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Improved Navigation in Challenging Areas by Robust Positioning

NAV-CAR

Abschlussbericht/Final Report

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Abbreviations

COOPERS	**CO-OP**erative Syst**E**ms for Intelligent **R**oad **S**afety, FP 6 project co-funded by the European Commission
CVIS	Cooperative Vehicle Infrastructure Systems, FP 6 project co-funded by the European Commission
DGPS	Differential Global Positioning System
EC	European Commission
EGNOS	European Geostationary Navigation Overlay Service
ESA	European Space Agency
GALILEO	European Global Navigation Satellite System
GIS	Geographische Informationssysteme
GLONASS	Global Navigation Satellite System
GNSS	Global Navigation Satellite Systems
GPRS	General Packet Radio Service
GPS	Global Positioning System
GSM	Global System for Mobil communications
HOV	High Occupancy Vehicle
IMU	Inertial Measurement Unit
ISA	Intelligent Speed Adaptation
NAV-CAR	Improved **Nav**igation in **C**hallenging **A**reas by **R**obust Positioning
OBU	On-Board-Unit
OVN	Österreichischer Verein für Navigation (Austrian Institute of Navigation)
SafeSpot	FP 6 project co-funded by the European Commission
SISTER	**S**atcoms **I**n **S**upport of **T**ransport on **E**uropean **R**oads
TMC	Traffic Message Channel
WLAN	Wireless Local Area Network

0 Executive Summary

0.1 English

NAV-CAR 2 anticipates the fact that current satellite-based Car Navigation Systems often do not fulfil the high requirements for continuous, reliable and accurate satellite navigation in specific environments such as urban canyons, woodlands and mountainous regions. In order to improve Car Navigation Systems and support new navigation-dependent applications that rely on a continuous high precision positioning service these positioning-gaps must be filled by additional data (e.g. via co-operative infrastructure to vehicle communication, in-vehicle data).

NAV-CAR 2 builds on experience made in the European IST-Project COOPERS (www.coopers-ip.eu) in order to develop a robust navigational system that uses a combination of information sources and algorithms to achieve highly reliable and highly precise vehicle positioning. NAV-CAR 2 complements the effort of COOPERS with respect to precise and reliable positioning systems, which allow exact lane identification even under difficult topological or environmental conditions e.g. in Alpine regions. This research area is not covered by COOPERS. NAV-CAR 2 results will be assessed and used for recommendations for the developers of in-vehicle Navigation Systems (therefore EFKON AG, Graz, was taken on board) as well as for defining guidelines for road operators to be prepared for the new generation of Car Navigation Systems, and for upcoming new services to be expected with the availability of Galileo signals. For validation of the applied methods, equipment and algorithms iterative cycles of realistic field tests were performed in two regions with quite diverse requirements, the Brenner Autobahn A13 (Alpine environment) and the A23 in Vienna (urban highway).

EFKON considers NAV-CAR 2 results to be very promising with respect to later commercial exploitation, and it fits perfectly into their strategic plans. Additionally, from COOPERS partners the equipment provider pwp Systems from Germany providing the Galileo simulation to assess potential improvements by the various Galileo services, was involved. The Austrian road operator ASFiNAG and the Autostrada del Brennero co-operated actively without requesting funding. This further emphasizes the strategic impact of the project.

The Objectives of the NAV-CAR project are to increase robustness, improve accuracy and to enhance reliability in comparison to existing solutions.

In a first step, 22 potential services in 9 groups which would benefit from high precision positioning and navigation were identified covering different stakeholders' interests. Four of the services were selected regarding technical and economical practicability and usefulness (as a result of expert workshops and interviews with stakeholders):

- Generating and Updating of (high precision) Maps (and use thereof)
- Road Charging to Influence Demand (scenario: motorway interchange)
- Lane Specific Advice (such as lane specific speed advice, opening/closing of hard shoulders, etc.)
- Accident Localization

A short overview on the results achieved and proven by the demonstrations (test drives) reveals the following:

Results of the demonstrations at the urban highway (scenario 1):

Result 1: CAN data (speed, steering wheel angle) can be used to complete GPS data (e.g. in tunnels) → *Continuous trajectory is guaranteed.*

Result 2: the longitudinal accuracy of GPS can be measured using well defined points where exact GPS values are available and which can be easily detected (e.g. expansion joints) → *requirements with respect to longitudinal accuracy of GPS are easily achievable*

Result 3: the position of the car on or under the bridge can be measured using GPS or altimeter → *Accuracy of height precise enough (3 m) for mapping on street maps.*

Result 4: the lane change can be detected both using CAN (speed, steering wheel angle) and GPS data. It can also be detected in a qualitative manner using gyro data of the IMU → *Lane specific navigation possible in combination with street maps*

Most important for OBU manufacturers is the fact, that using only vehicle independent data (CAN data speed, steering wheel angle, altimeter and IMU) is considerably improving OBU performance and positioning. Further vehicle dependent CAN data was examined (e.g. wheel speed) but did not result in any further improvement.

Implications for the project objectives:

Objective 1: increased robustness (in comparison to existing solutions): achieved by using more than one type of sensors to measure a given entity: trajectory (CAN / GPS in result 1), height (altimeter / GPS in result 3), lane change (CAN / GPS / IMU in result 4)

Objective 2: improved accuracy (in comparison to existing solutions): achieved by use of CAN data which improves the accuracy of the trajectory in areas where GPS is not available (result 1), and allows for detection of lane (result 4).

Objective 3: enhanced reliability (in comparison to existing solutions): requirements to provide a continuous trajectory (result 1) and measurement of the longitudinal accuracy of GPS (result 2) fulfilled.

Results of the demonstrations in the Alpine environment (scenario 2):

Result 1: In contrast to currently available GPS signals, the simulated Galileo commercial service positions provide promising results for the automated generation of enhanced maps with lane accuracy.

Result 2: Regarding height information, the Galileo simulation shows varying results, which is partially due to inaccuracies of the simulation parameters.

Implications for the project objectives:

Objective 2: improved accuracy (in comparison to existing solutions): achievable by using Galileo commercial service in combination with the OBU. Initial absolute accuracy as well as updating of the position when no satellite coverage exists allow the generation of enhanced maps.

In the final NAV-CAR 2 validation workshop (June 8th, 2011) the following issues were identified to be of crucial relevance to practice (1) Stability of data, (2) Real-time information about the degree of reliability, (3) Costs of OBU, (4) Problems related to the IMU sensor (difficult calibration for each individual IMU). Need for further research was identified with regards to IMUs (Elaboration of quality of low-price segment, (faster) self-calibration, interoperability of the software (mid-level devices in particular)).

0.2 Zusammenfassung (Deutsch)

NAV-CAR 2 geht davon aus, dass derzeitige satellitenbasierte Fahrzeugnavigationssysteme in spezifischen Umgebungen wie Tälern, Städten oder gebirgigen Regionen nicht immer den Anforderungen entsprechen, die für kontinuierliche, verlässliche und hochgenaue Satellitennavigation erforderlich sind. Um Anwendungen zu ermöglichen, die einen kontinuierlichen hochgenauen positionsabhängigen Dienst zur Voraussetzung haben, müssen diese Positionslücken und Ungenauigkeiten mittels zusätzlicher Informationen ergänzt werden (z.B. durch kooperative Infrastruktur – Fahrzeug Kommunikation, Daten aus dem Fahrzeug selbst).

NAV-CAR 2 baut auf den Erfahrungen des europäischen IST-Projekts COOPERS (www.coopers-ip.eu) auf, um ein robustes Navigationssystem zu entwickeln, welches eine Kombination von Informationsquellen und Algorithmen für exakte und zuverlässige Fahrzeugpositionierung nutzt. NAV-CAR 2 ergänzt die Anstrengungen von COOPERS in Bezug auf zuverlässige und hochgenaue Positionssysteme, welche auch unter erschwerten Umgebungsbedingungen wie z.B. in alpinen Bereichen fahrspurgenau arbeiten. Dieser Teil wird in COOPERS nicht abgedeckt. Die Ergebnisse werden für Empfehlungen zur Weiterentwicklung von Fahrzeug-Navigationssystemen (daher war EFKON AG, Graz, im Konsortium vertreten) und zur Erarbeitung von Richtlinien für Straßeninfrastrukturbetreiber herangezogen. Dies ist eine wichtige Grundlage, um auf eine neue Generation von Fahrzeugnavigationssystemen vorbereitet zu sein und neue Dienste einführen zu können, die mit Verfügbarkeit der Galileo Signale in Betrieb gehen können. Zur Validierung der eingesetzten Methoden, Geräte und Algorithmen wurden mehrere iterative Zyklen von realistischen Feldtests in zwei Regionen mit stark unterschiedlichen Anforderungen, der Brennerautobahn A13 (alpine Umgebung) und der A23 (Stadtautobahn Wien) durchgeführt.

EFKON betrachtet die NAV-CAR 2 Ergebnisse als sehr vielversprechend bezüglich späterer Verwertung und in ihre Zukunftsstrategie passend. Weiters muss hervorgehoben werden, dass von den COOPERS Partner pwpSystems aus Deutschland zur Durchführung der Galileo Simulation eingebunden war, um so die potentiellen Verbesserungsmöglichkeiten der verschiedenen Galileo Dienste bewerten zu können. Die ASFINAG als österreichischer Straßenbetreiber und die Autostrada del Brennero kooperierten ebenfalls aktiv ohne Fördermittel zu beanspruchen, was die strategische Bedeutung des Projektes noch mehr hervorhebt.

Die Ziele des NAV-CAR Projektes sind die Erhöhung der Robustheit, die Verbesserung der Genauigkeit und die Steigerung der Zuverlässigkeit im Vergleich zu existierenden Lösungen.

In einem ersten Schritt wurden 22 potentielle Dienste (in 9 Gruppen) identifiziert, die Vorteile aus hochgenauer Positionierung und Navigation ziehen könnten, aus unterschiedlichsten Interessensgruppen. Vier Dienste wurden ausgewählt bei denen man den meisten wirtschaftlichen Nutzen und die besten technischen Umsetzungsmöglichkeiten erwartet (die Auswahl wurde nach einem Expertenworkshop und Interviews mit weiteren Interessenten getroffen):

- Generierung und Aktualisierung (hochgenauer) Karten (und deren Verwendung)
- Flexible Straßenbenützungsgebühr zur Bedarfssteuerung (Szenario Autobahnkreuzung)
- Fahrspurspezifische Anweisungen (fahrspurspezifische Geschwindigkeitsregelung, bedarfsgerechte Mitbenützung des Abstellstreifens)

- Genaue Unfalllokalisierung

Ein kurzer Überblick über die erzielten Ergebnisse, die durch die Messfahrten nachgewiesen wurden, zeigt folgendes Bild:

Ergebnisse der Messfahrten auf der Stadtautobahn (Szenario 1):

Ergebnis 1: CAN Daten (Geschwindigkeit, Lenkradwinkel) können verwendet werden um GPS Daten zu ergänzen (z.B. in Tunneln) → *eine kontinuierliche Trajektorie ist garantiert.*

Ergebnis 2: Die Genauigkeit der Position in der Fahrtrichtung (longitudinal) kann sehr gut gemessen wenn gut definierte Fixpunkte mit exakten GPS Daten verfügbar sind, die auch leicht erkannt werden können (z.B. Dehnfugen auf Autobahnbrücken) → *die Anforderungen an die notwendige longitudinale Genauigkeit sind leicht erfüllbar.*

Ergebnis 3: Ob sich ein Fahrzeug auf oder unter einer Brücke befindet kann mit GPS und Altimeter gut bestimmt werden → *die Höhe kann genau genug (3m) für die Zuordnung auf Straßenkarten bestimmt werden.*

Ergebnis 4: Ein Fahrstreifenwechsel kann mit Hilfe von CAN Daten (Geschwindigkeit, Lenkradwinkel) gemeinsam mit GPS Daten festgestellt werden. Dies kann auch in qualitativer Weise mit den Gyrometerdaten der IMU festgestellt werden → *fahrstreifen-genaue Navigation ist möglich zusammen mit Karten.*

Von größter Bedeutung für OBU-Hersteller ist die Erkenntnis, dass die Verwendung ausschließlich fahrzeugunabhängiger Daten (CAN Daten Fahrzeuggeschwindigkeit, Lenkradwinkel, Höhenmesser und IMU) ausreicht, die OBU Güte und Positionierungsgenauigkeit erheblich zu verbessern. Es wurden auch fahrzeugabhängige CAN Daten herangezogen (z.B. Radgeschwindigkeit), doch konnte damit keine weitere Verbesserung erzielt werden.

Bedeutung für die Erfüllung der Projektziele:

Projektziel 1: Erhöhung der Robustheit (im Vergleich zu existierenden Lösungen): dies wird durch Verwendung von mehr als einem Sensor, die dieselbe Messgröße zu ermitteln erlauben, erreicht: Trajektorie (CAN / GPS, siehe Ergebnis 1), Höhe (Höhenmesser / GPS, siehe Ergebnis 3), Fahrstreifenwechsel (CAN /GPS / IMU, siehe Ergebnis 4)

Projektziel 2: Verbesserung der Genauigkeit (im Vergleich zu existierenden Lösungen): erzielt mit CAN Daten, welche die Genauigkeit der Trajektorie bei Ausfall des GPS Signals erhalten (Ergebnis 1), und die Fahrstreifenerkennung ermöglichen (Ergebnis 4).

Projektziel 3: Steigerung der Zuverlässigkeit (im Vergleich zu existierenden Lösungen): die Anforderungen an eine kontinuierliche Trajektorie (Ergebnis 1) und die Korrektur der longitudinalen Genauigkeit von GPS (Ergebnis 2) sind erfüllbar.

Ergebnisse der Messfahrten im alpinen Bereich (Szenario 2):

Ergebnis 1: Im Gegensatz zum herkömmlichen GPS Signal versprechen die Simulationen des Galileo Kommerziellen Dienstes gute Ergebnisse für die automatische Generierung genauerer Karten mit Fahrstreifenauflösung.

Ergebnis 2: Bezüglich der Höhenmessung zeigt die Galileo Simulation stark schwankende Qualität der Ergebnisse, was teilweise auf Ungenauigkeiten in den Simulationsparameter zurückzuführen ist.

Bedeutung für die Erfüllung der Projektziele:

Projektziel 2: Verbesserung der Genauigkeit (im Vergleich zu existierenden Lösungen): erzielbar mit kommerziellem Galileo Dienst gemeinsam mit OBU Daten. Bei genau bekannter Anfangsposition und Datenergänzung bei unzureichendem Satellitensignal erlaubt dies die Generierung genauer Karten.

Im abschließenden NAV-CAR 2 Validierungsworkshop (8. Juni 2011) wurden als kritisch für die zukünftige praktische Nutzung festgehalten: (1) Stabilität der Daten, (2) Informationen in Echtzeit über die Zuverlässigkeit (momentane Qualität) der Daten, (3) Kosten der OBU, (4) Probleme in Zusammenhang mit der IMU (Kalibrierung schwierig, muss für jedes Einzelstück erfolgen). Die Notwendigkeit weiterer Forschung wurde vor allem in Bezug auf die IMU identifiziert (Untersuchung der Qualität der IMUs im unteren Preissegment, (schnellere) Selbst-Kalibrierung, Interoperabilität der Software (insbesondere bei Geräten im mittleren Preissegment).)

1 Introduction

1.1 NAV-CAR Objectives

Current satellite based vehicle information-, navigation- and tolling systems rely on a minimum number of satellites that are both visible and well distributed to compute geo-reference data at the accuracy promised by the operators.
Nevertheless, specific environments such as urban canyons, woodlands and mountainous regions very often do not fulfil the requirements for a continuous and reliable satellite connection of the Navigation system leading either to wrong positional data or no data at all (Figure 1).
Objectives of the NAV-CAR project are to increase robustness, improve accuracy and to enhance reliability in comparison to existing solutions.

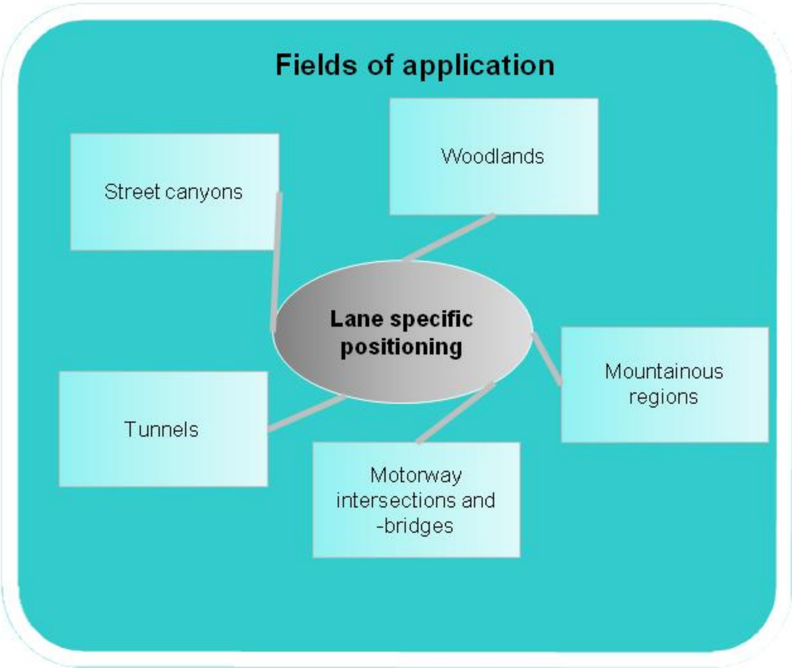


Figure 1: Fields of application

In NAV-CAR, positional information from navigational satellite is augmented by data collected by an in-car sensor network and combined with high precision map data. This in-vehicle process will not only allow the correction of the signal provided by the navigation satellites but also can, to a certain extent, substitute missing signals, as may occur in tunnels, urban canyons and mountainous areas.

NAV-CAR builds on experiences made in the European IST-project COOPERS [1] (www. coopers-ip.eu) and the know-how of pwp Systems in the field of high-precision car navigation and simulation. Within NAV-CAR this know-how is used and enlarged especially in the realm of sensor data fusion and map referencing.

The innovative part of NAV-CAR is the data fusion of navigational and in-car-sensor data to provide robust, accurate and precise positioning information (Figure 2). In combination with precise map data, which will be generated in the course of NAV-CAR for the proposed test sites, positioning accuracy which allow lane sensitive navigation and information will be demonstrated. In-car data (e.g. from CAN-Bus) are used to calculate a delta position from the last measured satellite positioning signal. The main problem to be resolved is to find suitable interfaces for data fusion and to really utilize all available sources of information in an innovative manner.

It must be noted that NAV-CAR does not aim at improving or developing communication systems. Reliability of the communication to the service provider is a result of COOPERS and is not addressed in the project NAV-CAR.

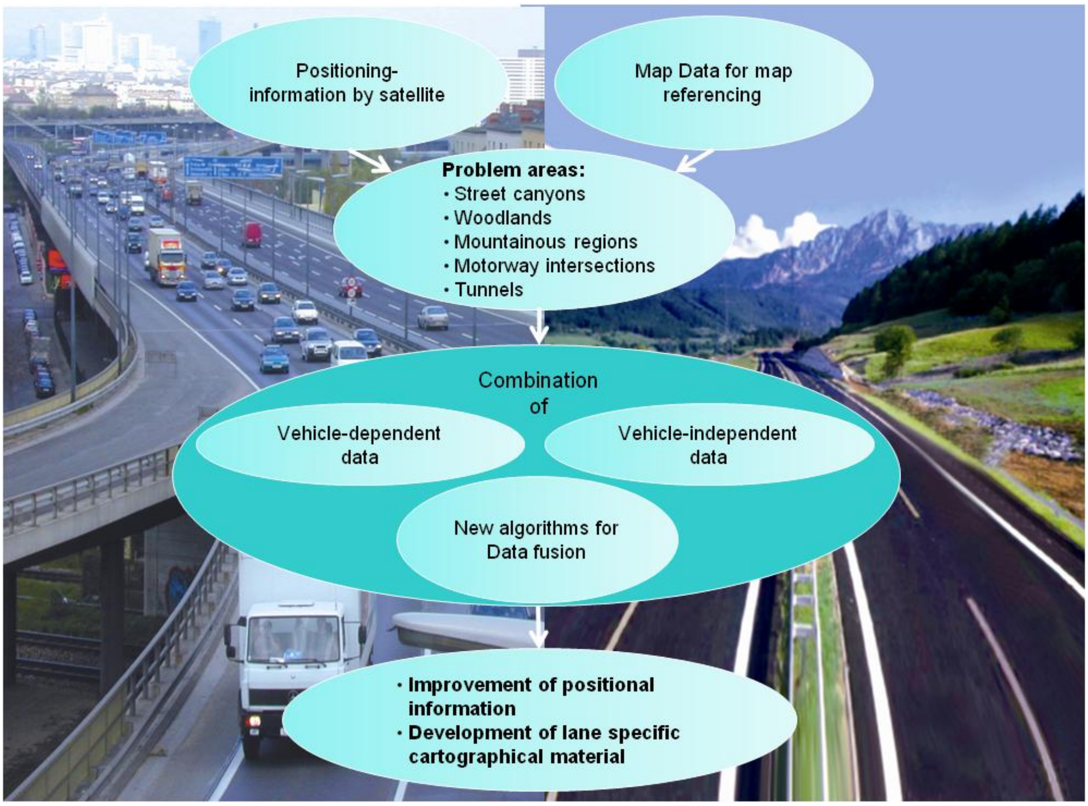


Figure 2: Focus of the project

The realization of the project is supported by the organizations pwp Systems, Asfinag and the COOPERS project [1].

1.2 NAV-CAR Added Value

In the European Framework 6 IP (integrated project) COOPERS ("Co-operative Systems for Intelligent Road Safety", which was launched February 2006 and ended June 2010) the purpose was to link vehicles up with the road infrastructure using wireless communication technology, taking for each region where it was tested the wireless media available (e.g. GSM/UMTS, DAB (Digital Radio Broadcast), short-distance communication like infrared and WiMAX). For positioning purposes a so-called "Robust Positioning Unit" (RPU) was developed in a subproject. The knowledge gained already in mid-term of COOPERS led to the idea that additional services could be provided if lane-specific positioning would be available. A new OBU should be designed and tested, targeting at higher positioning accuracy, including bridging gaps in data e.g. provided by GPS as well, and by anticipating the higher positioning precision which should become available with GALILEO.

The additional services which are expected to be enabled by lane-specific high precision positioning and navigation are described and discussed in NAV-CAR Deliverable D2100 [3]. Generation of enhanced maps and their use are additional aspects of NAV-CAR development which were not objectives of COOPERS.

The **"added value" of NAV-CAR** OBU as compared with COOPERS RPU is characterized by the following features:

- The NAV-CAR focus is on high precision of positioning data besides robustness (COOPERS is focussing on robustness rather than precision in the so-called RPU (Robust Positioning Unit)).
- NAV-CAR provides a detailed analysis of lane-specific services (deliverable D2100 [3]).
- NAV-CAR will evaluate the benefit gained from data fusion of data from different levels as explained in Figure 36: OBU performance data and required vehicle integration , especially of high precision positioning data to be derived from vehicle-specific in-car CAN-data and from independent OBU data (important for manufacturer of future equipment like EFKON, pwpSystems, because exclusive use of independent OBU data opens a much larger market).
- During drives, important data will be available real-time for driver and traffic control centres.
- NAV-CAR aims at the generation of high precision maps (with easier to use standard cars instead of slow moving special truck like RoadSTAR).
- Testing and validation of NAV-CAR OBU performance and results is done by high precision reference data from RoadSTAR.
- NAV-CAR includes better and additional sensors than were used in COOPERS, evaluating reliability and precision of sensors and mathematical algorithms used for calculation of accurate position and precise navigation (sensor fusion, drift and error correction):
  - Additional sensor for accurate altitude data
  - Comparison old/new GPS and their impact on precision
  - Considerations concerning calibration (tires!)
  - Evaluation of reliability and precision of sensors

1.3 Objective of the Final Report

The final report provides an overview over the project and its deliverables, and is composed of input delivered by the deliverables as outlined in the NAV-CAR 2 Technical Project Description, Update 2009.

NAV-CAR is divided into four work packages:

1. Work Package 1000 includes project management and co-ordination, organization of progress meetings and quality assurance. Progress meetings have taken place regularly to monitor progress, assure quality of deliverables and do risk management. Minutes and slides are available from each meeting. The progress meetings are listed here:
    - 24.8.2009 (Brimatech)
    - 12.10.2009 (ÖFPZ)
    - 27.11.2009 (AIT)
    - 19.1.2010 (EFKON)
    - 16.3.2010 (ÖFPZ)
    - 7.5.2010 (AIT)
    - 22.6.2010 (Brimatech)
    - 18.8.2010 (ÖFPZ)
    - 12.10.2010 (EFKON)
    - 15.12.2010 (Brimatech)
    - 18.2.2011 (ÖFPZ)
    - 28.3.2011 (AIT)
    - 27.4.2011 (Brimatech)
    - 23.5.2011 (AIT, preparation of Validation Workshop and OVN get-together June 8th, 2011)

2. In the development phase of work package 2000, scenarios for services were worked out, which require lane specific information and for which field tests were carried out. One of these scenarios contained tests in an urban environment, covering both motorway and access road. The second scenario took place in an alpine region addressing long distance travel. For these scenarios, services were identified and evaluated (Deliverable D2100 [3]). In a second step, the selection and technical implementation of the sensors and interfaces for the OBU (On-Board Unit) was performed (Deliverable D2200 [4]).

3. Work package 3000 contained a field test, where a test car was used in the previously defined test environments. Additionally, calibration-, sensor field tests and pre-field test runs, problem resolving and OBU improvement were included as an iterative process (test and enhancement part of “Implementation”). Data was collected for the final assessment of the performance of the system. Emphasis was put on the positional accuracy of the systems, its ability for lane matching, integrity of the signal and correction of data jitter (combined deliverable D3100/D3200 [7]).

4. In the result phase (WP 4000) an assessment of the demonstration results was carried out. Recommendations were given for future developments, and the potential for future applications were analysed. The results were made available through publications and workshops organised for interested developers and users (combined deliverable D4100/D4200 [8]).

1.4 Methodology

The technical meetings of WP 3000 provided insights into technical results and problems faced in the course of the project roll-out. Demonstration results were transferred into socio-economic impact analysis and served as a basis for the organisation of a validation workshop, taking place at the Technical University of Vienna on the 8th of June 2011. The workshop was organised prior to another navigation event (4th OVN Navigations-Get-Together), in order to allow synergies (participants, travel time for participants, space) between these two events.

In the validation workshop with project-internal and project-external experts, the project aims, methodology and results were presented. Results, potential and future research & developments were discussed and recommendations derived. This was considered as pre-review of the project.

The institutions taking part in the validation phase were:

- Efkon
- AustriaTech
- Austrian Institute of Technology (AIT)
- TeleConsult
- FFG
- Brimatech

2 Services and scenarios

This chapter provides an overview on the major information provided by D 2100, restricted to services beyond COOPERS.

2.1 Interesting Services for Road Operators

2.1.1 Road Surface Monitoring

For Road Surface Monitoring, not only the transversal, but also the longitudinal positioning accuracy is very important. The specified services interesting for the road operators are Surface Analysis (Exact Positioning of Road Defects) and the Optimization of Road Surface Monitoring (road condition such as temperature) for gritters.
Precise positioning information of road defects could be handed over from the road surface analysis vehicle to the maintenance team, whereby reconstruction can be accomplished in shorter time (through faster retrieval of detected road defects). Thus, the duration of traffic obstructions can be reduced.

The optimization of gritters could be attained via temperature sensors. The gritting of roads (e.g. salt) depends on the temperature of the road surface and results in an optimized usage of grit.

At present, road surface monitoring is carried out by video analysis and laser sensor systems, which is inaccurate with regards to positioning and the retrieval of the exact road defect location. It is also a very cost-intensive solution.

2.1.2 Generating and Updating of Maps

Precise positioning information could facilitate the generating and updating of maps. The goal is to create new digital maps including lanes by tracking precise positioning information of floating cars. Current approaches lead to satisfactory results (see Figure 3), but imprecise GPS signals do not allow reliable lane mapping. With the developments in NAV-CAR and the reduction of the scatter, the generation of those digital maps as well as their constant update will be possible. Nevertheless, it must be noted that maps of less-trafficked roads will not be as highly precise as other roads.

A local dynamic map was developed in the SafeSpot project. In the SafeSpot project, an electronic analysis of the surrounding of the car is supported exclusively by in-vehicle data. The data exchange between cars is time critical, as the system informs the driver about other vehicles up front changing lanes. Technological problems aroused in the course of the project due to a lack of points of precision, causing a systematic error.

Figure 3: Map of Vienna based on floating car data

2.1.3 Traffic Light Control / Regulation

Depending on the number of cars on specific lanes at an intersection controlled by traffic lights, stop/go phases could be made dependent on traffic flow/ traffic volume. By surveillance of all lanes, busier lanes are weighted higher than lanes/ access roads with lower traffic volume. This service would enable flexible and real time traffic management and regulation of traffic volume at intersections controlled by traffic lights, avoiding unnecessary congestion.

2.1.4 Distance Measurement between two cars

Data derived from the distance measured between two cars could be used for the surveillance and analysis of driving behaviour. This would be especially interesting for the development of microscopic traffic models. For example, aggressive driving behaviour could be modelled and measured when a driver keeps very short distances to other cars. The information could also be used by haulers, analysing the truck driver's behaviour and establishing a bonus-malus system according to the driving behaviour.
The Distance Measurement between two cars could also be used for the diagnosis of overtaking manoeuvres in the scope of accident analyses. This service is especially important in rural areas. The analysis of accidents in general considering exact positioning information could be of great importance and could be used as a basis for legal and political measures.

2.1.5 Traffic Flow Management

Among most services mentioned in COOPERS and the expert interviews (Lane Utilization, Variable Speed Limit, etc.), traffic flow management is a crucial service that could be optimized through exact positioning information. The OBU could be used as a feedback channel, communicating the status of roads and traffic. The strategy of traffic flow management can be adapted to driving behaviour. At present, driving behaviour is observed via video cameras. This is a very cost-intensive solution, which does not cover all sections of roads.

2.2 Interesting Services for Emergency Services

The exact accident localisation, the localisation of the caller and the route calculation are interesting services from the Emergency Services perspective.

In particular, the **exact accident localisation** is crucial for a time-efficient and adequate emergency operations planning. For this service, transversal and longitudinal positioning accuracy is crucial, especially in case of streets that run close from each other but require different access routes. It is also crucial, on which lane and driving direction the accident took place. For example, it has to be differentiated, if the accident took place on the motorway exit or on-ramp. In Germany, the position of the accident is reported via TMC by the police only at the moment of their arrival at the accident site. The information has an inaccurateness of up to 15 km, even though road operators have exact maps. This inaccurateness is a result from the incompatibility of the systems of police and road operator.
Also the **exact localisation of the caller** in case of an emergency is very important. At the moment, often the caller cannot be located. Different subfirms (e.g. providers of mobile services) are identified as “bottleneck”, as they do not provide existing data.
Some companies are not authorized to hand over information (e.g. providers of mobile telecom services are not allowed to provide positioning or other information of the caller without allowance, even in emergency cases), for others it imposes an excessive effort to provide available data (e.g. vehicle-specific information from car manufacturers).
Another, but not significant problem the emergency services are facing is an incorrect **route calculation** due to inaccurate vehicle positioning. When the emergency van is heading to an accident, sometimes the GPS system does not identify the exact position of the car (e.g. wrong direction) and therefore conducts an incorrect route calculation. This can lead in case of drivers not familiar with the place to time delays when driving to the accident site.

The services interesting for Infrastructure Operators, Tolling System Providers, Emergency Services, and ITS experts discussed in the expert workshop and problem-centered interviews are shown in an aggregated manner in the table below:

Service Category	**Service and Description**	**Specified Cases / Specification**	**Actual Problems/difficulties faced**	**"user/ beneficiary"**
Road Charging to influence demand	Charging based on Tracking & Tracing	To charge road vehicles in a more flexible way (guarantee a certain performance of the system) and to inform the drivers about the predicted toll-costs	Tolling Operators contracted to perform road charging usually have to guarantee a certain performance of the system (e.g. 99,9 % of the stretches driven in a given time are charged correctly), legal disputes might arise if precision/accuracy is not provided	Tolling System Provider, Road Operator, Driver

Service Category	Service and Description	Specified Cases / Specification	Actual Problems/difficulties faced	"user/ beneficiary"
Lane Utilization	Warning, Navigation (lane banning, lane keeping, auxiliary lane)	Construction site		Driver, Road operator
		Opening/closure of emergency lane	Leading the driver back on the first lane	Driver, Road operator
		Wrong-way driver warning		Driver, Road operator
		Obstacle detection		Driver, Road operator
		Information about blocked lanes (first lane, fast lane or highway exit)	Often the police reports a barrier (accident at motorway exit), but the barrier cannot be positioned adequately (often only the exit is blocked, not all lanes of the motorway)	Driver, Road operator
	Tracking & Tracing	Car drives on the emergency lane		Driver, Road operator, Emergeny Services
	Approval of Lanes	Approval of the emergency lane for emergency services		Driver, Road operator, Emergeny Services
	Warning and Approval of Lanes	Gritters and snow ploughs		Driver, Road operator
	Warning, Tracking & Tracing	Abnormal loads and hazardous goods transports - road barriers in sections		Driver, Road operator

Service Category	Service and Description	Specified Cases / Specification	Actual Problems/difficulties faced	"user/ beneficiary"
Variable Speed Limit	Traffic Control	Vehicle as a mobile sensor: informs control center about lane specific traffic flow (on which lane is a total stop)	Via gantries and the Telepass System (Italy); installed in 45% of the vehicles; very cost intensive	Driver, Road operator
	Lane-specific Speed Profiles	For congestion and accident detection and warning	Detection when congestion is detected by the nearest static sensor	Driver, Road operator, Emergeny Services
	Speed Information to the Driver	Exact speed limit information - input for the speed control - has to be precise, otherwise legal consequences could arise	Imprecise and obsolete speed limit information, temporary speed limits are not considered	Driver, Road operator, Automotive Industry, Navigation System Providers
Road Surface Monitoring - longitudinal positioning accuracy is important	Surface Analysis	Analysis of the road surface and exact retrieval of position (in case of road defects)	Exact localisation can be handed over to service personnel	Road operator
	Correction of Road Defects	Retrieval of road defects (detection - exact positioning - redetection by maintenance team) exact positioning of road defects in order to hand over the exact position for reconstruction	Duration of roadbarrier can be reduced	Road operator
	Optimization of Grit (Road Surface Monitoring)	e.g. via temperature sensors for gritters		Road operator

Service Category	Service and Description	Specified Cases / Specification	Actual Problems/difficulties faced	"user/ beneficiary"
Generating and Updating of maps	Facilitation of Map Updating	Supported by fixed reference points		Road Operator, Emergency Services
	Local Dynamic Map (SafeSpot) - Electronic Analysis of the Surroundings of the Car (data exchange between cars)	Time critical, is a surrounding car changing lane	Problems at test site (technology); system error amounts during the day - application has to be shut down several times a day and has to be restarted in order to clear the system error	Road Operator, Emergency Services
Traffic Light Control / Regulation	Surveillance of Lanes, Weighting of Lanes	Traffic light control according to lane-specific needs		Traffic Control Management
Distance Measurement (between two cars)	Surveillance of Driving Behaviour	Especially interesting for microscopic traffic models interesting for truck driver behaviour (bonus / malus system according to driving behaviour)		
	Diagnosis of Overtaking Maneuver	For analysis of accidents		Driver, Police
	Accident Analysis	Basis and starting point for political and legal measures		Driver, Police
Traffic Flow Management	Feedback Channel	Strategy can be adapted to driving behaviour	At the moment, driving behaviour is observed via video cameras, which is very cost intensive and does not cover all sections of the road	Driver, Road Operator

Service Category	Service and Description	Specified Cases / Specification	Actual Problems/difficulties faced	"user/ beneficiary"
E-Call	Exact Accident Localisation	Transversal and longitudinal positioning accuracy is crucial - especially in case of routes that run close from each other but need different access routes, also crucial, on which lane and driving direction the accident took place	In Germany reported via TMC by the police from the accident site, up to 15 km inaccurateness, road operators have exact map but it is not compatible with the map system of the police	Emergency Services, Driver
	Localisation of the Caller	Exact positioning of the caller in case of an emergency	Often the caller cannot be located - problem with different subfirms (do not hand over existing data)	Emergency Services, Driver
	Route Calculation	Exact positioning of the vehicle at the starting point	Sometimes incorrect route calculation due to inaccurate vehicle positioning at the starting point	Emergency Services, Driver

Table 1: Interesting Services identified in the workshop and interviews

2.3 Scenarios

On the basis of the foregoing services identified, four of the services identified in the previous chapter have been selected by the project consortium regarding technical and economical practicability and usefulness for the project:

- Generating and Updating of Maps
- Road Charging to Influence Demand (scenario: motorway interchange)
- Lane Specific Advice (such as lane specific speed advice, opening/closing of hard shoulders, etc)
- Accident Localization

These services will be used as a starting point for the detailed definition of scenarios that will be tested in the demonstration phase. Two main scenarios have been determined already in an earlier phase of the project, comprising an urban motorway as well as an alpine motorway. The selected services serve as a basis for the specification of the scenarios to be tested and as a starting point for the technical implementation. In the following chapters, the selected services are presented and described in detail from a user perspective. Furthermore the technical approach is specified. The evaluation and validation will then be realized from a technical perspective.

Two versions of the On-Board-Unit will be tested in both scenarios. In the first version the OBU will be fully integrated into the vehicle (access to CAN BUS data), whereas in the other version a vehicle-independent OBU will be embedded.
An important outcome of the demonstration phase is the difference in accurateness between a vehicle-independent OBU in contrast to a fully integrated OBU.

2.3.1 Scenario 1: Urban Motorway

The selected services that will be tested in the urban environment will be the Generating and Updating of Maps and the Road Charging to influence demand. In the urban scenario, street canyons, multi-path effects and motorway intersections and bridges impact the accurateness of the GPS signal and therefore impose problems for providing high-precision positioning. The test area for urban Motorway comprises the motorway A23 from junction *Kaisermühlen* in the north to exit *Inzersdorf Sterngasse* in the south with a total length of 11.5 km.

Description from a user perspective

Generating and Updating of Maps
Precise positioning information could facilitate the generating and updating of maps. Points of precision should be defined in order to avoid systematic errors. This issue has been encountered in the SafeSpot project and will be addressed in the development of the NAV-CAR test scenario. The Generating and Updating of Maps is a service required from the road operators in particular. Emergency services require maps of even greater detail within rural areas, which should include house and stairway numbers and the access to specific addresses. The preparation of an additional map layer for emergency services taking into account their specific needs and requirements is considered.

Road Charging to Influence Demand shall offer the possibility to charge road vehicles in a more flexible way and to inform the drivers about the predicted toll-costs of their planned journey. Additionally the data necessary for charging can be collected to provide this information to the toll-operator. This service is applied on motorways, including tunnels and bridges. Service companies contracted to perform road charging usually have to guarantee a certain performance of the system (e.g. 99,9 % of the stretches driven in a given time are charged correctly). Robustness is a crucial requirement for this service.
Rural areas can have sections with difficult circumstances for accurate positioning, such as street canyons, motorway interchanges (with motorway lanes crossing on different vertical levels) and charged road sections running nearby not charged sections. These circumstances make it difficult to triangulate the satellite signals, and thus receive accurate and reliable positions. Therefore, it is hard for the service providers to guarantee the required performance when offering satellite based tolling systems. Usually additional sources of data are used for accurate positioning, requiring expensive roadside infrastructure *(3)*.

The systems already developed in other projects such as COOPERS and SISTER are considered in the technical specification and will be used as a basis for the development of the NAV-CAR test solution.

2.3.2 Scenario 2: Alpine Motorway

The selected services that will be tested in the rural environment will be Lane-specific Speed Profiles and Accident Localisation. In the alpine scenario (Brenner corridor), especially tunnels and urban canyons lead to inaccurateness and unreliability of GPS signals and positioning information.

Description from a user perspective

Lane specific advice

Several services described above (e.g. lane specific speed advice, opening/closing of hard shoulder, allocation of grit or snow ploughs, etc.) need lane specific positioning as a pre-conditioning. Therefore one of the objectives of the tests within NAV-CAR will be to prove the ability to position a car 1m accurately.

Exact accident localisation

In particular, the **exact accident localisation** is crucial for a time-efficient and adequate emergency operations planning. The importance of this service was mentioned in particular by the German road operators as well as the emergency services. For this service, not only transversal but also longitudinal positioning accuracy is crucial, especially in case of streets that run close from each other but require different access routes. It is also crucial, on which lane and driving direction the accident took place. For example, it has to be differentiated, if the accident took place on the motorway exit or on-ramp. In Germany, the position of the accident is reported via TMC by the police only at the moment of their arrival at the accident site. The information has an inaccurateness of up to 15 km, even though road operators have exact maps. This inaccurateness is a result from the incompatibility of the systems of police and road operator.

2.4 Generic (device-specific) technical specification

The following technical specifications are valid for scenario 1 and scenario 2:

- **Transversal position accuracy: max. +/-1 m**
  The width of a lane on an Austrian motorway is 3.50 or 3.75 m (taken from [10]). If precise road maps are available, the used lane should be detected with the accuracy described above. If the detected position is within 1 m of the boundary of two lanes or on the boundary of the street, the position should be interpreted as “between two lanes” or “off road” respectively (see Figure 4).

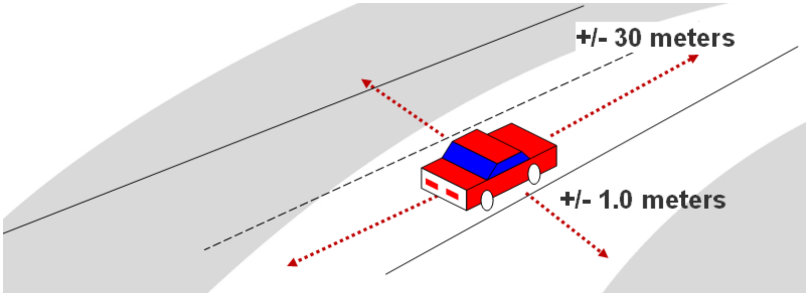


Figure 4: Requirements for lane specific vehicle localization

- **Longitudinal position accuracy: max. +/-30 m**
  This accuracy of the longitudinal position is sufficient for road charging applications and for critical sections such as on-ramp, exit or intersections. For the creation of precise maps, the accuracy of the longitudinal information should be improved to the level of transversal position accuracy (see Figure 4).

- **Vertical position accuracy: +/-3 m**
  In urban regions sometimes street sections are running in parallel or crossing in a very acute angle on different vertical positions (bridges). For a road charging application it is important to distinguish between a toll road from other non-toll roads which are situated below or above.

- **Update rate of position information: 0.8 s**
  The system delivers the position coordinates in a fixed time interval. A vehicle driving a typical closely curve on an urban motorway with a speed of 80 km/h should result in a transversal positioning deviation less than 1 m in this time interval. A calculation of distance travelled before the lateral deviation reaches 1 m for typical highway speeds shows a minimal update interval of 0.8 s (see Table 2 and Figure 5).

R [m]	80	200	400	800
V [km/h]	60	80	100	130
Distance travelled straight before deviation of 1 m is reached [m]	12.7	20.0	28.3	40.0
Elapsed time when travelled straight before deviation of 1 m is reached [s]	0.8	0.9	1.1	1.1

Table 2: Relation of curve radius, speed and update interval. Data for relation of curve radius and speed taken from (11)

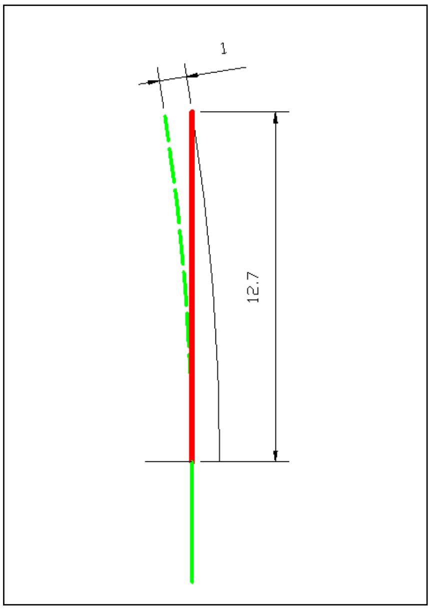


Figure 5: Calculation of update distance for curve radius of 80 m / 60 km/h
Green: target trajectory; red: deviation

- **Estimation of position accuracy (measure for robustness)**
  The precision of the position coordinates from the system depends on two main parameters: the accuracy of the GPS sensor and other OBU and vehicle sensor values. The accuracy of the GPS sensor depends mainly on the number of received satellites and is significantly lower in specific environment conditions, for instance in street canyons, in mountain regions, or in tunnels. The accuracy of vehicle specific sensor elements such as wheel speed sensor depends on the different slick in the acceleration or deceleration phase of the vehicle. The system should evaluate the different sensors and should return an estimation value for the accuracy.

- **Time stamp of each position data based on the internal clock of the system**
  Each coordinate data element should have a time stamp from an internal clock of the system, which is synchronised with the GPS-time. The internal clock is necessary because in the case of missing data from the GPS-receiver the internal NAV-CAR

clock is used. If GPS-time is available, the internal clock will be synchronised to the GPS-time.

- **Data display**
  A data display with available real time data should be implemented. The goal is to provide a direct feedback for the driver in the test scenarios while he or she is driving with the car. This feedback should only contain parameters which are directly given by the sensor or which are easy to calculate in real time and should also provide information if a sensor does not work correctly. A detailed analysis of the data is only done offline.

For the implementation of services in traffic management data exchange with service providers or other vehicles is essential. The main application can run at the control centre of the traffic management, in the vehicles or distributed in a network. In many cases data must be exchanged in real time within a given time delay.

2.5 Limitations for the specification of scenarios

Aim of this project lies in the establishment of precise and accurate positioning. Realtime evaluation (i.e. real-time communication of the information to the driver) will not be considered in the project.

Vertical positioning information was not considered as an important feature as it was not mentioned in the expert interviews and workshop. All the same, vertical positioning information is an issue and relevant in case of motorway crossings and bridges.

3 Technical OBU Component Implementation

3.1 General overview

This chapter describes the components to be integrated into the NAV-CAR On-Board Unit (OBU). It provides an overview of the configuration, technical details and the selection process are described in D 2200, the actual equipment installation in D 2300. The validation details for on-board equipment are reported in D 2400.

(1) The hardware configuration of the AIT (NAV-CAR) MECU (Minimal Electronic Control Unit)
(2) The AIT MECU Board with its interfaces
(3) The sensors implemented (GPS receiver, inertial sensor, altimeter)
(4) Some additional implementation issues such as time synchronization which is a critical issue in high precision positioning when integrating several data sources of different kind with different error propagation, and the interfaces to the on-board host computer for simulation and evaluation purposes.

The integration of the components was completed and the OBU successfully installed in the AIT Concept Car, a FORD FOCUS. The OBU integration comprises the following:

- On-board system using AIT MECU-Board (see Figure 6),
- Implementation of CAN-Interface, tested with Vector CANalyzer,
- Higher quality GPS system than used before in COOPERS
- Inertial Sensor (6 degrees of freedom, high resolution Gyroscope fulfilling automotive robustness and temperature specifications, including temperature sensors for all axis for compensation calculations)
- Altimeter Sensor

From the functional point of view, the implementation provides two additional features required for the test drives (data acquisition and evaluation):

- Time synchronization with time stamp 1 ms for CAN-bus data, Inertial Sensor, Altimeter and GPS-PPS (Pulse per Second) signal (could be improved up to 10 µsec, but this not necessary for this project),
- Communication with in-car PC (portable notebook), which is performing the high-level tasks (under preparation: data fusion, algorithms using and extrapolating data in case of loss of inputs, plausibility checks in case of errors of one data source etc., user interface, important results will be real-time for the driver (except Galileo simulation), validation/comparison with RoadSTAR geo-reference data).

3.2 Overview of the Hardware Configuration of the AIT OBU

Figure 6 provides an overview over the hardware configuration of the NAV-CAR OBU as block diagram. The configuration concept includes the AIT MECU as central unit for control of sensor data and the communication with the on-board portable host PC. A modern high sensitive GPS module with reference time output (PPS signal) is connected to the MECU via the UART interface and provides medium precision x/y position data and low precision altitude data and a 1PPS (one pulse-per-second) signal for time synchronization purposes. CAN bus data are acquired via a CAN connector by the eCAN (enhanced Controller Area Network) interface of the MECU. The data from the vehicle include all four wheel speeds, steering angle and some other data which are not vehicle-type independent and differ therefore depending on OEM brand and type.
The main sensors implemented are:

- Inertial sensors with 6 degrees of freedom (3 linear accelerometers and 3 gyroscopes) with temperature sensor for correction purpose included,
- Altimeter (air pressure sensor): additional data for measuring of the altitude more precise than GPS.

For debugging, programming and test purposes of the OBU firmware, a JTAG connector (Joint Test Action Group, IEEE-Standard 1149.1) is available. For data transfer to the portable host-PC a USB connection is provided. It is realized with a SPI (Serial Peripheral Interface) to USB converter.
For the electric power supply a built-in unit in the AIT Concept Car provides several voltages derived from the 12 V vehicle power (battery).

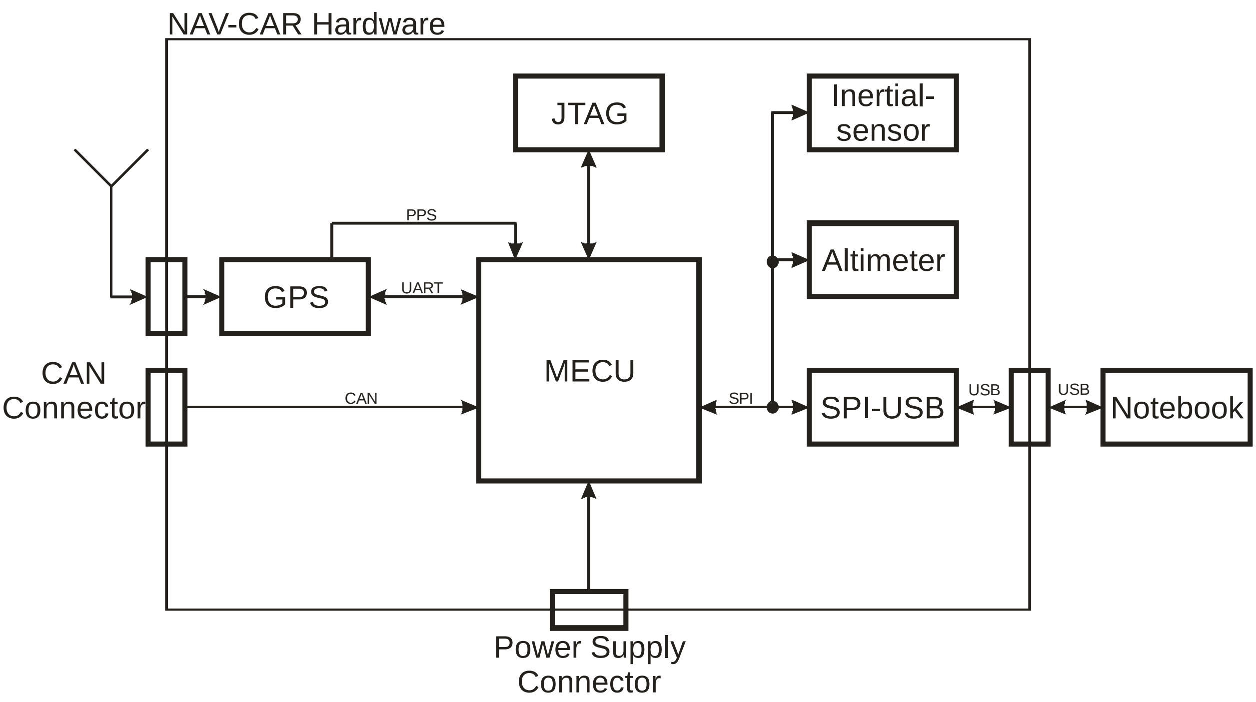


Figure 6: Block diagram of the NAV-CAR OBU

4 Selection of Motorway Reference Sections

As specified in D2100, the relevant scenarios for evaluation are (1) urban motorway and (2) mountainous region, identified as challenging areas for robust positioning. These areas and their challenges are described in Table 3 below.

Scenario	Challenges
Urban motorway	Dense adjacent local road network, many entries and exits, lane deviations, considerable satellite shadowing due to noise barriers
Mountainous region	Alpine environment, large topographic changes, low satellite coverage due to surrounding mountains

Table 3: Selected scenarios and their challenges

For the planned comparison of GPS measurements and Galileo simulation results, a digital elevation model of the test area is necessary. As mentioned in chapter 1, NAV-CAR builds on the experience gained in Coopers. As a side effect, NAV-CAR is able to make us of the terrain model created in Coopers [1].

4.1 Urban Motorway

For the urban motorway scenario, the A23 motorway “Südosttangente” between junction “Kaisermühlen” and junction “Inzersdorf” was chosen as test section. The A23 motorway is one of the highly frequented motorways in Europe (up to 180.000 vehicles per day) and consists of up to 4 lanes per carriageway. Short tunnels and noise barriers with heights up to 8 m provide a demanding environment with respect to satellite coverage (see Figure 7).

A clover-leaf interchange between the motorways A23 and A3 (“Knoten Prater”) is well suited for the investigation of three dimensional positioning and determination of height accuracy (see Figure 8). Both carriageways partly run on separate bridge constructions, which lead to different absolute height of the carriageways.

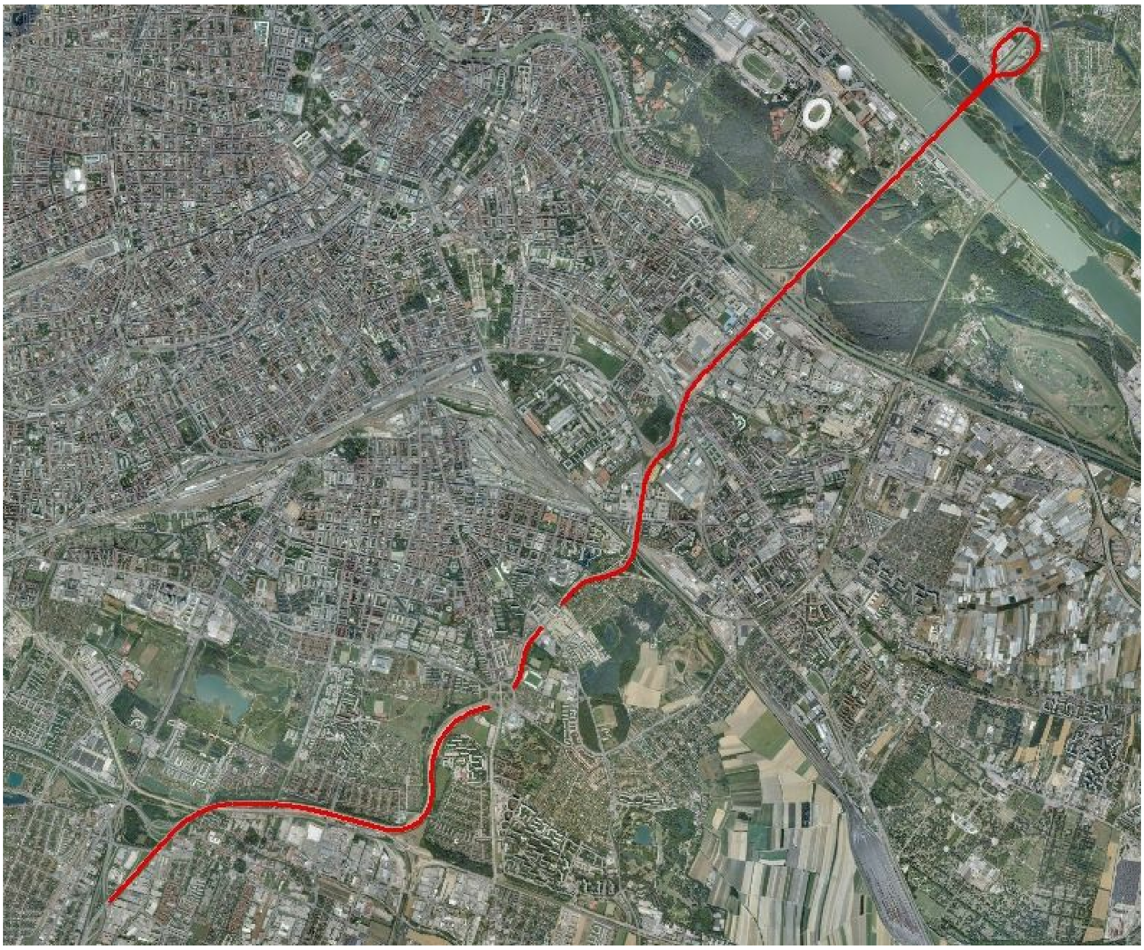


Figure 7: Test track urban motorway [Aerial image: Bing]

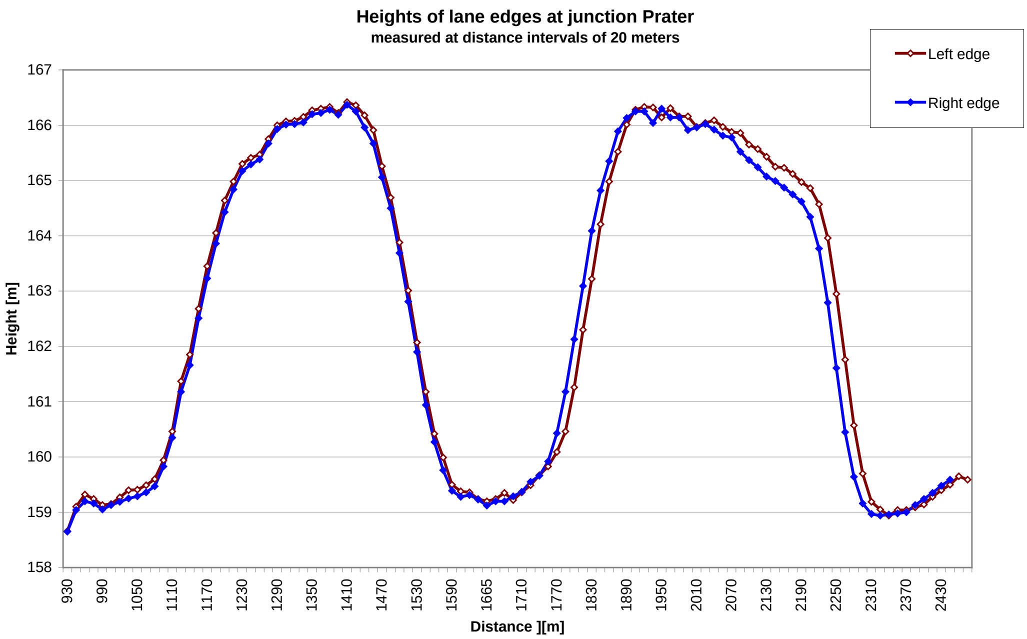


Figure 8: Height differences at clover leaf

4.2 Mountainous Region

The scenario "mountainous region" is situated on the A12 motorway "Inntalautobahn" and A11 "Brennerautobahn in the Tyrol. The evaluation sections form a triangle between the exits "Innsbruck Ost" and "Innsruck West" on A12 "Innsbruck Süd" on A11 (see Figure 9). The availability of a terrain model (as already used in the EC funded project "COOPERS") allows the simulation of Galileo satellite availability and the comparison of GPS and Galileo positioning accuracy. Due to the mountainous environment, GPS satellite reception is also degraded; especially the mountains on the south side of the motorway block the sight to a significant number of satellites.

Figure 9: Evaluation section in Tyrol (red)

4.3 Creation of Reference Data

To evaluate the position accuracy of the OBU, an independent reference measurement system with accuracy better than the OBU is needed. To create this reference data, the high-performance measurement vehicle "RoadSTAR", a special vehicle for road safety inspection and road safety audit, is used (see Figure 10). RoadSTAR uses the high-end navigation system Applanix POSLV420 consisting of two GPS/GLONASS receivers, a Distance Measurement Instrument (DMI) for exact speed measurement and an Inertial Measurement Unit (IMU) to determine the attitude of the vehicle. All these instruments are tightly coupled to achieve exceptional positioning quality even in demanding environments. With post-processing, the position accuracy of the vehicle trajectory is indicated below 10 cm, for sections without GPS reception with a length below 1 km, the position accuracy stays below 1 m.

Figure 10: High performance survey vehicle RoadSTAR

Using a stereoscopic video system (see Figure 11), the positioning of lane markings with accuracy below 0.5 m is possible. The evaluation software for the stereoscopic measurements is depicted in Figure 12.

Figure 11: Position of stereoscopic video camera system on survey vehicle

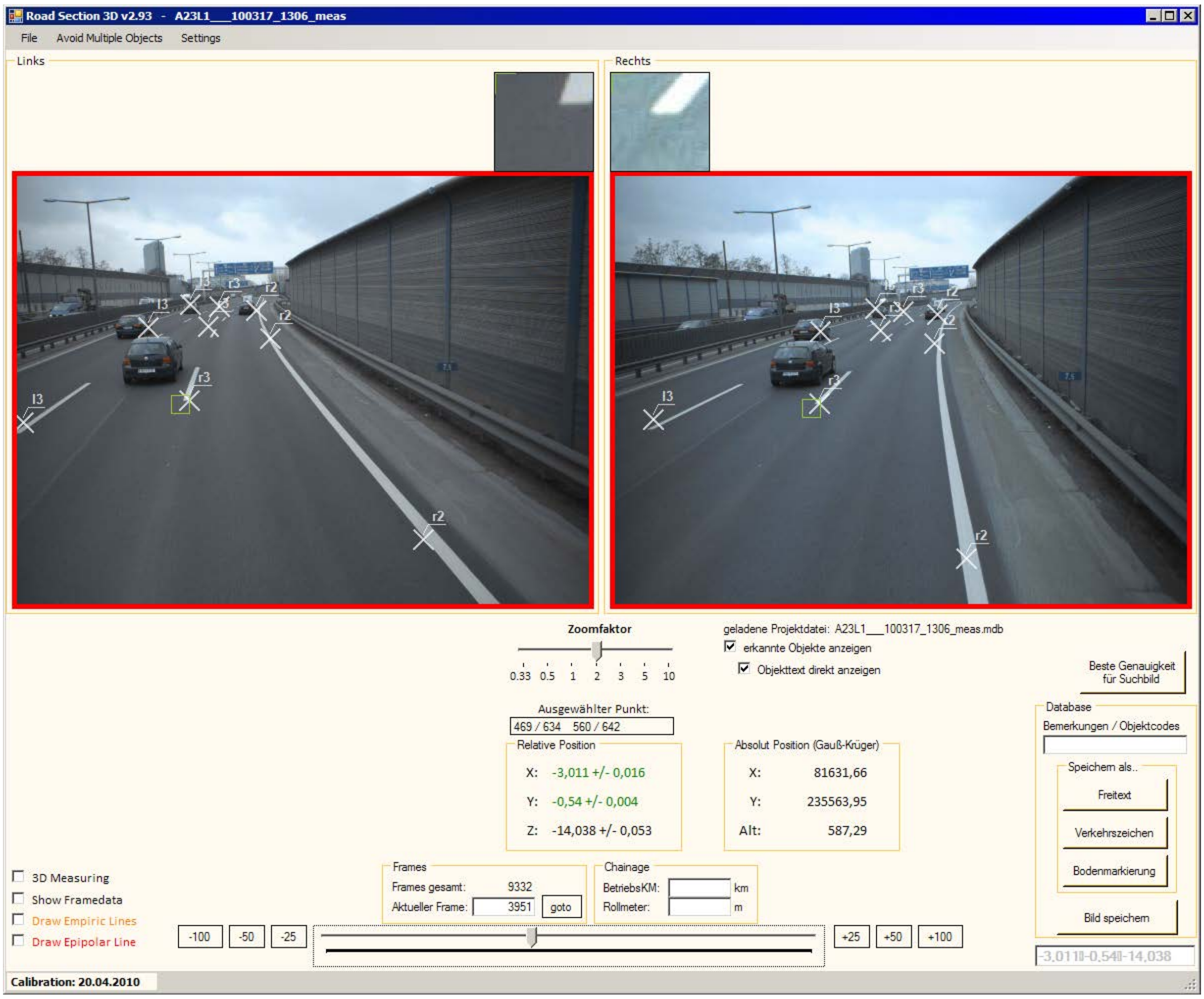


Figure 12: Photogrammetric software used to determine lane markings on A23 test track

4.3.1 Reference Data Collection

On March 17th, the reference data for scenario 1 were collected. Two runs, one on the first lane and one on the third lane were carried out on both carriageways. The clover-leaf interchange was covered in a separate run. Stereoscopic videos were recorded on all runs.
The collected raw data was post-processed afterwards using data from the Austrian Positioning Service (APOS) and the vehicle trajectories were generated.

From the video, the lane markings were positioned every 20 m for all lanes (see Figure 13). The markings were then connected with poly lines and "lane corridors" were created. From these corridors, centre lines were calculated for later evaluation of the OBU.

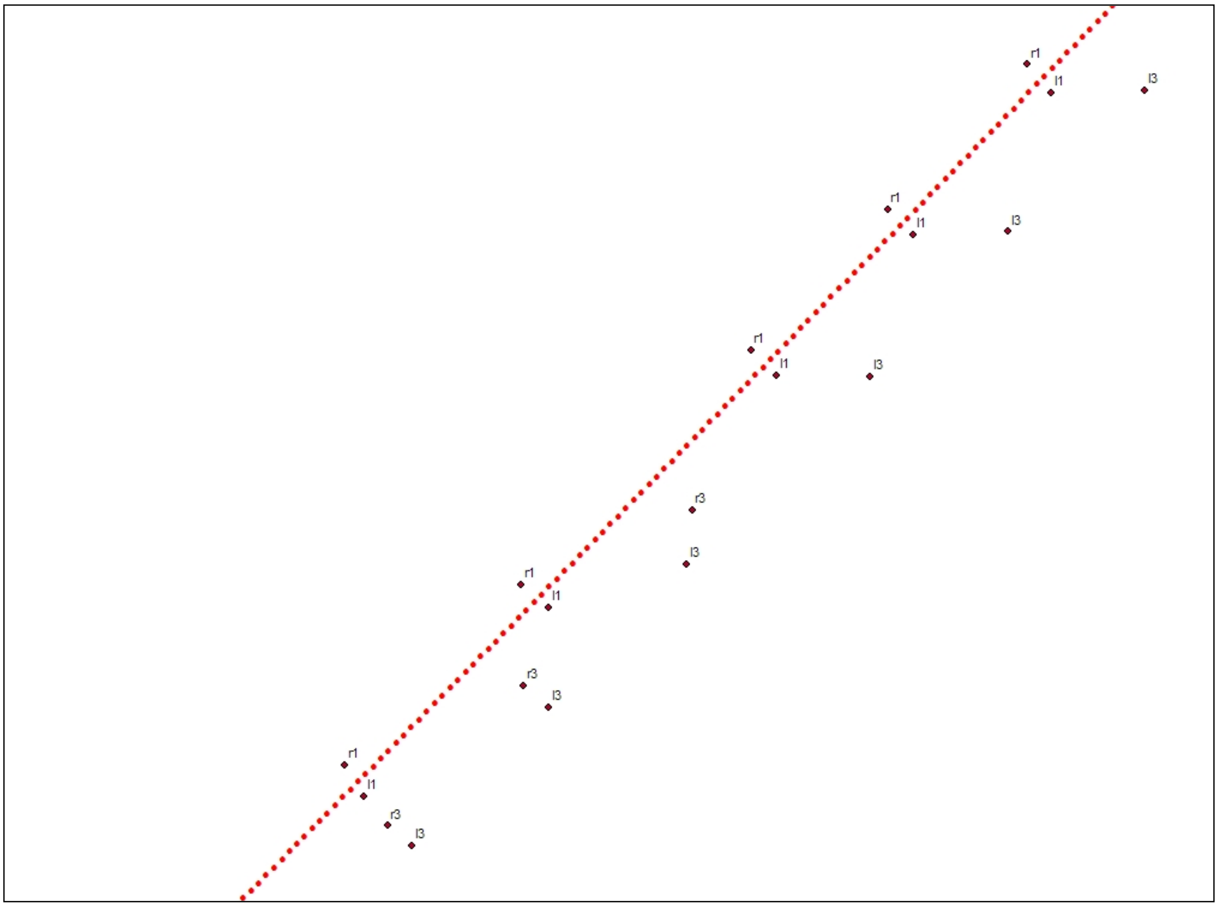


Figure 13: Example of vehicle trajectory (red) and lane markings on A23 motorway.

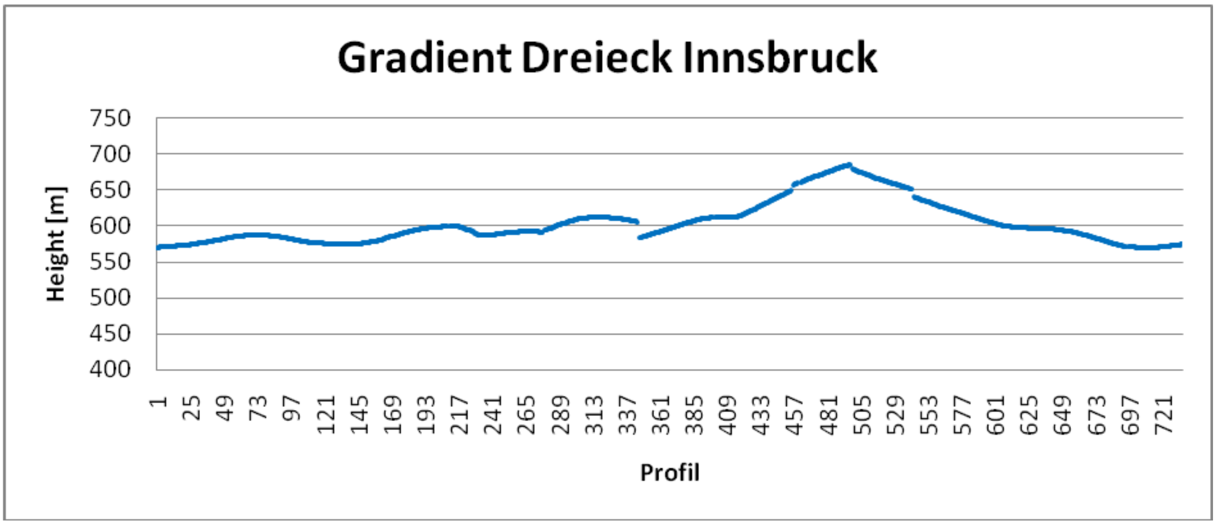


Figure 14: Gradient of A12/A13 test track. Gaps are caused by tunnels.

5 Test runs Mountainous Region

5.1 Start positions/end positions probe vehicle

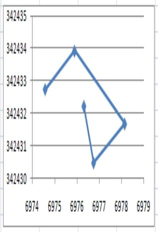
The probe vehicle is equipped with a standard consumer grade GPS receiver with a positioning accuracy of about 5 m at good satellite coverage. For the evaluation of the enhanced positioning system, precise start/end locations are necessary to eliminate the inherent error. Therefore, the starting and ending positions of the probe vehicle were defined and marked with fluorescent paint (see Figure 15). Then, these positions were surveyed using the reference equipment described above. From the wheel positions, centroid points of the car were calculated (see Figure 16).

Figure 15: Marked end position of urban motorway test track

For the mountainous region test track, two stop lines at the turning points of the test tracks in Innsbruck and at the exit “Innsbruck Süd” were traced in the same way as the start/stop positions of the urban area test track.

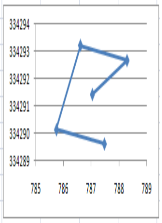
ASt Kaisermühlen, Parkplatz

StrCode	Text	X_M34	Y_M34	lon_WGS84	lat_WGS84
Ast_KM	lv	6974,57	342432,74	16,42599424	48,22025225
Ast_KM	rv	6975,89	342433,93	16,42601202	48,22026294
Ast_KM	rh	6978,15	342431,67	16,42604240	48,22024259
Ast_KM	lh	6976,75	342430,46	16,42602354	48,22023172
	Mittelpunkt	6976,3141	342432,2187	16,42601770	48,22024755



ASt Inzersdorf, Parkplatz

StrCode	Text	X_M34	Y_M34	lon_WGS84	lat_WGS84
Inzersdorf	lv	787,48	334289,61	16,34272151	48,14705391
Inzersdorf	rv	785,74	334290,13	16,34269813	48,14705859
Inzersdorf	rh	786,61	334293,21	16,34270982	48,14708629
Inzersdorf	lh	788,3	334292,66	16,34273253	48,14708134
	Mittelpunkt	787,0431	334291,4178	16,34271564	48,14707017



Knoten Prater

StrCode	Text	X_M34	Y_M34	lon_WGS84	lat_WGS84
Knoten_Prat	lv	6096	339400,49	16,41412940	48,19299121
Knoten_Prat	rv	6097,83	339400,47	16,41415401	48,19299102
Knoten_Prat	rh	6097,68	339397,03	16,41415194	48,19296008
Knoten_Prat	lh	6095,9	339397,14	16,41412800	48,19296109
	Mittelpunkt	6096,8395	339398,761	16,41414066	48,19297566

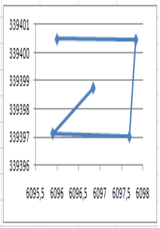


Figure 16: Centroids and wheel positions of start, middle and end position of urban motorway test track

5.2 Collecting data for Galileo Simulation and Enhanced Maps

For scenario 2 – "Mountainous Region", test drives were carried out on April 4th and April 5th 2011. Ten runs were done, five on the first (right) lane of the motorway, five on the second (left) lane. The runs started and ended with fine alignment-phases with duration of one minute on a car park near the motorway. At the western and southern turning point of the run, another minute for alignment was spent. Changing of lanes was marked in the data stream using the following codes:

0 – start/stop
1 – beginning/end of first lane
2 – beginning/end of second lane
9 – alignment

A complete circle took about 25 minutes to drive. The scenario 2 was also chosen for the Galileo simulation and the generation of enhanced maps (see chapter 8 and chapter 9).
The probe vehicle was equipped with the hardware described in deliverable D 2200 [4]. For the collection of GPS raw observation data, an additional GPS receiver "U-blox Antaris 4" was installed with and external antenna and operated with an additional notebook. All raw data streams were collected on notebooks and back upped on external hard disks.

The runs were divided into distinct run on left or right lane to ensure a sufficient number of positions on both lanes for the generation of enhanced maps.

For the Galileo simulation, the following NMEA and raw data messages were recorded (Table 4):

Type	Name	Content
NMEA	RMC	Recommended Minimum data
NMEA	GGA	GPS fix data,
NMEA	GSA	GPS DOP and Active satellites
NMEA	GSV	GPS Satellites in View
NMEA	VTG	Course over ground and Ground speed
NMEA	GLL	Latitude and longitude, with time of position fix and status
NMEA	ZDA	Time and Date

Type	Name	Content
AID	HUI	GPS Health, UTC and Ionosphere parameters
NAV	CLOCK	Clock Solution
NAV	POSLLH	Geodetic Position Solution
RXM	RAW	Raw Measurement Data
RXM	SFRB	Subframe Data
RXM	SVSI	GPS SV Status Info
RXM	ALM	GPS Constellation Almanach Data
RXM	EPH	GPS Constellation Ephemeris Data

Table 4: NMEA and raw data messages for Galileo simulation

All messages were recorded using the u-blox software "µ-center", resulting in mixed ASCII and binary stream data. The recorded files were sent to subcontractor PWP systems for the simulation of Galileo pseudo ranges and calculation of Galileo position solutions.

6 Test Runs Urban Region: Enhanced navigation

6.1 Description of the measurements

We performed the following measurement drives.

6.1.1 Calibration drives

In order to test and calibrate the sensors and to check the plausibility of the results, a 300 m calibration drive (Vienna Paukerwerkstraße, see Figure 17) was performed on February 28th.

Figure 17: Calibration test drive

In order to calibrate the CAN steering angle data, we performed a further calibration drive in a roundabout on March, 24th.

6.1.2 Measurement drives

We performed the measurement drives on the test track for scenario 1 (Vienna, A23, see Figure 7) on the following days: March 3rd, 24th, 31st, April 1st, 5th, 12th, 13th, May 11th, 31st. We logged the following data:

- GPS data (NMEA protocol)
- IMU data (gyro and acceleration values)
- CAN data (speed, steering angle, wheel speeds)
- Altimeter data (height data)
- Lane data (value of the lane).

Due to problems with the GPS receiver (u-blox v6, which in fact was the latest and enhanced version, and should have delivered the better results), a second GPS receiver was used which yielded better results (u-blox v4).

6.2 Results of the measurements

We gained the following results. Note that the figures are created from the data of the measurement drives of April, 13th and of May, 31st (lane change).

6.2.1 Completion of the GPS trajectory using CAN data

In order to complete the trajectory obtained from GPS data which is interrupted in areas where there is insufficient reception of satellite signals (e.g. in tunnels), CAN data as well as altimeter data are used. The GPS position data (from latitude and longitude values) is obviously not correct in tunnels (see Figure 18).

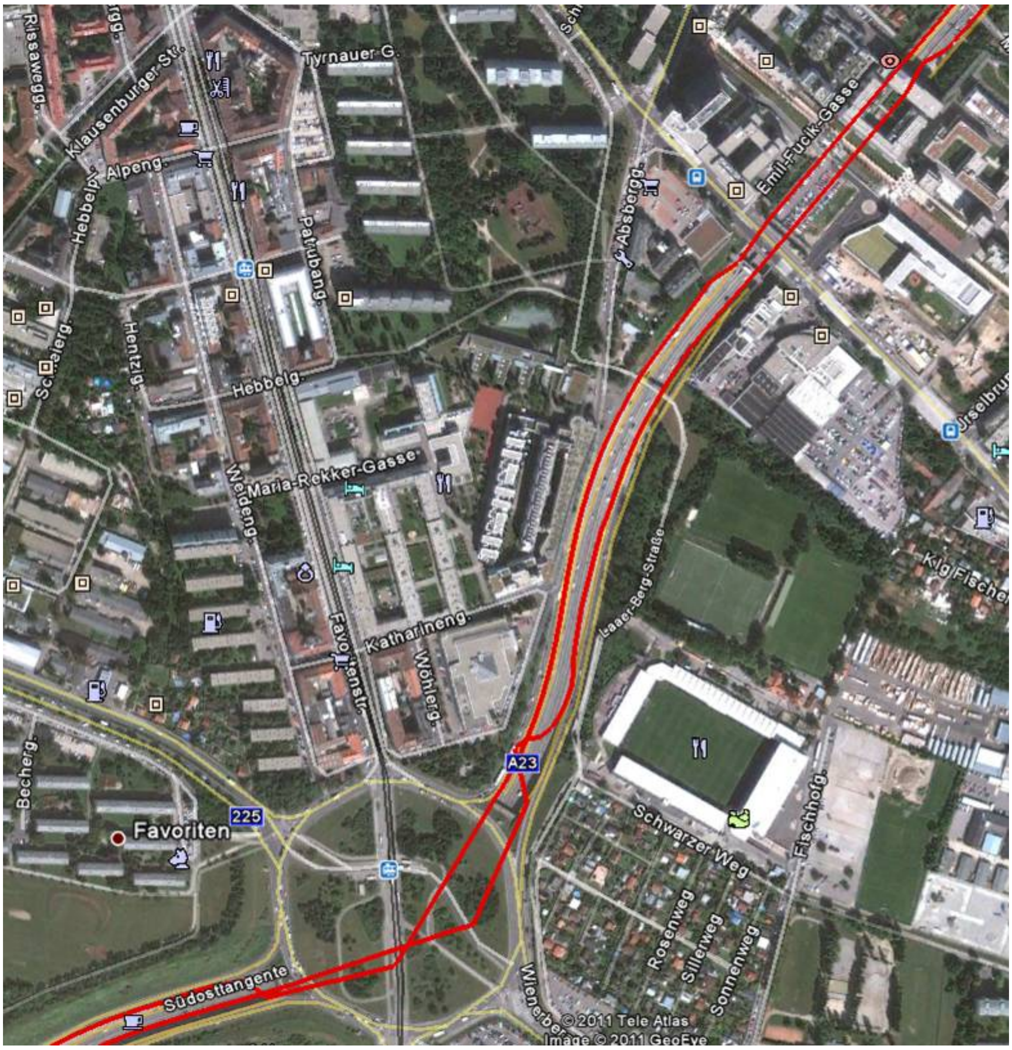


Figure 18: Trajectory obtained from GPS data

We used CAN speed data and steering angle data in order to complete the GPS position data. In order to better integrate the CAN data, GPS speed and heading data is used to obtain the position data. This is useful in order to avoid the conversion between longitude and latitude and meters and is possible because the precision of the GPS position data is sufficient enough.

Figure 19 shows the position from GPS only (blue line) and GPS and CAN (green line) for both directions. Before tunnel 1, the blue and green lines are identical, in tunnel 1 there is a small difference (the tunnel is rather straight). For tunnel 2 the additional difference is much higher because in the tunnel there is a bend to the right. The green line is obviously correct because it corresponds to the original GPS position data (see Figure 19).

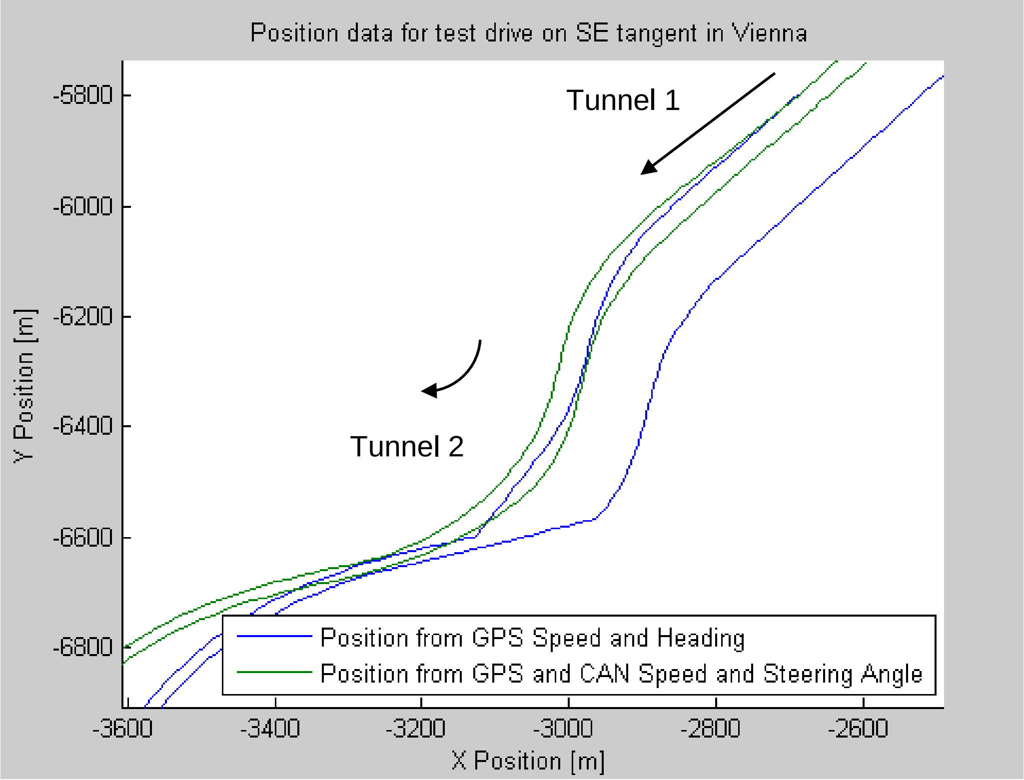


Figure 19: Position from GPS and CAN data

Result: CAN data can be used to complete GPS data (e.g. in tunnels).

6.2.2 Measurement of longitudinal accuracy of GPS

In order to measure the longitudinal accuracy of GPS we used the expansion joints on the A23 where exact GPS values are available. We used the z acceleration value of the IMU sensor in order to detect the time where the car passes the expansion joint. There is a significant peak in the z acceleration in the moment the car lands in the expansion joint (see Figure 20).

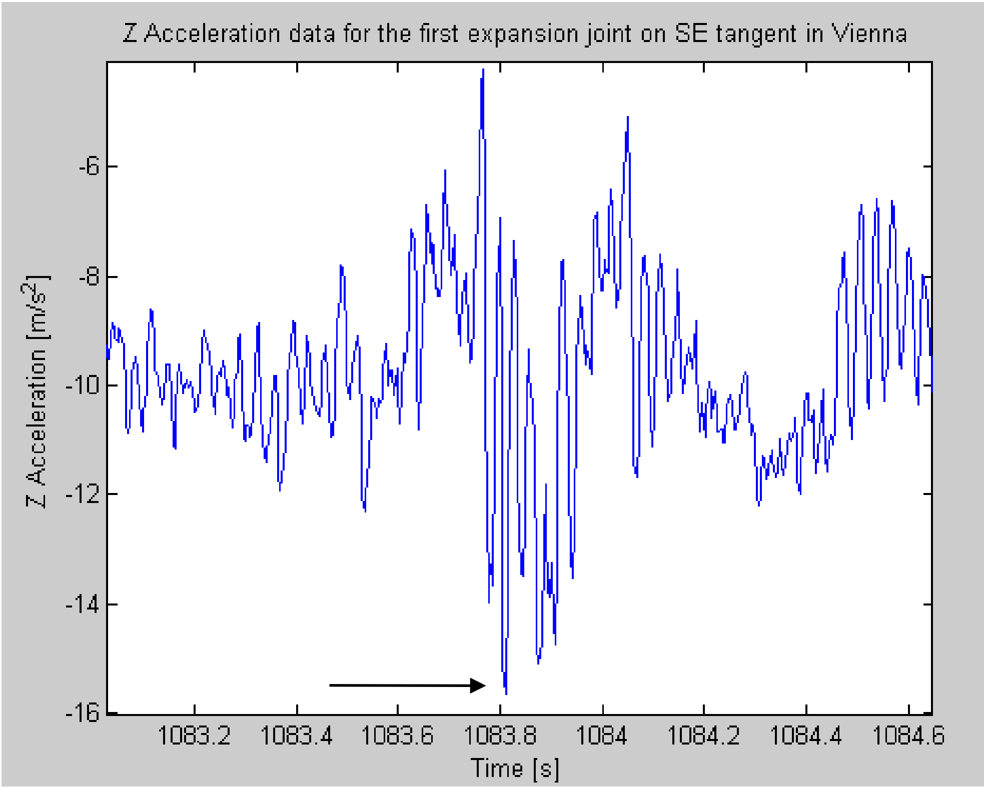


Figure 20: Z acceleration values

We calculated the GPS position value for the time stamp of the peak and compared it to the exact GPS value. The difference is around 7 m (see Figure 21).

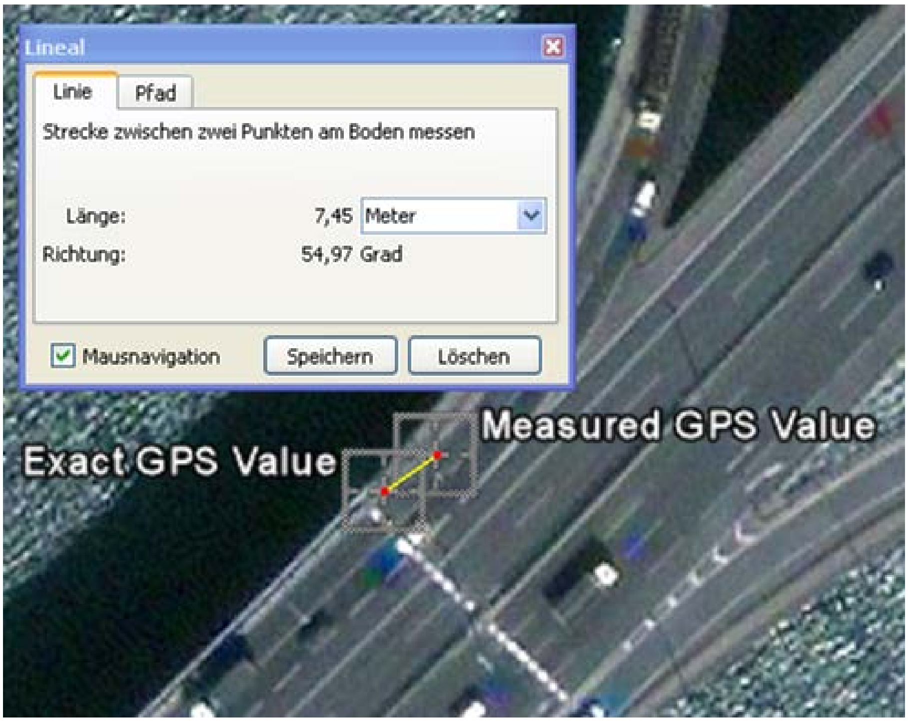


Figure 21: Measured vs. exact GPS value

Result:
The longitudinal accuracy of GPS can be measured using well defined points where exact GPS values are available and which can be easily detected (e.g. expansion joints).

6.2.3 Detection of position of the car on or under a bridge

We used the altimeter value to detect whether the car is driving on or under a bridge. The bridge in our example is situated in the cloverleaf (see Figure 22). The driving direction is symbolized by the three black arrows.

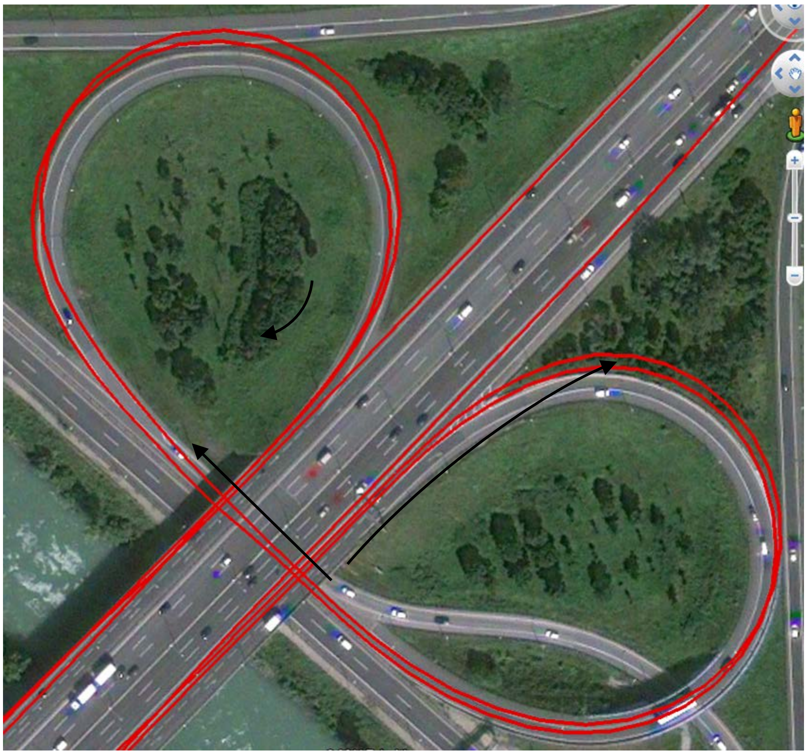


Figure 22: Bridge in the cloverleaf

The height values obtained from GPS and altimeter (see Figure 23) show the height difference when the car is driving under the bridge (around 167 m above sea level) and when the car is driving on the bridge (around 173 m above sea level). The difference of 7 m corresponds to the height of the bridge. Note that the altimeter measures a higher value when the car is passing under the bridge (see arrow in Figure 23). The difference is about 2 m caused by the temporary increase of air pressure which is reflected by the lower edge of the bridge when the car is passing. We observe the same effect when the car is entering a tunnel, since the altimeter measurement depends on air pressure.

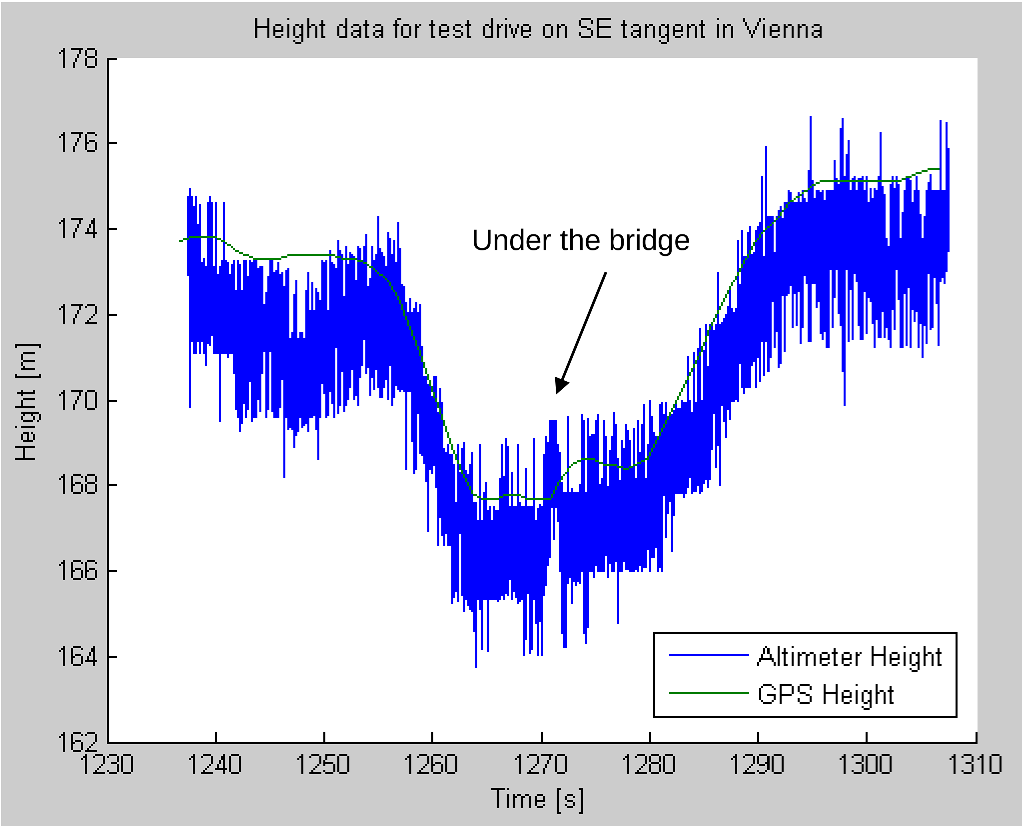


Figure 23: Altimeter values in the cloverleaf

Result: the position of the car on or under the bridge can be measured using GPS or altimeter.

6.2.4 Detection of lane change

We used the CAN data (speed and steering angle) as well as GPS data (speed and heading) to detect a lane change. In Figure 24 the calculated trajectories based on CAN and GPS data as well as the start and destination lanes (distance 3.5 m) are depicted. Both CAN and GPS yield optimal values and are nearly identical.

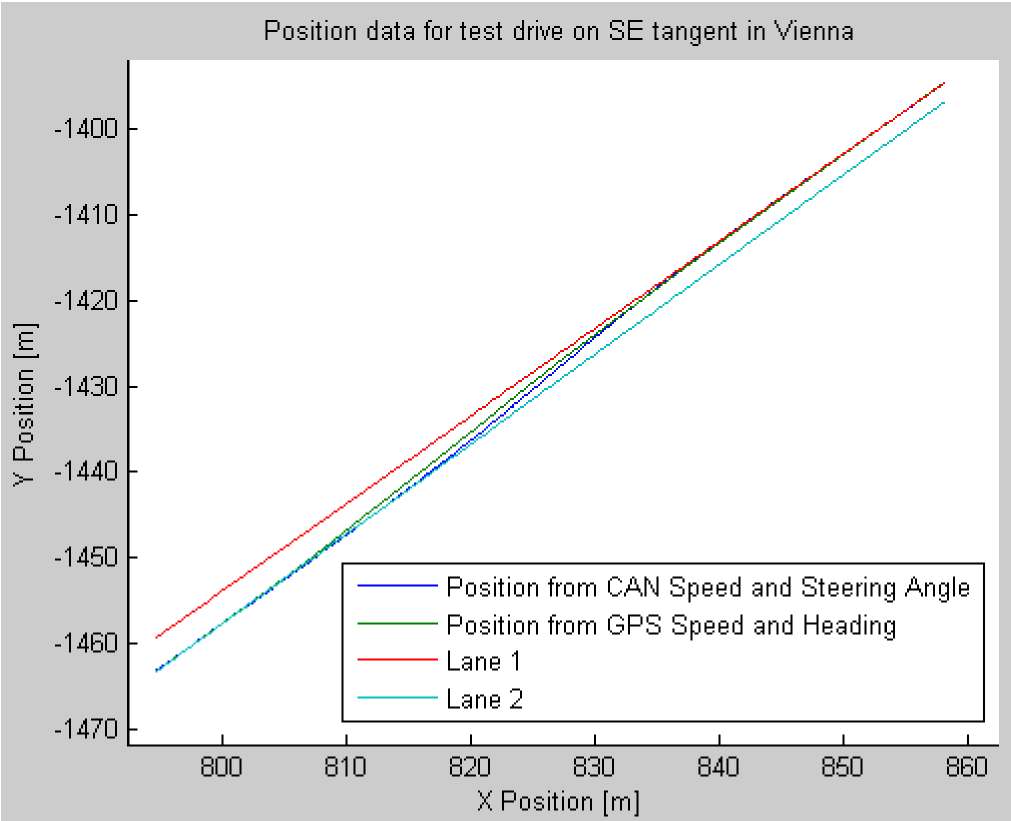


Figure 24: Detection of lane change using CAN and GPS data

The z gyro value of the IMU can also be used to detect a lane change in a qualitative manner (see Figure 25). The integrated value can be used to detect whether the car is in a parallel position before and after the lane change.

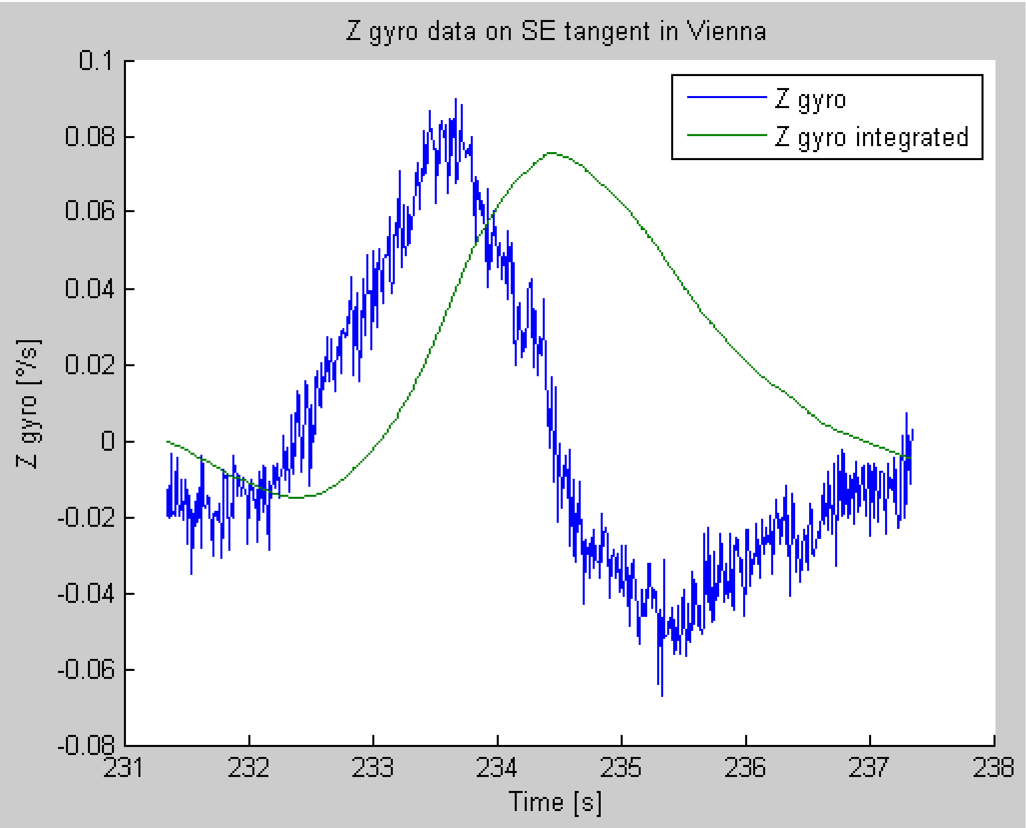


Figure 25: Z gyro values

Result: the lane change can be detected both using CAN and GPS data. It can also be detected in a qualitative manner using gyro data of the IMU.

6.2.5 Limitation for the use of IMU data

We spent a lot of time in order to analyse IMU data in combination with GPS data. We used the MATLAB toolbox Aided Inertial Navigation System (AINS) Toolbox of the University of Calgary in order to calculate the trajectories. Although there was an intensive cooperation with the University we were not able to obtain a trajectory in an acceptable quality, which seems to be caused by the method used in this toolbox to correlate GPS and IMU data by prioritizing the validity of GPS data. So we could not derive any useful result using coupled navigation with GPS and IMU data. We looked at several toolboxes, but the one chosen seemed to be the only one publicly being available fitting the purpose. As far as we could find out are the commercially available much more expensive complete IMUs using proprietary software adapted to the characteristics of the specific IMU which is not available separately.

7 Galileo simulation

7.1 Methodology

GPS is fully operational for more than 16 years now and has become an everyday tool. Since May 2nd 2000, when selective availability was turned off, every new generation of GPS receivers provides better, more reliable satellite tracking, faster signal acquisition and better accuracy. However, the progress in the low cost domain of receivers seems to have reached saturation for the last 10 years.

The GPS operation regime remains fully in the hand of the United States government. To overcome this dependency, the European Union has started to establish its own satellite navigation system "Galileo". Galileo has finished its design phase and is currently in the build up phase. Two test satellites are in orbit since 2005 and 2008 (a third one could be cancelled because of the success of the second one) and two IOV (In Orbit Validation) satellites were launched on October 21st, 2011. The next two satellites are planned to be launched in 2012, first services based on 18 satellites are expected 2014, the full configuration of 30 satellites not before 2020.

Galileo will offer different services for different user needs. "Open service" (OS) and "Commercial service" (CS) are two of them. Open service will be provided on two frequencies (L1B, E5a) and commercial service will be provided by three frequencies (L1B, E5b, E6b). While open service is more or less equivalent to GPS from a user point of view, commercial service will provide higher accuracy with encrypted signals, but will be liable to pay costs. There will be an availability guarantee for commercial service. These two services are investigated in NAV-CAR.

Due to the fact of lacking satellites, a real Galileo measurement is not possible today. In Coopers, a European integrated research project [1], an approach to evaluate the potential of Galileo using simulation of satellite signals was taken. The whole procedure is described in detail in COOPERS Deliverable D4500-2 "Evaluation of scientific test vehicle and achieved results (incl. section regarding the substitution of GPS with Galileo" [2].

In this document, a brief summary of the simulation approach is given.

The first stage was the validation of the simulation of GPS satellite signals. Simulation results were compared to real measurements and the errors were compared. The simulation results showed a good correlation to the real measurements and were taken as indicator for the correctness of the simulation approach. An important factor is the availability of satellite signals, which is strongly connected to the terrain in which the measurement takes place. For every simulation point, an elevation mask is calculated to determine which satellites are in view. To achieve consistent result, a detailed digital terrain model is necessary. In Coopers, a digital terrain model of the surroundings of Innsbruck was used. From the availability of

GPS satellite signals, the simulation of Galileo signals and hence the position calculation using only Galileo signals is possible. The methodology of "Virtual Galileo" is shown in Figure 26. During the Coopers project, the main focus was set on the calculation in plane, the vertical accuracy of the results of the Galileo simulation were not assessed, since the Coopers services did not require any height information.

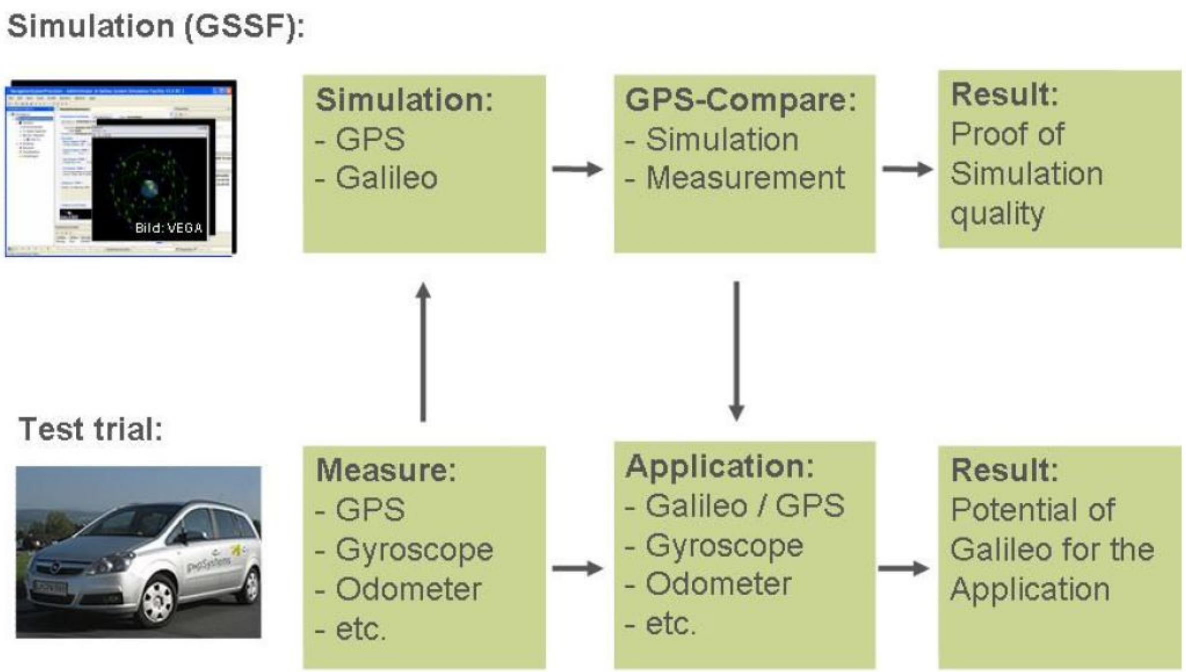


Figure 26 - Workflow of GPS and Galileo simulation and validation (from [2])

In NAV-CAR, the same approach was taken. Additionally to the work done in Coopers, special emphasis was put on the vertical errors of GPS and Galileo.

The workflow was adapted to the project needs as follows: The simulation of GPS was skipped, as this part was sufficiently investigated in Coopers and is to be seen as prerequisite for the validation of the simulation approach itself.

During the test trials in Innsbruck, raw observations of GPS satellites were recorded as binary streams as well as satellite ephemeris data and ionosphere correction values. Together with the reference trajectory (see chapter 5.3) and the recorded wheel speeds, the Galileo simulation was run. Optimally each test run would require a high performance reference trajectory in 4D (which could be generated with the equipment from chapter 5.3), but due to budget constraints a simplified 4D reference trajectory had to be used as input to the simulation process. The first output of the simulation, were the satellite signals of the Galileo system in RINEX 3.0 format. These signals were then used to calculate the 3D-positions for the open service and the commercial service of Galileo. For the calculation using open service, an L1 receiver model was used. For the commercial service a L1 and E6 receiver model was used.

The next step was the evaluation of the position error both in lateral and vertical direction for the measured GPS and simulated Galileo positions. The flow chart of this process is shown in Figure 27.

At first, the GPS positions were converted into 3D features and projected into the Austrian coordinate system. Then, the nearest section of the reference trajectory was determined. Finally, the nearest 3D position on the reference trajectory was determined and the lateral and vertical distances were calculated. These distances represent the absolute error of the GPS measurement and the Galileo simulation. The lateral and vertical deviations of the measured points to the reference trajectory are shown in Figure 28.

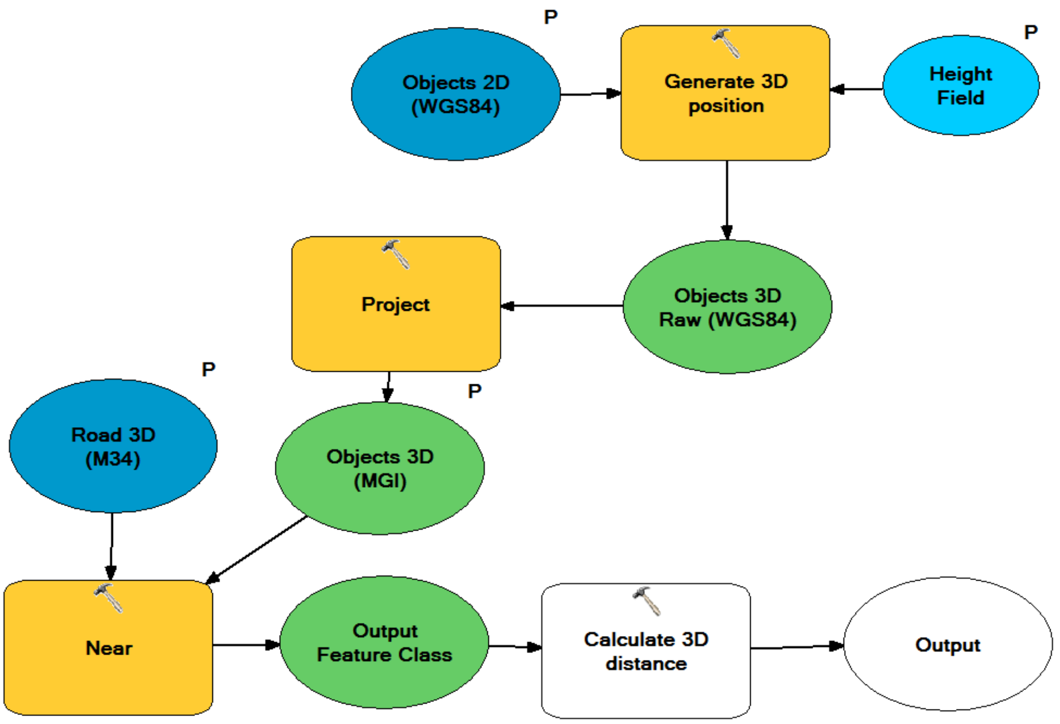


Figure 27: Work flow of 3D distance calculation for the evaluation of position accuracy of GPS and Galileo positions.

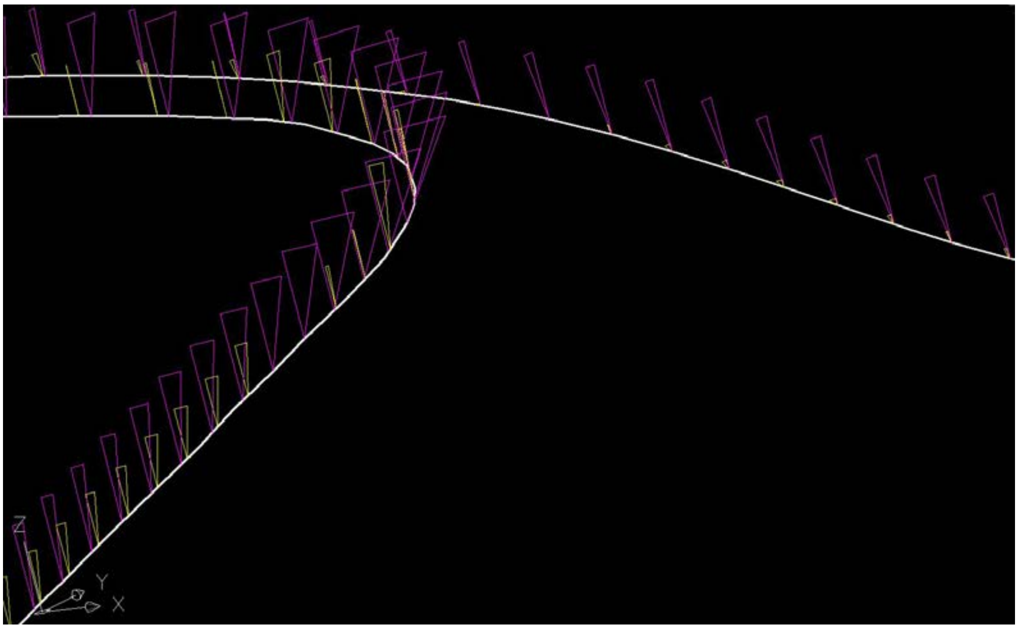


Figure 28: Example of visualised transversal and vertical deviations of GPS measurement (magenta) and Galileo simulation (yellow) to reference trajectory (white).

7.2 Assessment of Galileo simulation results

The absolute errors of measured GPS and simulated Galileo services in relation to the reference trajectory were assessed. The following figures (Figure 29 and Figure 30) show the cumulated frequencies of the absolute errors of GPS (green), Galileo commercial service (red) and Galileo open service (blue). For the lateral error, Galileo commercial service shows a distinct improvement of accuracy compared to GPS. The Galileo open service shows the same performance as GPS, which is accordance to the expectations. The primary benefit of Galileo open service is generally seen in the higher number of available satellites (27 in comparison to 24 GPS satellites) and thus better coverage in demanding environments.
Where GPS and Galileo open service have about 50 % of the points with an error better than 2 m, Galileo provides almost 75 % of the points in this error range. Regarding the requirements in NAV-CAR, that were defined in Deliverable D-2100 [3], the assessment shows the following results:

Lateral accuracy:
Here, the requirement was defined with ± 1 m. The simulation of the open service shows that 25.4 % of all points have a smaller deviation than 1 m. Regarding the commercial service, 44.5 % perform better than the required 1 m. In contrast, GPS achieves 28.2 % of the points with a smaller deviation than 1 m.

Vertical accuracy:
Here, the requirement was defined with ± 3 m. The simulation of the open service shows that 23 % of all points have a smaller deviation than 3 m. Regarding the commercial service, 39.3 % perform better than the required 1 m. In contrast, GPS achieves 56.2 % of the points with a smaller deviation than 3 m.

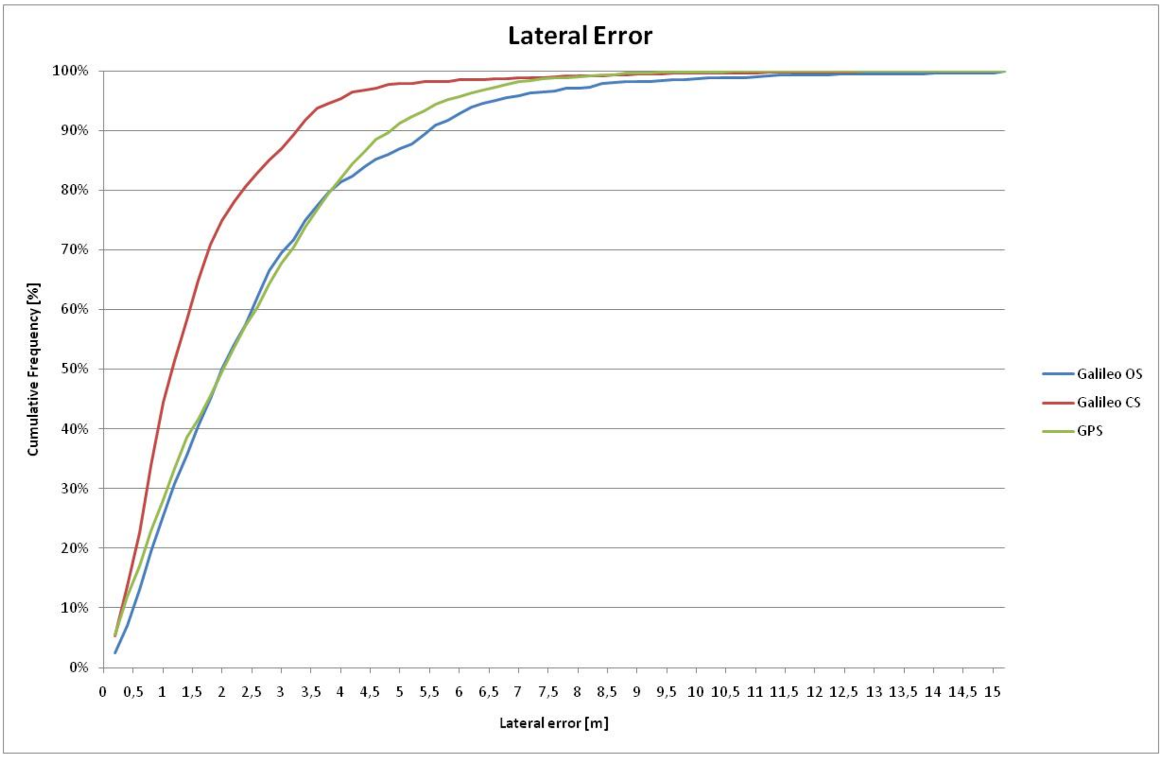


Figure 29: Cumulative frequency of lateral position error of Galileo simulation

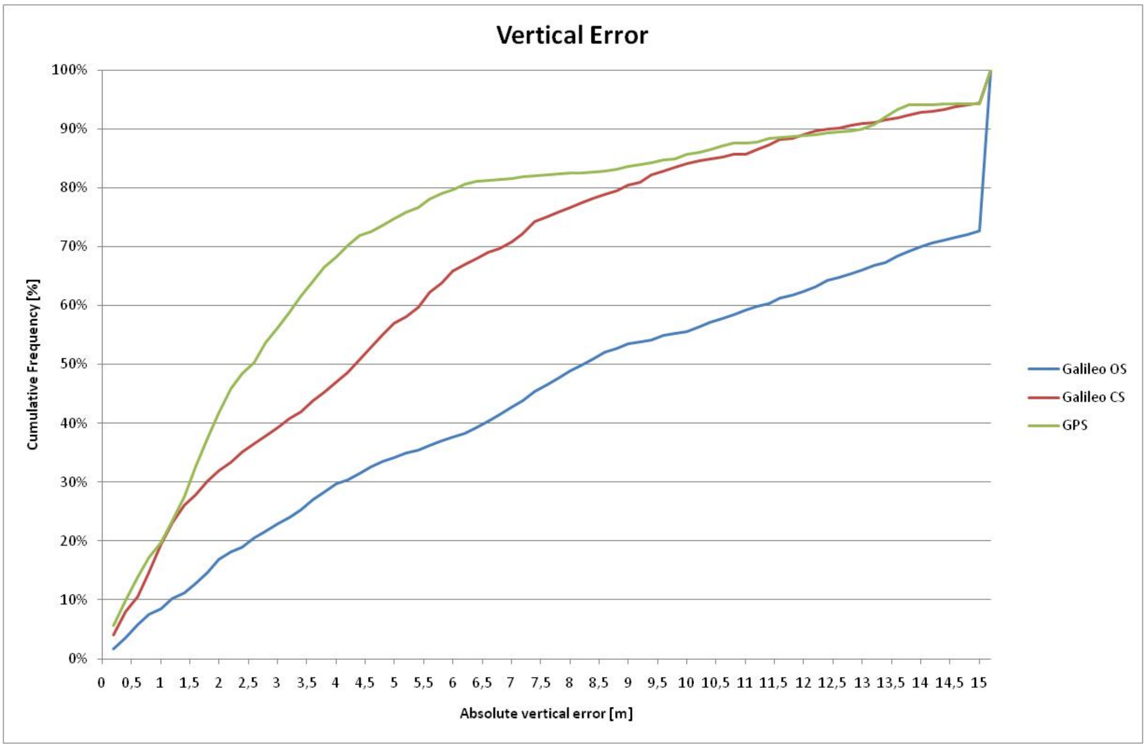


Figure 30: Cumulative frequency of absolute vertical position error of Galileo simulation

The large differences of GPS and Galileo were not expected and a deeper investigation was carried out. The deviations can be explained from various sources of error, which are described as follows:

Accuracy of reference trajectory:
Due to budget restrictions, the reference trajectory could not be measured with the High-End positioning system (see chapter 5.3) during all runs. Hence, the reference trajectories had to be calculated from a weighted average of GPS positions and the calculated RoadSTAR trajectory. This means that only the GPS information could provide the correct timing information for each test trial, while the calculated RoadSTAR trajectory contained the high performance with respect to accuracy and reliability. As a matter of fact, the accuracy of the vertical channel of GPS is worse than the lateral channel with a factor of 2 to 3. This leads to degradation of the reference trajectory in the same order of magnitude.

Satellite constellation:
Due to the demanding environment (mountainous region), the ratio of VDOP/HDOP is 2.5 on average. This is another limiting factor of the vertical accuracy of the reference trajectories.

Calculation of position:
From the simulated Galileo pseudo ranges in RINEX 3.0 format, the positions were calculated using the “Single Point positioning” (SPP) method. Here, every position fix is calculated separately, which gives a better insight into the true performance of the system. Modern GPS receivers have pre-defined usage profiles such as “automotive” or “pedestrian” that imply a certain typical movement of the receiver. For example, using the “automotive” profile, the receiver expects no sudden sharp turns and only slow changes in height – a behaviour that is to be expected from a driving car. This leads to extensive smoothing of the real position calculations. So the comparison of the simulated Galileo positions and the measured GPS positions is misleading as the true calculated GPS positions are never shown. Especially in the vertical channel, extensive smoothing is used in the “automotive” profile and this leads to a seemingly much better relative accuracy for the z-Axis.

Taking into account the points above, the conclusion that Galileo performs worse in the vertical channel than GPS cannot be drawn. Too many preconditions limit the significance of the Galileo simulation in the vertical channel. Nevertheless it has to be stated that the applied methodology of “Virtual Galileo” has the capability to generate realistic signals for the assessment of the vertical performance. In this respect, the simulation depends on the reference trajectory, which comes as an input. To overcome these shortcomings, an even more thorough creation of the reference trajectory seems to be necessary and possible to achieve. The raw GPS measurements and the high-end combined IMU and satellite measurements need to be done simultaneously for an optimal comparison which was not possible during the NAV-CAR project. Furthermore, the calculation of the position for the GPS pseudo ranges should be done with the same method as for the Galileo pseudo ranges. As the implemented profiles of the receiver are proprietary and cannot be recalculated, a direct comparison of today’s commercial GPS receiver output and Galileo results will always give – to a certain degree – varying results.

8 Generation of Enhanced Maps

8.1 Objectives and Components of Map Generation

The defined services (see deliverable D2100 [3]) like lane-specific applications based on high precision position data need the availability of high precision map data as reference system. The objectives of the task "enhanced maps" are to analyze the position data and the requirements to:

- Increase level of detail
- Enhance the information basis
- Create the background information for new fields of application

In consideration of defined scenarios including precise navigation of cars the road network needs to include a higher level of detail. The network information basis needs to meet the requirements for lane specific navigation in geometries and attributes. Nowadays network data represents a road with a geometry independently of allowed driving directions and the number of available lanes. Further information is stored as attributes to the corresponding geometries. The creation of enhanced maps means to represents the road network as realistic as possibly especially geometries for each lane. The objective of this task is to determine the criteria of data availability and quality and to figure out the requirements and possibilities to create more detailed background information for new fields of application.

The project NAV-CAR includes the analysis of satellite based data from GALILEO system, which is still under construction. In COOPERS, a European integrated research project [1], an approach to evaluate the potential of Galileo using simulation of satellite signals was taken. The whole procedure is described in detail in COOPERS Deliverable D4500-2 "Evaluation of scientific test vehicle and achieved results", a summary can be found in chapter 12 of this deliverable.

A database was configured to handle position data of different sources in standard data format. Observed Data from standard GPS receiver were imported and analyzed on information content and accuracy. As one objective in WP 2200 in NAV-CAR the applicability of data for generating enhanced maps has to be evaluated. The evaluation is part of the first step in process concerning following aspects, referenced to software components as illustrated in the following Figure 31.

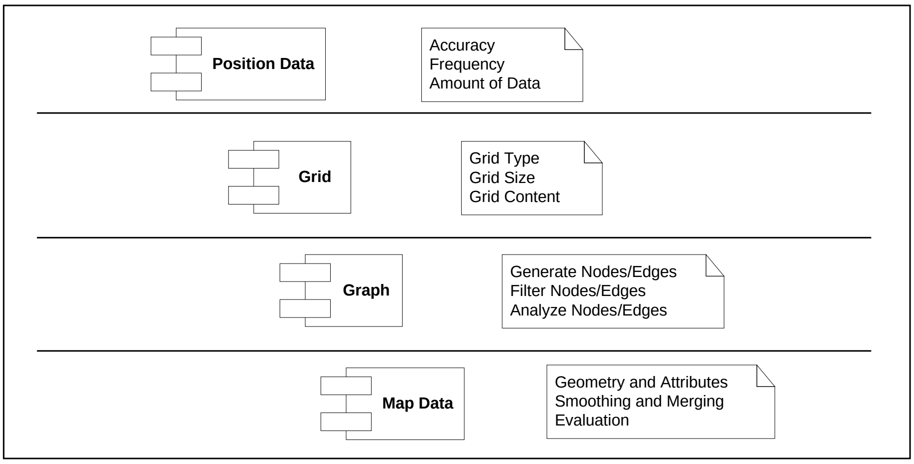


Figure 31: Generating Map - Components and relevant Aspects

The components represent steps in process from analyzing position data to generate a digital map. Aspects like position accuracy, reporting frequency and amount of data are fundamental to analyze the position data itself. First test scenarios were calculated based on GPS data, with simulated GALILEO data. By using simulated GALILEO position data a higher accuracy can be expected and a grid with high resolution can be used. The implementation calculates an initial graph, analyzes nodes and edges and benchmarks the relevance.

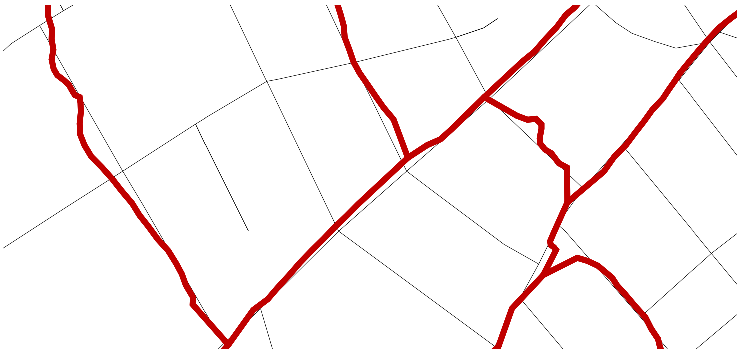


Figure 32: Generating Map - Map based on limited GPS Data (red) with 10 Meter Grid Size

The algorithm is testing the derived graph on logical exceptions, smoothing geometries and adding some attributes to describe geometries. The resulting map data, as shown in Figure 32 can be referenced to existing maps or aerial photos to estimate correctness and quality.

8.2 Data analysis using test drive data and Galileo Simulation

The data analysis is based on position data. On the one hand position data is gathered with GPS from test drives and on the other from GALILEO simulation. The drives were divided into distinct drives on left or right lane to ensure a sufficient number of positions for lane-specific data analysis. Data analysis is done including following steps:

- **Selection of road sections**
  The test drives for task "enhanced maps" where done on A12 ("Inntalautobahn") and A13 ("Brennerautobahn") in Tyrol, also illustrated in Fig. 4.
- **Representation of data in form of Trajectories**
  A Trajectory shows the path of a moving object in space. The resulting geometry is a polyline connecting the points of position data.
- **Definition of orthogonal cuts**
  In order to achieve a look on the sectional view the taken trajectories are cut by orthogonal lines (cross-sections)
- **Analysis of lateral distribution**
  The resulting distances on the orthogonal line represents the lateral distribution of the trajectories on the specific cross-section on the highway.

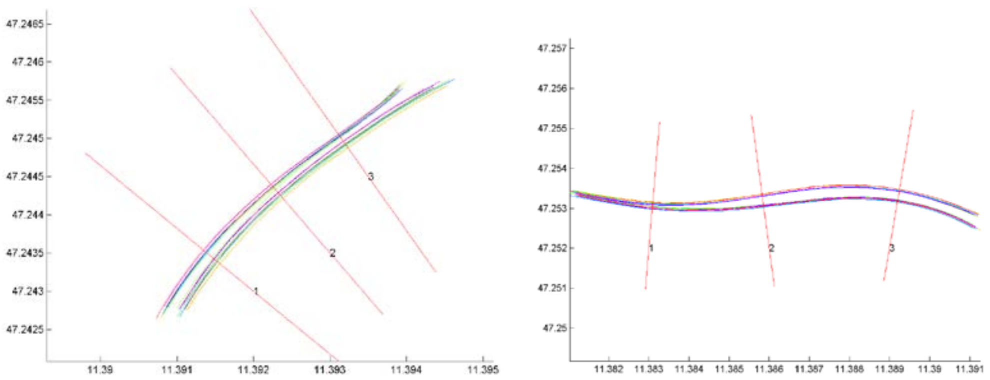


Figure 33: Trajectories of test drives and orthogonal cuts for analysis of lateral distribution

The test field of mountainous region consists of road segments on A12 ("Inntalautobahn") and A13 ("Brennerautobahn"). The data acquisition was organized to cover the triangle built by these two highways. For data analysis the test area was arranged in three sections: *east*, *west* and *south*. As illustrated in Figure 33 each section includes both driving directions and consists of three orthogonal cuts (cross-sections).

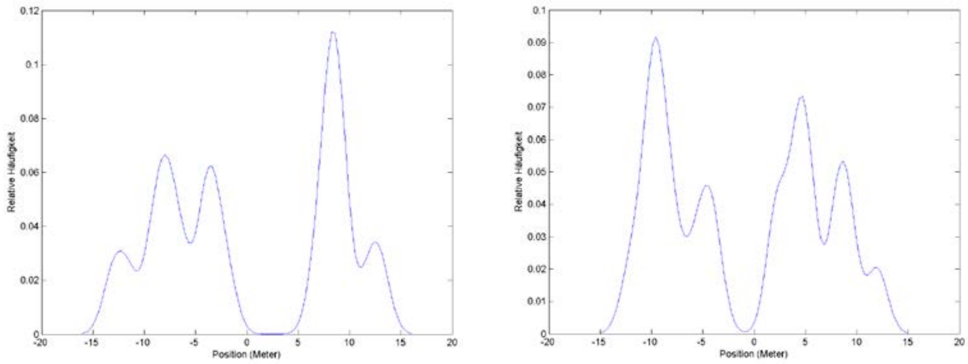


Figure 34: Samples of lateral distribution, trajectories from Galileo CS data set

The orthogonal cut and especially the lateral distances from an estimated centre point are shown in Figure 34. The diagrams present the relative distribution of trajectories in relation to their lateral position. As expected the driving direction and for position data with best lateral accuracy (GALILEO CS) the number of lanes can be recognized.

The evaluation was set up for each section (east, west, south) and for each available data set, which are:

- GPS
- Galileo OS (Open Service)
- Galileo CS (Commercial Service)

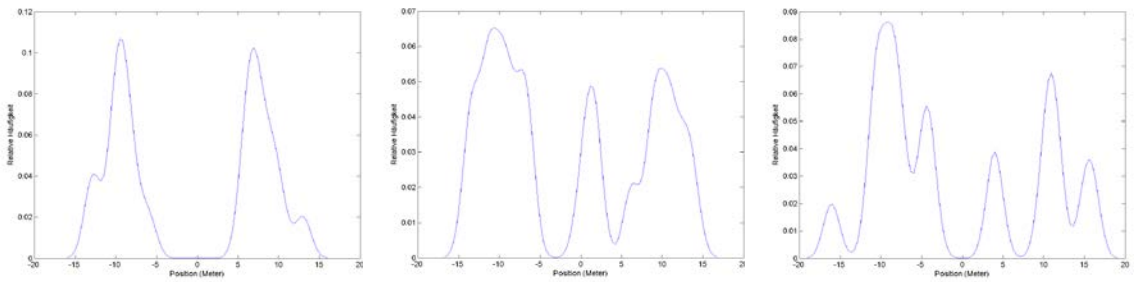


Figure 35: Comparative Evaluation of lateral distribution on one cross-section with GPS (left), Galileo OS (middle) and Galileo CS (right)

The characteristic of the lateral distributions are dependent of the system accuracy of the used data set (see Figure 35). Therefore, the lateral distributions based on GPS trajectories shows one peak for each driving direction and allows almost no differentiation of lanes. The trajectories received from Galileo Open Service results in a more expanded distribution and overall figures out more details on potential lanes. Following the results of reference measurements, reported in chapter 8, with the best performance of Galileo CS in terms of lateral accuracy the distribution based on Galileo CS trajectories allows to differ potential lanes on cross-sections.

As shown in Figure 35, the simulated Galileo signal in commercial service mode allows recognizing potential lanes on evaluated cross-sections. Considering the evaluation site, a highway in mountainous region, the results are promising for lane-specific applications.

9 Assessment of demonstration results

For the assessment of demonstration results, the demonstration outcome based on the scenarios developed were analysed and the road stretches most interesting for technology implementation in Austria were characterised.

Brimatech actively participated in the technical meetings of WP 3200, where demonstration results were discussed. This Action Research approach has proved to be an appropriate tool for transferring technical results into socio-economic impact analysis. In a workshop with selected experts project results were discussed and analysed with regard to socio-economic aspects. The scenarios developed in WP 2100 were the starting point for the discussion. An important outcome of the discussion is the identification of criteria for the selection of road stretches for implementation. AIT and arsenal took part in and contributed to the evaluation of results.

9.1 Scenarios

On the basis of the services identified in WP 2100, four services have been selected by the project consortium regarding technical and economical practicability and usefulness for the project:

- Generating and Updating of Maps
- Road Charging to Influence Demand (scenario: motorway interchange)
- Lane Specific Advice (such as lane specific speed advice, opening/closing of hard shoulders, etc)
- Accident Localization

These services were used as a starting point for the detailed definition of scenarios that were tested in the demonstration phase. Two main scenarios have been determined already in an earlier phase of the project, comprising an urban motorway as well as an alpine motorway. The selected services served as a basis for the specification of the scenarios to be tested and as a starting point for the technical implementation. The following two subchapters include an overview of results achieved in the respective scenario setting and implications for further research and development from a project-internal perspective.

9.1.1 Scenario 1: Urban Motorway

The selected services that were tested in the urban environment were the Lane specific advice and the Road Charging to influence demand In the urban scenario, street canyons, multi-path effects and motorway intersections and –bridges impact the accurateness of the GPS signal and therefore impose problems for providing high-precision positioning. The test area for urban Motorway comprises the motorway A23 from junction *Kaisermühlen* in the north to exit *Inzersdorf Sterngasse* in the south with a total length of 11.5 km (see Deliverable D3100 [7], chapter 2 for details)..

Results of the demonstrations:

The results for scenario 1 are summarized from the Deliverable D3100 [7]:

Result 1: CAN data (speed, steering wheel angle) can be used to complete GPS data (e.g. in tunnels)
→ Continuous trajectory is guaranteed

Result 2: the longitudinal accuracy of GPS can be measured using well defined points where exact GPS values are available and which can be easily detected (e.g. expansion joints).
→ Longitudinal accuracy of GPS is measurable

Result 3: the position of the car on or under the bridge can be measured using GPS or altimeter.
→ Accuracy of height precise enough (3 m) for mapping on street maps

Result 4: the lane change can be detected both using CAN (speed, steering wheel angle) and GPS data. It can also be detected in a qualitative manner using gyro data of the IMU.
→ Lane specific navigation possible in combination with street maps

Implications for the project objectives:

Objective 1: increased robustness (in comparison to existing solutions): OK
Explanation: more than one type of sensors can be used to measure a given entity: trajectory (CAN / GPS in result 1), height (altimeter / GPS in result 3) lane change (CAN / GPS / IMU in result 4)

Objective 2: improved accuracy (in comparison to existing solutions): OK
Explanation: usage of CAN improves the accuracy of the trajectory in areas where GPS is not available (result 1), detection of lane (result 4)

Objective 3: enhanced reliability (in comparison to existing solutions): OK
Explanation: continuous trajectory (result 1), measurement of the longitudinal accuracy of GPS (result 2)

9.1.2 Scenario 2: Alpine Motorway

The selected services that were tested in the rural environment were Generation of enhanced maps and Accident Localisation. In the alpine scenario (Brenner corridor), especially tunnels and urban canyons lead to inaccurateness and unreliability of GPS signals and positioning information. In this scenario, possible advantages of the use of Galileo were assessed as well, using a simulation approach.

Results of the demonstrations:

Result 1: In contrast to currently available GPS signals, the simulated Galileo commercial service positions provide promising results for the automated generation of enhanced maps with lane accuracy.

Result 2: Regarding height information, the Galileo simulation shows varying results, which is partially due to inaccuracies of the simulation parameters.

Implications for the project objectives:
Objective 2: improved accuracy (in comparison to existing solutions): OK
Explanation: Using Galileo commercial service in combination with the OBU, initial absolute accuracy as well as updating of the position when no satellite coverage exists allow the generation of enhanced maps.

9.2 Requirements

9.2.1 Improvement of the OBU performance

As identified in WP 2100 and reported in D 2100, system integrators, such as EFKON are trying to continuously improve the performance of on-board units (OBU). OBU traditionally receive relevant data from the vehicle itself (i.e. the CAN BUS). However, the integration of the OBU with each brand and type of car available is a timely and costly undertaking.

Therefore one objective was to improve the OBU performance by means of data that require no or minor vehicle integration (vehicle independent data), such as acceleration sensors, positioning via WLAN, Infrared, GPS and UMTS cells, etc. (compare Figure 36, result of [9]).

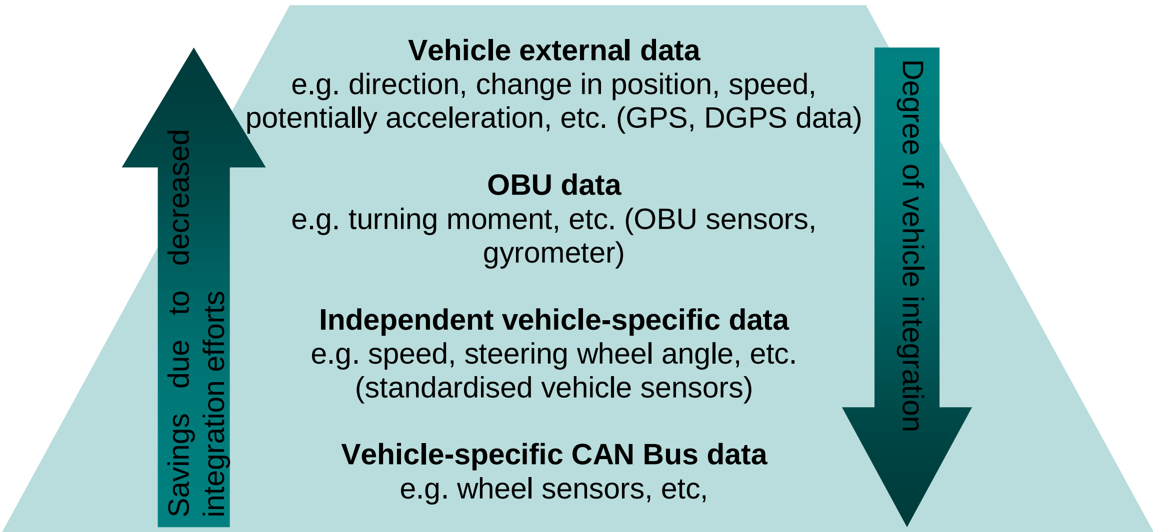


Figure 36: OBU performance data and required vehicle integration

Therefore, two versions of the On-Board-Unit were tested in both scenarios. In the first version the OBU was fully integrated into the vehicle (access to CAN BUS data), whereas in the other version a vehicle-independent OBU was embedded. An important outcome of the demonstration phase was the difference in accurateness between a vehicle-independent OBU in contrast to a fully integrated OBU.

Results of the demonstrations:

Results of the demonstrations: see the results in chapter 10.1.1.

Note that the CAN data used (speed, steering wheel angle) is vehicle independent. Further CAN data was examined (e.g. wheel speed) but did not result in any further improvement.

Implications for the project objectives:

Objective: improvement of the OBU performance by means of data that require no or minor vehicle integration (vehicle independent data): OK
Explanation: the results based on GPS can be sufficiently improved using only CAN, altimeter and IMU data which are vehicle independent.

9.2.2 Accuracy

Requirements on Vehicle Positioning with lane specific localisation of the vehicle are stated with +/-1 m transversal positioning accuracy and +/- 30 m longitudinal positioning accuracy (compare Figure 4 and chapter 3.4).

Results:

Results of the demonstrations: see the results in chapter 10.1.1.

Implications for the project objectives:

The longitudinal accuracy of GPS is at least +/- 15 m (proved with expansion joints via IMU): thus the requirement (+/- 30 m) is reached.
The transversal accuracy of GPS in combination with the detection of lane changes is around +/- 2 m (the width of a lane is 3.5 to 3.75 m): thus the requirement (+/- 1 m) is not reached. It is, however, sufficient for lane specific navigation in combination with precise street maps.

Note that further research would be necessary to achieve a better absolute vertical accuracy. The current solution allows to recognize a lane change when it happens but not to identify the lane number in absolute terms from position data when keeping the lane. The latter requires data fusion with precise street maps.

Precision of height measurement is around +/- 3 m (relative height, proved by passing over and under a bridge using the altimeter).

9.2.3 Visualisation and real-time data

User acceptance is an important aspect mentioned in the expert workshop and problem-centred interviews. The visualisation of the exact positioning information, an easy-to-use user interface and different languages of instructions are crucial for all services identified. This needs to be considered in the developments of NAV-CAR.
Some of the services are time-critical. Those services need to be identified, which might also be an output of the test and demonstration phase.

Results:
The work in NAV-CAR was focused on delivering the foundation of the services identified in WP2100 and described in D2100. Precise positioning delivers one building block of these services – among many others. The visualisation of the service has to be done in such a way, that the function of the service itself is clearly communicated to the user. In case of degraded accuracy it depends largely on the service itself which kind of information should be provided for the user, and how. This can range from a simple “on/off” information to a qualitative scale (e.g. from 0 to 10) or a quantitative measure (e.g. “current accuracy is 5.5 m”). Due to this fact, no generic user interface has been developed in NAV-CAR.

9.3 Target achievement (Summary)

In summary, the main objectives of the project NAV-CAR and thus starting point for validation is the increase in robustness, the improvement of accuracy, the enhancement of reliability and the improvement of the OBU in comparison to existing solutions.

- Lateral accuracy +/- 1m
  - Change of lanes through CAN (speed, steering wheel angle) or GPS (speed, heading) data (+/- 2 m)
  - Galileo within reach for commercial service
- Accuracy in longitudinal direction +/- 30m
  - +/- 15m reached with GPS, proven with expansion joints via IMU
- Accuracy of altitude metering
  - 3m accuracy reach with altimeter
  - Galileo data is not better than GPS (not sufficient)
- Robustness
  - GPS can be replaced by CAN-speed and angle of the steering wheel (area of tunnels on the “Tangente” Vienna)
- Generation of enhanced Maps
  - The generation of lane enhanced maps with lane accuracy has shown to be possible when using Galileo commercial service signals.
- Enhancement of reliability and improvement of the NAV-CAR OBU as compared with existing solutions (e.g. COOPERS OBU):
  - Integration of various sensors (GPS, CAN, IMU (6 degrees of freedom), altimeter) in a compact device
  - Common timestamp with internal precise clock (GPS timestamp) for all sensor data and GPS timestamp → synchronisation with global GPS time.
  - Realtime sensor data fusion possible (in order to achieve the objectives above)
  - State of the art GPS module

10 Recommendations of the Validation Workshop

10.1 Validation Workshop June 8, 2011, TU Vienna

The validation of the results was carried out in the course of a validation workshop with project partners and project external experts. In this workshop, the project aims, methodology and results were presented by the project partners. Results, potential and future research & developments were discussed and recommendations derived together with all workshop participants.

10.1.1 Agenda:

- NAV-CAR Overview (Introduction, Objectives)
- Technical Implementation (OBU)
- Reference Data
- Galileo Simulation and Results
- Test Drives and Results
- Enhanced Maps
- Validation – Discussion
- Recommendations

10.1.2 The institutions taking part in the validation workshop

- Efkon
- AustriaTech
- Austrian Institute of Technology (AIT)
- TeleConsult
- FFG
- Brimatech

On the basis of foregoing presentations about the technical implementation, reference data, Galileo simulation and enhanced maps the results of the project were discussed. Following questions provided the basis for discussions.

What are the recommendations for the project team?

- Are the project results practice oriented and if yes, in what way?
- Could the use of EGNOS increase accuracy?
- Which further research and development would you suggest?
- Where could the NAV-CAR results be applied to?
- Target Achievement from participants' perspective?
  - o Particularly interesting results
  - o Unanswered questions

- Accordance with expectations
- Further research and development
  - Interesting further issues
- Further recommendations

10.1.3 Recommendations

This subchapter reveals the discussions and outcomes of the validation workshop.

Relevance of the results for practical applications
Crucial for relevancy to practice:

- Stability of data
- Real-time information about the degree of reliability
- Costs of OBU
- Problems related to the IMU sensor

The stability of data is very important when it comes to the application in practice. Services can only be built on the basis of secure data. When deviations occur, it should be indicated in which intervals these deviations are located with what level of probability (interesting to know is the level of reliability of data).

A 50% probability of knowing whether you are, for example, in the left lane is not sufficient. Could safety be guaranteed with the presented packet? Yes, in combination with precise street maps, see result 4 in 10.1.1!

In order to guarantee data security, additional sensors would be necessary. Decisive for the reliability is the inclusion of additional external sources, for example maps (virtual points of reference) or bridges. A correction of data could possibly be done through Egnos. There is a general trend towards consulting maps as additional information for exact navigation (via virtual points of reference).

Ex-post information about data reliability is problematic. The **degree of accuracy of the data needs to be available in real-time**. By including gantries, the use of GPS for the provision of tolling services becomes obsolete

Costs of the on-board unit could be relevant for the application in practice. Costs for the majority of sensors used are reasonable (e.g. altimeter 10€), only the price of the IMU sensor is seen as critical. The IMU sensor is available in different models, with costs ranging from two to five-digit Euro figures. Cheaper sensors offer poor quality (with a view to accuracy) and are not recommended for the implementation and usage in the project.

Following **problem areas** are identified **in the application of the IMU sensor**, which should guarantee the smallest possible integration of the OBU into the vehicle and in doing so keeping costs and effort at a minimum:

- Costs: the costs can reach five digit Euro figures, depending on the respective model. Then again, cheaper models are less accurate (example: smartphone sensors).
- Elaborate calibration: the fitting of the IMU sensor should be simple. This is opposed by the need for exact calibration to reach a good level of functionality, which can currently only be achieved with a lot of effort that is hardly feasible in practical applications. The sensitivity of the IMU sensor puts its advantages into perspective (e.g. the number of people in the car influences accuracy). Due to the complexity of the IMU sensor calibration, the usage of the sensor in operating systems in the area of road charges is perceived as impractical whereas standardised data would be easier to implement.
- Standardisation: currently there is no standardisation, but supposedly such standardisation is planned on a European level.

Target achievement form participants' points of view – particularly interesting results and unanswered questions.

- The determination of altitude is not known from other projects. However, the relevance of this aspect was challenged.
- Differences in accuracy between open service and closed service. The difference could lie in the bigger data rate, in additional frequency. It is not known whether the open service operates with one or two frequencies (this has to be investigated for the final report).
- A costly sensor does not equal easy integration.
- Combined testing of GPS and Galileo data was carried out in the Coopers project. A comparison of NAV-CAR data with data obtained in Coopers would be of interest.

Technological developments (R&D) – interesting further research questions

Further development of IMU:
An aggregation of multiple users' data is being considered (accelerations etc.) in order to detect damage on the road surface, for example. One starting point for external sources of information would be the integration of existing infrastructure, such as expansion joints and road markings in order to support the entire process. External points of orientation should not be under physical stress as this leads to abrasion and/or other changes. Thus, external sources should not be located directly on the road.
The integration of additional sensors for the data acquisition of external sources is feasible but problematic due to differing interests of different stakeholders. The added value for the stakeholders involved and the respective responsibilities are not obvious from the point of view of the project team (diverging interests between maintainer and user). At the moment, the monitoring of the state of the road surface works well via telephone hotlines.

Integration of EGNOS:
To increase the absolute accuracy of the GPS receiver, the use of EGNOS correction signals would be interesting. The low satellite constellation of EGNOS in Europe with geostationary satellites over Africa makes a reception of correction signals in both scenarios nearly

impossible. For future development, an integration of the OEGNOS service, that was developed in a complimentary ASAP-project would be of interest.

A very fundamental question concerns the **point of departure of the innovation** (network effect):
Should the focus be on vehicles or infrastructure? Which one requires higher costs or more effort, respectively? These problems affect all innovations with a network aspect (e.g. benefit of using a cell phone increases with the rising number of cell phone users).

Need for further research with regards to IMUs:

- Elaboration of quality of low-price segment
- (Faster) self-calibration
- Interoperability of the software (mid-level devices in particular)

The **immediate and direct display** of a change of lanes through the CAN-Bus would be interesting. The CAN-Bus can only identify the side of the lane thus, cannot recognize if the car changes between two lanes on roads with three lanes.

Interfaces: Technical feasibility is given and could be supported through certification. A barrier is the lack of demand and legal regulations (the driver must have full control of the vehicle).

11 Concluding Summary and Recommendations

11.1 Galileo simulation

The simulation approach showed reasonable results. When looking at the absolute errors, one has to keep in mind that the scenario "mountainous region" was selected because of its challenging environment. So the performance tends to show results of a "worst case scenario" and the assumption that the performance would improve in most other environments seems reasonable.
The cumulative frequencies of the lateral position errors show a considerable better performance of the Galileo Commercial service. Here, 50 % of the absolute lateral errors are smaller than the required 1 m. GPS and Galileo Open Service show almost the same performance where only around 25 % of the points have a smaller error than 1 m.
The absolute vertical position errors are somewhat different. Here, GPS performs best with 56 % of the points having smaller vertical errors than 3 m. Galileo open service has 23 % of the points inside the 3 m range, whereas Galileo commercial service has 39 % of the points within the 3 m range. The reasons for this unexpected difference between lateral and vertical accuracies are described in chapter 8.2.

For the NAV-CAR requirements, Galileo commercial service would give a significant improvement, although additional sensors (IMU or gantries at the roadside) seem to be necessary anyhow. Galileo open service shows the same performance as GPS for lateral errors. Here, a combined solution of GPS and Galileo would be of interest. With more than the double amount of satellites, the availability of "good" satellite configurations should improve significantly, even in demanding environments.

Although the vertical position errors show higher values than the lateral errors, one has to keep in mind that the requirements are equally lower. As mentioned in chapter 8.2, the calculation method in the simulation environment has an impact on the result. Commercially available Galileo receivers are likely to use similar smoothing algorithms as current GPS receivers and so it is fair to say that the performance in the vertical channel will improve.

11.2 Enhanced maps

Considering the evaluation site, a highway in mountainous region, the results are promising for lane-specific applications. The number of simulated Galileo signals was limited during project, but the reference trajectories were organized to cover all lanes permitting to demonstrate the methods for lane detection. In contrast to the trajectories from GPS and Galileo open service, the simulated Galileo signal in commercial service mode allows recognizing potential lanes on the evaluated cross-sections.

Additional the lateral distribution based on GPS trajectories from a major urban road was analyzed with the result of mostly no lane specific characteristics. This could be caused by the city geometries (or “urban canyons”) and the number of satellites in view and also by more difficult road conditions like the width of lanes and more difficult traffic conditions like the number of lane changes within the test trajectories.

Therefore further work should be done with increased samples of data on different types of road. Furthermore the area of map generation, especially in automatic extracting of detailed map geometries and attributes from GPS and/or Galileo trajectories needs further research.

11.3 Enhanced navigation

The results indicate that navigation can be enhanced in comparison to navigation based on GPS only. The enhancement is based on the use of CAN, altimeter and IMU data. The following results were obtained: GPS data can be completed in tunnels, its actual longitudinal precision can be measured and lane changes can be detected. Further measurements are necessary to obtain whether a lane specific measurement can be performed over a long distance.

11.4 Summary and Recommendations for future work

The **result phase** revealed the assessment of the demonstration results. Recommendations were given for future developments and the potential for future applications analyzed. The results were made available through publications and workshops organized for interested developers and users.

Pivotal to the practical relevance of results of the NAV-CAR project is stable data, which form the basis of the services to be offered. If the stability and reliability is not always given, then information about the degree of reliability in real-time is required. In the course of the application of the IMU sensor, problematic areas were identified, which render the application in practice difficult. Barriers to practical application are high acquisition costs, complex calibration and a lack of standardization.

Particularly interesting results and unanswered questions are the determination of altitude and the differences in accuracy between Galileo open service and commercial service. A surprising result was that a cost-intensive sensor did not equal easy integration. The example of the IMU sensor demonstrates this, as it is deemed to be not practical due to high costs and complex calibration.

There is a need for further research in particular with regards to the IMU sensor. The IMU sensor could become more interesting for practical applications through cheaper models, faster self-calibration and a more universal design of software. Interfaces are technically feasible and could be supported through certification but there is a lack of demand and market needs. Furthermore, legal regulations restrict the realization (the driver must fully retain control of the vehicle).

Using vehicle independent CAN bus data it is possible to detect a lane change with sufficient relative accuracy. Using this technology in combination with precise street maps it would be feasible to have a direct display of the current lane of the car.

The question of increased initial absolute position can be addressed with the use of Galileo commercial service or dual frequency open service receivers. For automatic generation of enhanced (i.e. lane accuracy) maps, increased absolute positioning is indispensable. This increased accuracy was determined during the Galileo simulation using the commercial service. Until the introduction of Galileo, possible benefits of EGNOS over the Internet should be investigated.

12 References

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[4] D 2200 – Technical Report on Work Progress – Report on Technical Implementation, NAV-CAR Deliverable WP 2200, Implementation of Architecture

[5] D-2300 - Technical Report on Work Progress - Report on Equipment installation, NAV-CAR Deliverable WP 2300: Equipment and Installation

[6] D-2400 - Report on on-board equipment validation, NAV-CAR Deliverable WP 2400: Validation of on-board equipment.

[7] D 3100/3200 – D3100: Demonstration - description of planned measurements, test tracks. Results and interpretation, advantages of the usage of Galileo, and D-3200: Report on Assessment of collected data and simulation, NAV-CAR Deliverable WP 3000: Demonstration, assessment of collected data and simulation.

[8] D4100/4200: Report on Results Assessment and Recommendations, NAV-CAR Deliverable WP 4000: Result assessment and recommendation.

[9] Fuchs, S., et al.: Workshop between EFKON and Brimatech. 2009: Graz.

[10] RVS 03.03.31 Querschnitte. Querschnittselemente Freilandstraßen; Verkehrs- und LIchtraum. Österreichische Forschungsgemeinschaft Straße und Verkehr, Vienna, 2005

[11] RVS 03.03.23 Trassierung. Linienführung. Österreichische Forschungsgemeinschaft Straße und Verkehr, Vienna, 2001

13 Annex

13.1 Agenda Expert Workshop (D 4300-3)

Datum: 08. Juni 2011
Ort: TU Wien, Gusshausstr. 27-29, SEM124, 3. Stock
Uhrzeit: 15:15 – 17:00 Uhr

Participants: EFKON, AustriaTech, TeleConsult, FFG, AIT, Brimatech, ÖFPZ-Arsenal.

Die **AGENDA** des Workshops war wie folgt aufgebaut:

- NAV-CAR Overview (Introduction, Objectives) (Erwin Schoitsch, AIT)
- Technical Implementation (OBU) (Reinhard Kloibhofer, AIT)
- Reference Data (Roland Spielhofer, ÖFPZ)
- Galileo Simulation and Results (Roland Spielhofer, ÖFPZ)
- Test Drives and Results (Egbert Althammer, AIT)
- Enhanced Maps (Martin Reinthaler, ÖFPZ)
- Validation – Discussion (Sabine Jung, Brimatech, all)
- Recommendations (Sabine Jung, Brimatech, all)

13.2 Vortrag beim 4. Navigations-Get-Together des OVN am 8. Juni 2011 an der TU Wien "Location Based Services" (D 4300-2)

Unmittelbar anschließend an den NAV-CAR Workshop fand an der TU Wien das 4. Navigations-Get-Together statt.
Bei dieser Veranstaltung des OVN (Österreichsicher Verein für Navigation) wurde auch das Projekt NAV-CAR vorgestellt und diskutiert.

Programm: LBS (Location-Based Services)

- **Georg Gartner (Inst. f. Geoinformation u. Kartographie, TU Wien)**
  „LBS und Fussgängernavigation"
- **Clemens Strauß (Inst. f. Geoinformation, TU-Graz)**
  „LBS-Studierenden Projekte an der TU-Graz"
- **Reinhard Kloibhofer (AIT Austrian Institute of Technology), Sabine Jung (Brimatech)**
  „NAV-CAR: Services enabled by improved NAVigation in Challenging Areas by Robust positioning "

13.3 Dissemination Aktivitäten:

Dissemination Aktivitäten umfassten:

- NAV-CAR LOGO (s. Titelblatt der Document-Deliverables)
- Homepage eingerichtet, www.nav-car.at
- Projektinterner Webfolder eingerichtet
- NAV-CAR Folder in Deutsch und Englisch (D 4300-1)
- NAV-CAR Poster (s. 6.4, Ausstellungsstand auf der ITS Austria, 11.11.2010 und AARIT Konvent, 16.11.2010, beides in Wien)
- Experten-Workshop 15.10.2009, Autobahnmeisterei Vomp (bei Innsbruck)
- Amsterdam Intertraffic: Folder aufgelegt
- RS überlegen Stand auf AGIT, TRA (Anfang Juni)
- Brimatech: Vortrag auf AGIT
- Brimatech: Vortrag bei ENC GNSS
- ETSI ITS Workshop, Sophia Antipolis, 11.-12.2.2010, Vortrag E. Schoitsch "COOPERS and NAV-CAR – Intelligent Transport Systems"
- ITF Leipzig (25.-28.5.2010, Ausstellungsstand AIT (ADOSE), COOPERS Stand AustriaTech): Folder
- SAFECOMP 2010 in Wien (AIT Stand: Poster, Folder) (14.-17.9.2010)
- SAFECOMP 2010, ERCIM/EWICS/DECOS Workshop, NAV-CAR Vortrag (AIT) (14.9.2010)
- World Congress in Busan (Korea) (EFKON Stand: NAV-CAR Folder)
- ITS Belgien (EFKON): Folder aufgelegt
- 2010: Weiters Folder resp. Poster gezeigt und verteilt auf
  - DATE 2010, Nizza, 9.3.2010, Ausstellungsstand AIT
  - ME 10, Wien: 7.-8.4.2010
  - CPS Stockholm (13.-15.4.2010)
  - ARTEMIS Spring Event, Rom, 9.-10.6.2010
  - ICT 2010 (Brüssel, großer AIT Stand), 27.-29.09.2010
  - EPoSS Annual Forum (Lissabon) (AIT), 7.-8.10.2010
  - ARTEMIS/ITEA2 Co-Summit Ghent, 26.-27.10.2010
  - Euromicro (Lille) (AIT), 1.-3.9.2010
  - IDIMT (Tschechien) (AIT), 8.-10.9.2010
- Lakeside Konferenz (Klagenfurt): Vortrag AIT, Reinhard Kloibhofer
- Artikel in ERCIM NEWS 84 (Jan. 2011) (Print- und Web-Version www.ercim.eu) „Intelligent Transport Systems on the Road - Lane-Sensitive Navigation with NAV-CAR" (by Egbert Althammer, Reinhard Kloibhofer, Roland Spielhofer and Erwin Schoitsch
- Brimatech: Artikel in OVN Flashlight (2011/3)
- Beiträge zu ASAP Broschüren (NAV-CAR2, NAV-CAR Feasibility Study) 2010
- SAFECOMP 2011, 19.9-22.9.2011, Neapel: NAV-CAR Folder aufgelegt und verteilt
- Vortrag beim Navigations-Get-Together des OVN am 8. Juni 2011 an der TU Wien "Location Based Services" (see chapter 14.2)

13.4 NAV-CAR Poster

www.ait.ac.at

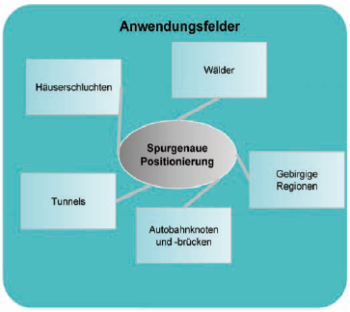
NAV-CAR

Improved NAVigation in Challenging Areas by Robust Positioning

NAV-CAR ist ein nationales Forschungsprojekt, das vom Bundesministerium für Verkehr, Innovation und Technologie im Rahmen der 6. Ausschreibung von ASAP (Austrian Space Programme) kofinanziert wird. NAV-CAR baut auf die im europäischen IST-Projekt COOPERS gewonnenen Erfahrungen auf und erweitert dieses im Projekt besonders im Bereich der Sensordatenfusion und der Kartenbezüge zum Zweck der spurgenauen Positionsbestimmung (www.nav-car.at).

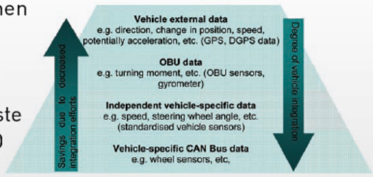
Herausforderung

Derzeitige satellitenbasierte Fahrzeuginformations- , -navigations-, und Mautabrechnungsysteme sind von einer Mindestanzahl von Satelliten abhängig, entsprechen in spezifischen Umgebungen wie Städten, Tälern oder auch gebirgigen Regionen jedoch nicht immer den Anforderungen, die für kontinuierliche und verlässliche Positionierung notwendig sind.



Ziele

- Verbesserung der Treffsicherheit von Verkehrssteuerungsmaßnahmen der Traffic Control Centers durch Nutzung spurgenauer Fahrzeugpositionsdaten
- Verringerung der Störungsanfälligkeit von Autonavigationssystemen
- Verbesserter Genauigkeitsgrad bei Positionierung
- Verbesserte Kartenbezüge (Erzeugung hochgenauer Karten)
- Höhere Zuverlässigkeit der Verkehrs- und Navigationsdienste
- Spurabhängige Sevices für Notfall-, Wartungs- und Monitoringdienste
- Untersuchung des potenziellen Nutzens des kommenden GALILEO Systems für bodennahe Anwendungen durch Simulation



Integration verschiedener Ebenen von Fahrzeug- und externen Daten

Innovation

Der innovative Aspekt von NAV-CAR ist die Datenzusammenführung von Navigations- und In-car-Sensor Daten für stabile, fehlerfreie und präzise Positionsinformation. Die Kombination mit exaktem Kartenmaterial, das im Rahmen von NAV-CAR in den Testphasen erstellt wird, ermöglicht hoch-präzise Positionierung zur spurgenauen Informationsbereitstellung. In-car Daten (z.B. vom CAN-Bus) werden herangezogen, um die Delta Position vom zuletzt gemessenen Satelliten-Positionierungssignal zu berechnen. Die besondere Herausforderung besteht darin, angemessene Interfaces für die Datenzusammenführung zu entwickeln und alle zur Verfügung stehenden Informationsquellen innovativ für verschiedene Dienste zu nutzen.

coopers | pwpSystems | ASFINAG | Brimatech | EFKON | >asap> | bmvit | FFG

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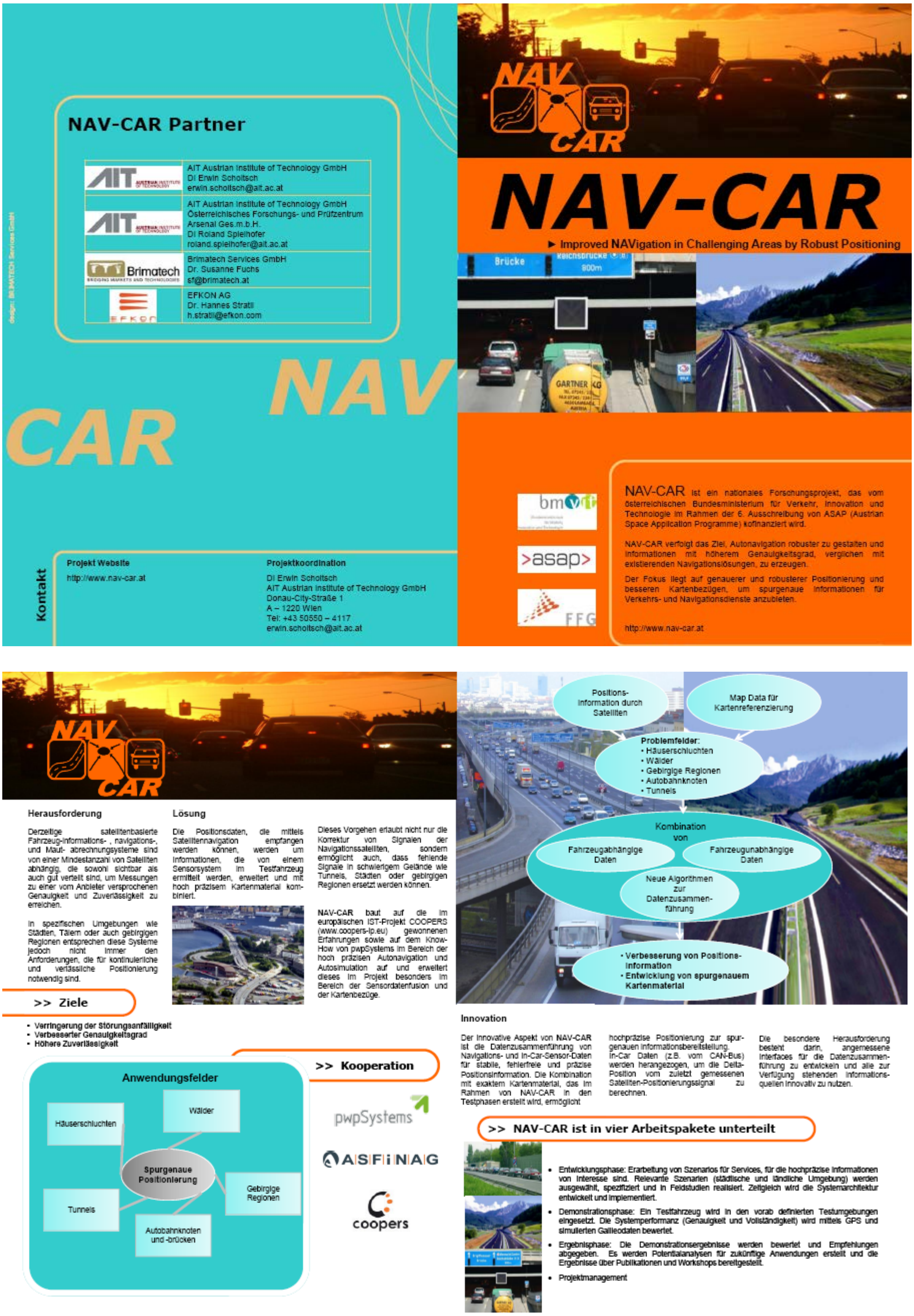
TOMORROW TODAY

13.5 NAV-CAR Folder (2 versions, German and English)



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NAV-CAR

► Improved NAVigation in Challenging Areas by Robust Positioning

NAV-CAR ist ein nationales Forschungsprojekt, das vom österreichischen Bundesministerium für Verkehr, Innovation und Technologie im Rahmen der 6. Ausschreibung von ASAP (Austrian Space Application Programme) kofinanziert wird.

NAV-CAR verfolgt das Ziel, Autonavigation robuster zu gestalten und Informationen mit höherem Genauigkeitsgrad, verglichen mit existierenden Navigationslösungen, zu erzeugen.

Der Fokus liegt auf genauerer und robusterer Positionierung und besseren Kartenbezügen, um spurgenaue Informationen für Verkehrs- und Navigationsdienste anzubieten.

http://www.nav-car.at

Herausforderung

Derzeitige satellitenbasierte Fahrzeug-Informations- , navigations-, und Maut- abrechnungsysteme sind von einer Mindestanzahl von Satelliten abhängig, die sowohl sichtbar als auch gut verteilt sind, um Messungen zu einer vom Anbieter versprochenen Genauigkeit und Zuverlässigkeit zu erreichen.

In spezifischen Umgebungen wie Städten, Tälern oder auch gebirgigen Regionen entsprechen diese Systeme jedoch nicht immer den Anforderungen, die für kontinuierliche und verlässliche Positionierung notwendig sind.

Lösung

Die Positionsdaten, die mittels Satellitennavigation empfangen werden können, werden um Informationen, die von einem Sensorsystem im Testfahrzeug ermittelt werden, erweitert und mit hoch präzisem Kartenmaterial kombiniert.

Dieses Vorgehen erlaubt nicht nur die Korrektur von Signalen der Navigationssatelliten, sondern ermöglicht auch, dass fehlende Signale in schwierigem Gelände wie Tunnels, Städten oder gebirgigen Regionen ersetzt werden können.

NAV-CAR baut auf die im europäischen IST-Projekt COOPERS (www.coopers-ip.eu) gewonnenen Erfahrungen sowie auf dem Know-How von pwpSystems im Bereich der hoch präzisen Autonavigation und Autosimulation auf und erweitert dieses im Projekt besonders im Bereich der Sensordatenfusion und der Kartenbezüge.

>> Ziele

- Verringerung der Störungsanfälligkeit
- Verbesserter Genauigkeitsgrad
- Höhere Zuverlässigkeit

Anwendungsfelder

Spurgenaue Positionierung
Häuserschluchten
Wälder
Gebirgige Regionen
Autobahnknoten und -brücken
Tunnels

>> Kooperation

pwpSystems
ASFINAG
coopers

Positions-information durch Satelliten
Map Data für Kartenreferenzierung
Problemfelder:
• Häuserschluchten
• Wälder
• Gebirgige Regionen
• Autobahnknoten
• Tunnels
Kombination von
Fahrzeugabhängige Daten
Fahrzeugunabhängige Daten
Neue Algorithmen zur Datenzusammen-führung
• Verbesserung von Positions-information
• Entwicklung von spurgenauem Kartenmaterial

Innovation

Der innovative Aspekt von NAV-CAR ist die Datenzusammenführung von Navigations- und In-Car-Sensor-Daten für stabile, fehlerfreie und präzise Positionsinformation. Die Kombination mit exaktem Kartenmaterial, das im Rahmen von NAV-CAR in den Testphasen erstellt wird, ermöglicht hochpräzise Positionierung zur spurgenauen Informationsbereitstellung.
In-Car Daten (z.B. vom CAN-Bus) werden herangezogen, um die Delta-Position vom zuletzt gemessenen Satelliten-Positionierungssignal zu berechnen.

Die besondere Herausforderung besteht darin, angemessene Interfaces für die Datenzusammenführung zu entwickeln und alle zur Verfügung stehenden Informationsquellen innovativ zu nutzen.

>> NAV-CAR ist in vier Arbeitspakete unterteilt

- Entwicklungsphase: Erarbeitung von Szenarios für Services, für die hochpräzise Informationen von Interesse sind. Relevante Szenarien (städtische und ländliche Umgebung) werden ausgewählt, spezifiziert und in Feldstudien realisiert. Zeitgleich wird die Systemarchitektur entwickelt und implementiert.
- Demonstrationsphase: Ein Testfahrzeug wird in den vorab definierten Testumgebungen eingesetzt. Die Systemperformanz (Genauigkeit und Vollständigkeit) wird mittels GPS und simulierten Galileodaten bewertet.
- Ergebnisphase: Die Demonstrationsergebnisse werden bewertet und Empfehlungen abgegeben. Es werden Potentialanalysen für zukünftige Anwendungen erstellt und die Ergebnisse über Publikationen und Workshops bereitgestellt.
- Projektmanagement