to operate in real time and for road applications due to phase instability and signal outage. As reported in [4], in practice the accuracy obtained is the same as standalone GNSS.

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Enhanced mapping

Mapping has to be considered as a necessary complement of GNSS, in order to get relative location of one's vehicle with respect to the environment.

Existing prototypes

Previous experiences exist where researchers have made enhanced maps for the road transport sector. Most of them were done by mobile mapping, but photogrammetry with high resolution images can achieve very good results too, and collaborative mapping can also bring a possible solution, by aggregating GNSS traces [5].

All lanes should be represented, as shown in the different prototypes which were produced within the ITS community so far. CVIS (Cooperative Vehicle Infrastructure System) e-maps (figure 4) were among the former research [6]. Only the centerline is represented, consisting in series of clothoids, but every lane is included in this representation. Crossroads were not concerned yet.

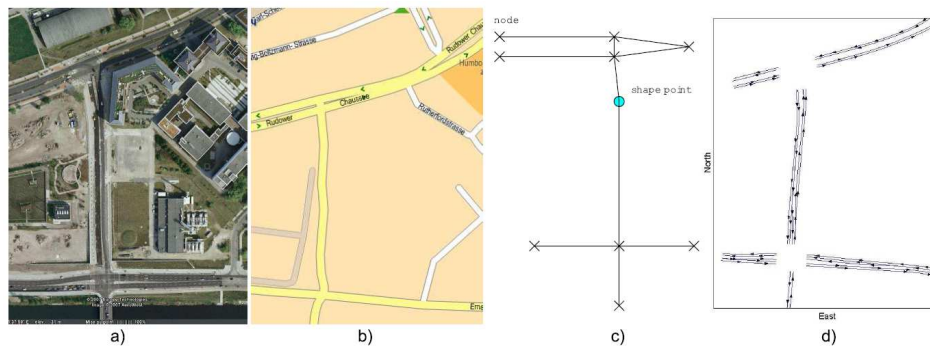


Figure 4: describing the CVIS prototype

Lanelet formalism was introduced for the Bertha Benz's historic route replay in automated driving mode, in 2013 [7][8].

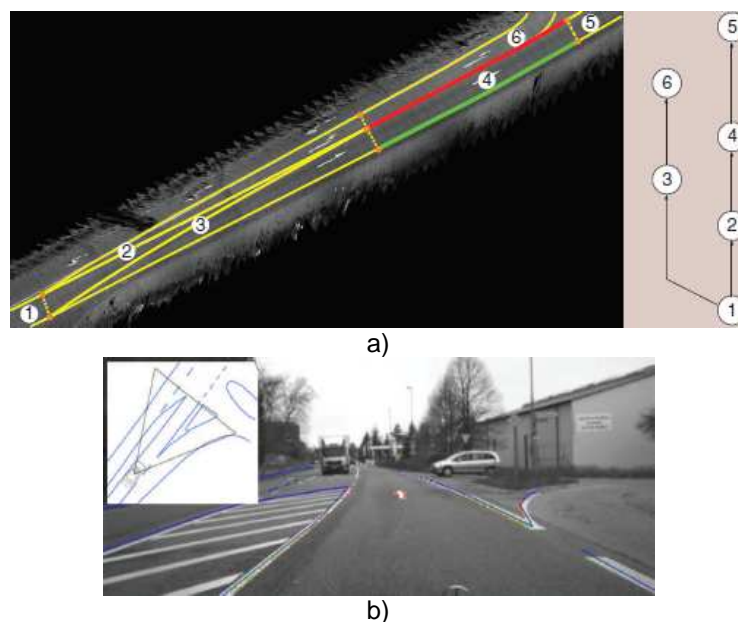


Figure 5: describing Bertha Benz's route mapping (from J. Ziegler et al., 2014, IEEE ITS Magazine)

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As mentioned by their authors, this map includes the lane geometry and the resulting lane topology. Here on figure 5a, lanelet 4 is highlighted: the right border is displayed in green, the left in red. Lane segments are interconnected at the orange dots.

Note that the background image on figure 5a has been obtained by projecting stereo pairs of images of the road scene like that of figure 5b. These images were acquired on-board a mobile mapping vehicle (georeferenced by a DGPS-aided inertial navigation system). The same images are used both to map markings and define lanelets. That way, not only the lane geometry and topology but also the landmarks (particularly the markings) are coherent, but also there are georeferenced themselves.

Perspectives

What can be done in terms of map-matching/map-aiding, i.e. combination of map and GNSS?

Previous research investigations have shown the interest of improving GNSS positioning using 3D city models. This technique should start from reasonable positioning hypotheses, which belong to either driving or pedestrian spaces depending on who is concerned. In the frame of a car, the driving space is organized in lanes, which make several hypotheses to test. This has been recently investigated successfully [9], proving that the concept deserves interest for environments with severe multipath and well-known building design geometry. Nevertheless, decimeter accuracy is far from being reached. And lane-level street map is required: in the city of Nantes, France, for example, a prototype is foreseen and a project started to achieve this. It should be mentioned that in this city, a specific GIS layer has been progressively made for vehicle/pedestrian space boundary, as shown on figure 6. There is still work to do in order to organize these data and define its topology and relation with the different road lanes. Noticeably, "shared" zones between vehicles and pedestrians like crosswalks are still not digitalized.

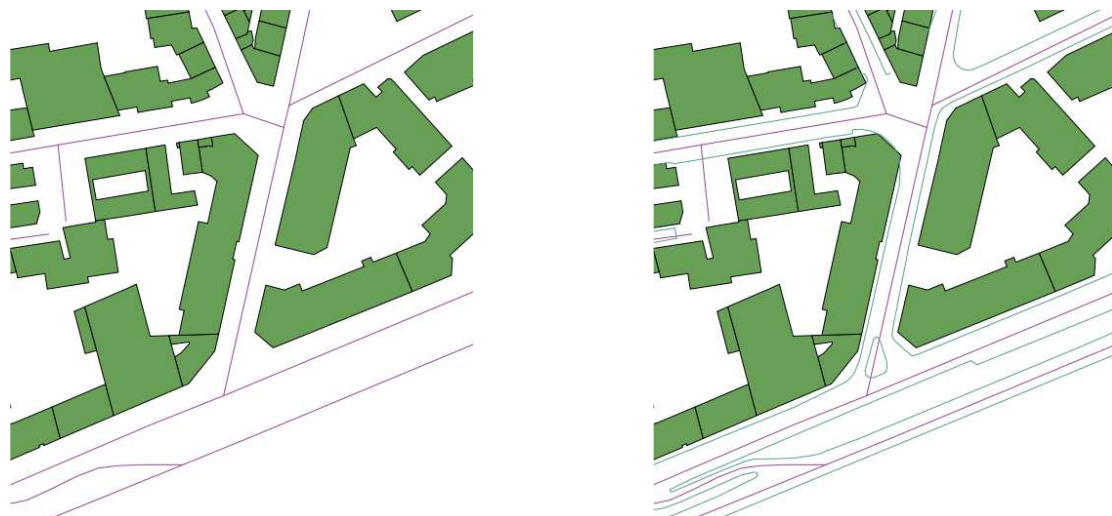


Figure 6: road and building layers (left) and vehicle/pedestrian boundary layer added (right)

Another research direction concerns the positioning integrity, i.e. error bounding. This issue could be addressed in the map domain and not only in the plane domain, with interesting results in terms of applications.

Last, but not least, let us underline that computer vision and GNSS will really cooperate (like the different GNSS interoperate today) when landmark detection will refer to georeferenced objects: lane markings, but also point clouds, road signs, posts and urban furniture. And when the integrity of both computer vision and GNSS will be properly characterized for further data fusion: it is actually not possible to perform such statistical process without error modelling which one could rely on. Such modelling apply either onto raw measurements or - after error propagation - onto final positions.

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