Feasibility of a GNSS-Probe for Creating Digital Maps of High Accuracy and Integrity

Dimitris Vartziotis[1], Alkis Poulis[1], Alexandros Minogiannis[1], Panayiotis Siozos[1], Iraklis Goudas[1], Jaron Samson[2], and Michel Tossaint[2]

[1] NIKI Ltd, Ethnikis Antistatis 205, GR 45500, Katsika, Ioannina, Greece
{dimitris.vartziotis,alkis.poulis,alex.minogiannis, panos.siozos,iraklis.goudas}@nikitec.gr
[2] European Space Agency-ESTEC, Keplerlaan 1, 2201 AZ Noordwijk, The Netherlands
{Jaron.Samson,Michel.Tossaint}@esa.int

Abstract. The "ROADSCANNER" project addresses the need for increased accuracy and integrity Digital Maps (DM) utilizing the latest developments in GNSS, in order to provide the required datasets for novel applications, such as navigation based Safety Applications, Advanced Driver Assistance Systems (ADAS) and Digital Automotive Simulations. The activity covered in the current paper is the feasibility study, preliminary tests, initial product design and development plan for an EGNOS enabled vehicle probe. The vehicle probe will be used for generating high accuracy, high integrity and ADAS compatible digital maps of roads, employing a multiple passes methodology supported by sophisticated refinement algorithms. Furthermore, the vehicle probe will be equipped with pavement scanning and other data fusion equipment, in order to produce 3D road surface models compatible with standards of road-tire simulation applications. The project was assigned to NIKI Ltd under the 1st Call for Ideas in the frame of the ESA - Greece Task Force.

Keywords: GNSS, EGNOS, Digital Maps, Accuracy, Integrity, ADAS.

1 Introduction

As the existing Global Navigation Satellite Systems (GNSS), such as GPS and GLONASS, have been available for well over three decades, their limited accuracy, reliability, availability and integrity prevent any advanced use in safety critical and precision demanding applications. As a consequence, the same holds true for publicly available GPS or GLONASS generated digital maps, since they were not compiled with the above mentioned precision and safety criteria in mind.

Today's available digital maps and GNSS positioning options are adequate mainly for turn-by-turn navigation uses. The ongoing research in advanced road passenger safety has already defined new precision requirements for enabling new enhanced applications of digital maps in safety applications and ADAS. Some critical examples, for which the automotive industry has already defined the preliminary requirements, are systems for Vehicle Control, Driver Warning and Exact Path Prediction.

F. Granelli et al. (Eds.): MOBILIGHT 2009, LNICST 13, pp. 387–396, 2009.

In addition, the novel use of digital 3D Road Surfaces in the vehicle engineering process has increased the market need for more precise datasets in advanced automotive simulation related to road-tire-vehicle interaction. The simulation of the vehicle mechanical system can be enhanced with the use of accurate input for the road geometry, in terms of its geometric characteristics, such as slope, elevation and curvature enhanced with metadata for their surface properties.

The required accuracy and integrity of digital maps for the forthcoming demanding applications can be achieved through the utilization of the latest sensor technology in combination with the more reliable, precise and publicly available European Navigation Systems such as EGNOS and later GALILEO. The ROADSCANNER methodology will refine existing digital maps with the use of proper algorithms in terms of precision and integrity. The combination of both technologies will lead to digital maps products/datasets certified and verified for use in critical applications.

2 Project Description

The “ROADSCANNER” project assessed the feasibility of a GNSS probe vehicle designed to generate enhanced digital maps (fig. 1). These digital maps will be useful in demanding and critical applications, such as safety related ADAS applications and automotive simulation.

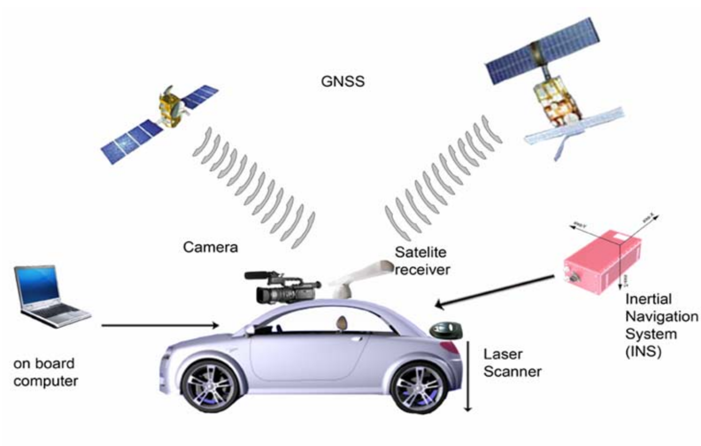


Fig. 1. The ROADSCANNER Preliminary Concept

This feasibility study initially examined the market potential of the probe vehicle and the enhanced digital maps. This market survey evaluated the digital maps and GNSS systems available today and the potential value of enhanced accuracy and integrity products. Furthermore, an additional state of the art technology market survey was conducted in order to identify existing components and possible solutions that can be adopted to build the vehicle probe and corresponding infrastructure required to achieve the ROADSCANNER’s demanding objectives. After the state of the art evaluation, preliminary navigation equipment and map refinement algorithm tests took place at selected roads in Greece and Europe. Finally, the product specifications for the probe vehicle including all needed technologies, algorithms, software and hardware sub-components where defined, thus, concluding to a detailed development plan for the complete product.

3 Work Description

The Market Study has identified the needs for high accuracy and integrity digital maps and their applications to innovative ADAS pilots, digital road simulators, as well as current developments on similar vehicle probes. Digital maps and respective services are a profitable and expanding industry [1]. Furthermore, digital 3D roads are implemented in several simulation products for comfort simulation, tire simulation, vehicle durability, accident reconstruction and driving simulation.

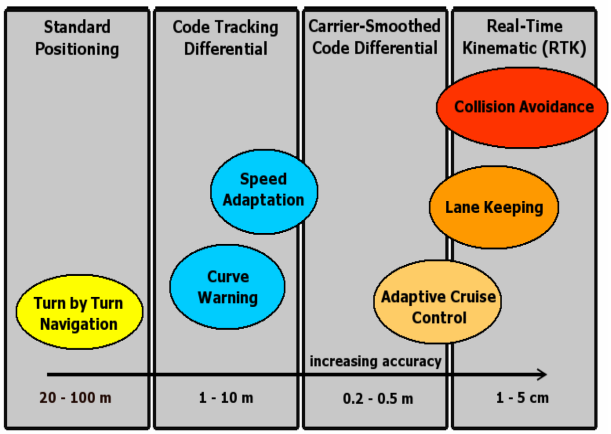


Fig. 2. Required navigation accuracy for various driver assistance systems [1]

However, the digital maps based ADAS applications are yet mainly a matter of research efforts especially due to their demanding requirements in terms of accuracy and integrity (Fig. 2), in transnational research projects like PReVENT [2], Cooperate Vehicle-Infrastructure System [3], NextMap [4], EuroRoadS [5], Gallant [6], etc.

With regard to existing vehicle probes, several types of commercial road and surface scanning vehicles are used in different kind of applications [7-13]. The equipment that is installed differs depending on the needs of each application like highway maintenance and survey, terrain mapping, city modelling, 3D reconstruction, standard road map production and geological survey.

The initial design of ROADSCANNER called for a modularized system comprising mainly of a positioning system, a road surface scanning system and the video camera system. To that end, a review was carried out for existing equipment fitting the requirements of the project, like GNSS receivers and services, accuracy enhancing services (e.g. DGPS), INS devices, road scanning devices, sensors integration and data flow management processes and finally on map refinement algorithms. The GNSS receivers research was focused on those that featured Dual frequency (L1/L2), GLONASS, SBAS (EGNOS) and a maximum number of channels. The road scanning devices presented three choices, namely, LIDAR devices, 3D laser scanning and photogrammetry.

3.1 Algorithm Implementation

A preliminary implementation of the algorithm was used in order to conduct a series of tests on captured data. The modular programming approach was chosen in order to facilitate successive component upgrades. Figure 3 describes the functionality of each module of the preliminary version used during the series of tests.

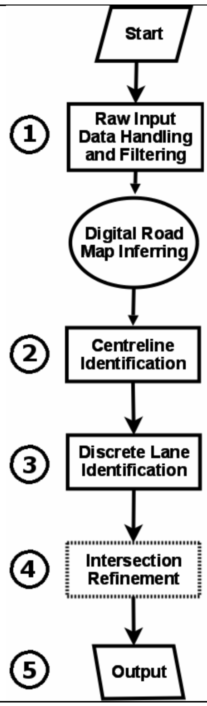
Implementation flow chart	Functionality Status
	1. The input format used was NMEA 0183. A simple filtering technique disregarded GNSS points with DOP values over a specific threshold and with ground speed of less than 10 km/h.
	2. A clustering algorithm and road segmentation was implemented. The output was fed to a simple b-spline algorithm in order to generate the centreline.
	3. Traces were projected to the centrelines using a custom variant of the topological map matching algorithm. The trace subsets that correspond to discrete lanes were fed to the b-spline algorithm in order to extract the desired centrelines.
	4. The custom b-spline algorithm was used to manually extract the connecting splines.
	5. For the preliminary tests, the refined road segments are dumped in a simple ASCII text file.

Fig. 3. Preliminary algorithm implementation flow chart

3.2 Preliminary Tests

In order to validate the ROADSCANNER concept and in particular the map refinement algorithm employed, a series of tests was carried out. The tests were split in two parts that where carried out in Greece and in Germany. The choice of a European, apart from Greece, site was necessary for testing EGNOS, since there was no coverage in Greece at the time.

During the tests, a Septentrio PolarX2 receiver was used along with a Novatel GPS-702 antenna. PolarX2 is a general-purpose 48 channel receiver for high-end Original Equipment Manufacturer (OEM) applications. The receiver supports reception of L1 and L2 signals from up to 16 GPS satellites and additionally can track the L1 signals from up to 6 SBAS (EGNOS) satellites. Moreover, signals arriving from low elevation angles are attenuated. The RxControl software package developed by Septentrio was used to facilitate the data acquisition. RxControl is a Java-based graphical user interface to configure all types of the PolaRx2 receivers. With RxControl the activity of the receiver and log/post data both on site and remotely was monitored. Results were output mainly via industry-standard NMEA-0183 messages and secondly via Septentrio's binary format (SBF).

The algorithm performance is affected by the number of acquisitioned points due to the fitting procedures. Therefore, the receiver's output rate for the kinematics' tests had to be set at 10 Hz (receiver's maximum available) in order to achieve the highest performance. On the other hand, the receiver output rate for the static tests (where the EGNOS performance in Greece tested) was set at 1 Hz.

The tests in Greece were performed in selected routes around the city of Ioannina in the northwest area of the country, during February 2008. The test cases where as follows:

- Two way, single lane road segment
  - Length : approximately 4.9 km from start to end
  - Number of passes: 10 (both lanes)
  - Curvature was also evaluated in this test case
- Road segment with varying elevation
  - Length : approximately 10 km from start to end
  - Number of passes: 7 (both lanes)
- Intersection
  - Number of passes: 12 (equal to permitted traversals) x 2
- Roundabout
  - Number of passes: 8 (equal to permitted exits/entrances to roundabouts)

The tests in Germany were performed in the area of the city of Stuttgart, from the 4th to the 7th of April 2008. The hardware setup was the same with the one used for the tests in Greece. Similar to the tests in Greece, the following test cases were examined:

- Two way, single lane road segment
  - Length : approximately 3.3 km from start to end
  - Number of passes : 10 with standalone GPS (both lanes) 10 with EGNOS enabled (both lanes)
  - Curvature was also evaluated in this test case

- Road segment with varying elevation
  - Length : approximately 25km from start to end
  - Number of passes : 1 with standalone GPS (from start to finish), 1 with EGNOS enabled (from finish to start)
- Intersection
  - Number of passes: 12 (equal to permitted traversals) x 2
- Roundabout
  - Number of passes: 6 (equal to permitted exits/entrances to roundabouts)

The results of the road segment test confirmed that multiple passes can indeed improve the accuracy of a digital map. It is shown that the constant adding of new passes moved the centrelines away from the ones regarded as the initial base map. The first 5 passes exhibited higher Dilution of Precision (DOP) values, and as such are of lower quality in terms of relative accuracy. Figure 5 clearly shows that the addition of passes of better quality drives the centreline away from the initial result of low accuracy and towards a better and more correct result.

EGNOS was enabled during the tests in Germany. Figure 6 illustrates the DOP values and number of satellites used for both lanes. In comparison with the GPS standalone case (Fig. 6) a smaller number of satellites was used on all passes which led to higher DOP values. Overall Position DOP (PDOP) values average to 2.25, while Horizontal DOP (HDOP) to 1.16. By utilizing EGNOS, it is evident that a settlement between maximum relative accuracy and signal integrity has to be made.

Although EGNOS enabled tests were characterized by larger relative errors, the signal's validity was confirmed. Of course, in the final software version, reception of EGNOS could be improved by using SISNET technology. This can help avoiding situations where DOP values that do not correspond to reality (e.g. in case of satellite failure) lead to mistaken mapping results that cannot be monitored in any other way.

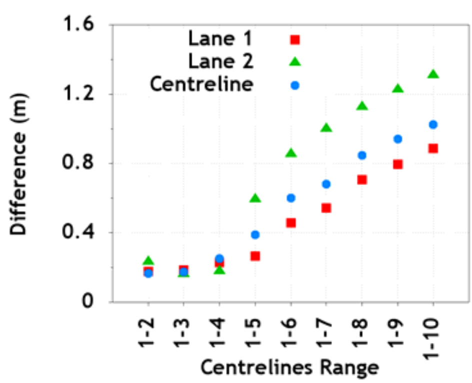


Fig. 4. Average Difference – Greece road segment test case

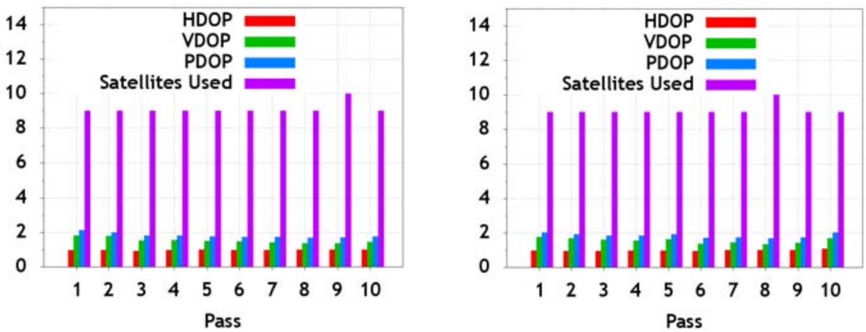


Fig. 5. DOPs & satellite usage for lane 1and lane 2 (Germany, using GPS signal)

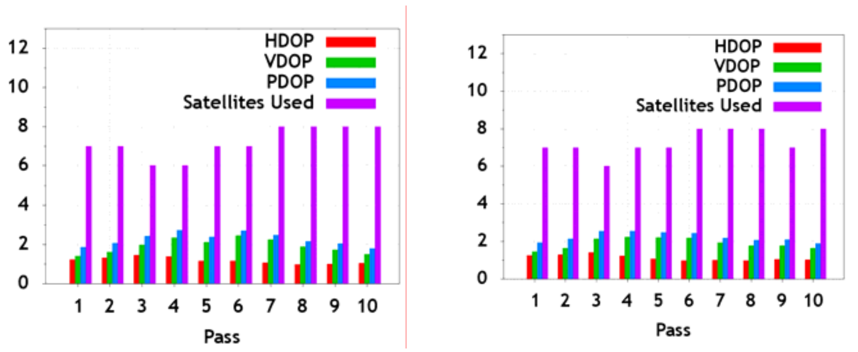


Fig. 6. DOPs & satellite usage for lane 1and lane 2 (Germany, using EGNOS signal)

3.3 Product Design and Development Plan

The ROADSCANNER's action flow of the client/system interaction procedures is the following:

- The client poses a request for creating a digital road map of high accuracy and integrity and/or a 3D digital road surface model for a specific area. In the first case either an existing digital map of the area is provided for refinement or a new one is requested to be created from scratch.
- The ROADSCANNER Service Centre receives the client's request and deploys the ROADSCANNER vehicle in the specified area for probing.
- After all measurements are made, accumulated data is transferred back to the Service Centre for processing.
- For the case of digital road maps, the consecutive passes of the probing vehicle from the designated area are combined (along with the existing digital map, if available) in order to produce a refined map with high accuracy and integrity characteristics.
- In case a 3D digital road surface model was requested, data from the probe vehicle is analyzed and combined in order to form a highly detailed 3D model of the road surface.

- The final product in both cases is bundled in standardized formats and delivered to the client.

The system functions are based on the principal that highly accurate digital road maps and models can be created by combining data from multiple probing passes over a road network.

Table 1. ROADSCANNER Requirements

Requirement	Coverage
Absolute accuracy (Digital map)	1 m
Absolute accuracy (3D road model)	1 m
Relative accuracy (Digital map)	0.2 – 0.5 m
Relative accuracy (3D road model)	0.2 – 0.5 m
Resolution (Digital map)	10 – 20 cm
Resolution (3D road model)	~ 1 cm^2

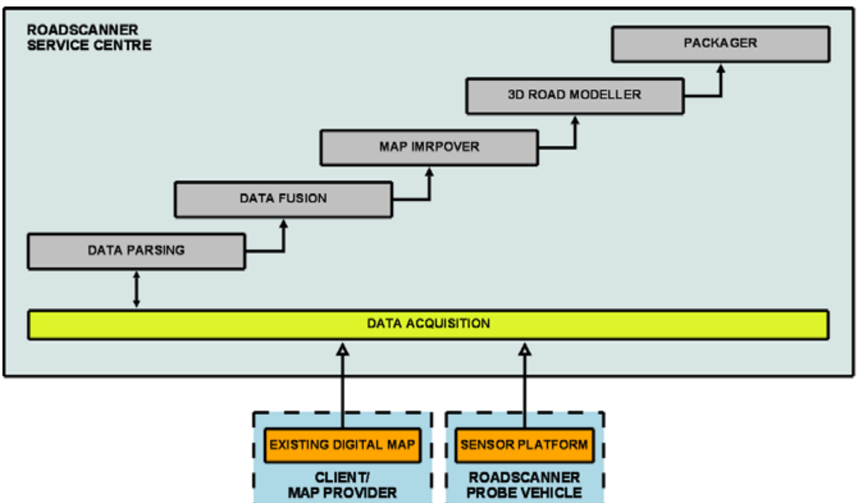


Fig. 7. ROADSCANNER system architecture

The ROADSCANNER product requirements are depicted on Table 1 and an architectural view on Fig 8. The functional specifications of the vehicle are presented in Table 2.

The vehicle probe includes three different platforms (fig. 9):

- The navigation platform
- The road scanning platform
- The computer and storage platform

Table 2. Functional specifications of the probe vehicle

Requirement	Value/Range
Operation speed width	30 - 80 km/h
Scanning width	3.75 m (Highway lane width)
Optimum number of road passes	10
Minimum road scanning resolution	1 point per cm^2
Minimum vehicle operational time	8 h

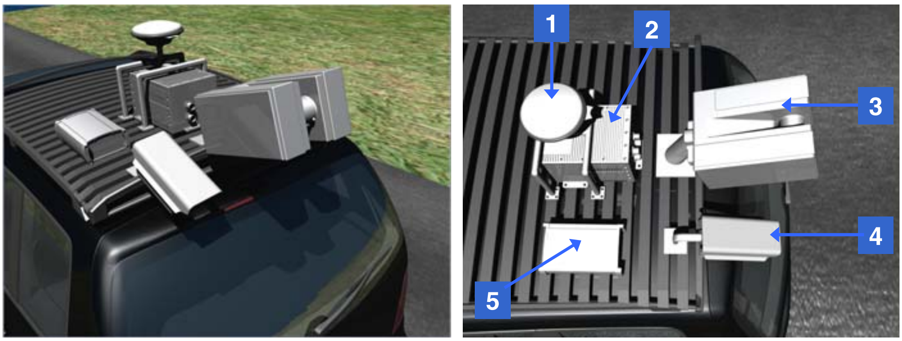


Fig. 8. Visualisation of the probe vehicle: 1) GNSS antenna, 2) INS unit, 3) LIDAR road scanner, 4) Video camera, 5) GNSS receiver

The navigation platform includes the GNSS device, the INS device and a distance meter. The road scanning platform includes the road scanning sensor and the video camera. Finally, the computer and storage platform will include two computer systems the communication system (Ethernet, USB, RS232 or RS422) and the storage unit (removable hard disks for storage). The navigation and the road scanning platform will be placed on a customised roof rack and only the computer and storage platform will be placed in a customised rack inside the vehicle.

In order to build the product a development plan was drawn including the final detailed product design, INS/GNSS integration, Data fusion and algorithmic software components, together with presentation and cooperation actions with the interested industrial stakeholders prior to vehicle construction.

4 Conclusions, Future Development

The main objective of the ROADSCANNER project was to assess the feasibility of a vehicle probe designed to produce digital maps of high accuracy and high integrity. The outcome of this project confirmed that the construction of the probe is feasible, due to following results of the respective tasks. The initial market analysis for existing and future applications, in need of enhanced digital maps and 3D road surface models, showed that there is a growing market trend for this kind of applications and intense research is focused on these subjects. Furthermore, the market study for the required equipment discovered that existing components can be used to construct the probe. Also, the processing and storage requirements are covered by existing technology.

The implementation of the proposed map refinement algorithm showed promising results, since it was able to reach a level of accuracy that can satisfy the needs of some ADAS applications. The algorithm was validated through the tests that took place in Greece and Germany. These tests, also displayed the importance of using EGNOS in terms of increased accuracy and data validity. Besides the construction of digital maps, the integrity feature of EGNOS was also reported to be crucial in safety applications. The increased accuracy introduced with the deployment of the GALILEO satellite constellation, will improve even more the obtained data in terms of accuracy. Using the output of the market study and the test results, the product design and the corresponding development plan followed.

References

1. European Commission, European Space Agency: Business in satellite navigation - An overview of market developments and emerging applications, Galileo Joint Undertaking (2003)
2. PReVENT Integrated Project, http://www.prevent-ip.org/
3. CVIS project (Cooperative Vehicle-Infrastructure Systems), http://www.cvisproject.org/
4. NextMap Project, http://ertico.webhouse.net/en/activities/activities/nextmap_website.htm/
5. EuroRoadS Project, http://www.euroroads.org/
6. Gallant Project (GaLileo for safety of Life Application of driver assistance in road Transport), http://www.crfproject-eu.org/
7. GSSI RoadScan, http://www.geophysical.com/RoadScan.htm
8. 3D Laser Mapping (3DLM), IGI Gmbh, http://www.streetmapper.net
9. The Stanford CityBlock Project, http://graphics.stanford.edu/projects/cityblock/
10. Mobile Mapping Van Brochure NA-8003-0107 (2007)
11. Newby, S., Mrstik, P.: Inertial Map the Kabul Road, GPS World (July 2005)
12. VISAT Mobile Mapping System, http://www.gisdevelopment.net/magazine/years/2004/nov/landbased.htm
13. RoadSTAR, Arsenal Research, http://www.arsenal.ac.at/roadstar/products_mob_roadstar_en.html