Prototype Implementation and Positioning Performance Results of the GAIN Enhanced Active Green Driving Assistant

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ABSTRACT

The aim of the GAIN project [1] is to enhance the positioning performance of an already existing Active green driving Assistant (AGD) and to extend it to an Enhanced Active Green Driving (EAGD) system for real time optimization and reduction of CO_2 emission and fuel consumption. Due to erroneous positioning solutions, the existing AGD prototype often proposes inappropriate maneuvers to the driver. This avoids a successful market entry of the existing green driving application. To remove this limitation new positioning strategies for low-cost GNSS receivers will be implemented in GAIN. These approaches have a special focus on integrity issues in order to prevent the application from taking misleading decisions. That refined positioning algorithm will be introduced in this paper. The proposed positioning solution is based on Galileo/GPS and EGNOS/EDAS. The concept of position integrity is introduced and used to innovatively detect multipath in urban areas through a GNSS/INS tightly coupled approach and 3D modeling of the environment with probabilistic multipath mitigation. This paper gives an overview about the GAIN prototype implementation and shows first results of the positioning performance.

Keywords: Gain project, green driving, probabilistic multipath mitigation

1. INTRODUCTION

Figure 1: Left: Example of how current positioning systems may handle uncertain measurements. While the solid car is driving along a highway, the estimated vehicle position is mapped to the exit ramp where the AGD application would lower the velocity. Right: With the EAGD system the position of the vehicle is mapped to correct lane

The steadily increasing road traffic density in Europe is causing considerable negative effects such as traffic congestion, accidents and increasing CO_2 emissions. The European project GAIN is co-funded within the 7th Framework of the GSA with the aim to reduce the energy consumption of vehicles. The anticipation of the road ahead (Electronic Horizon) allows a smooth driving style resulting in decreased fuel consumption. Information about the road layout ahead is obtained from advanced digital map data that contains curvature and slope information. Thus, systems which actively intervene in the driving process in order to achieve decreased fuel consumption (Active Green Driving (AGD) systems) yield an enormous potential to significantly improving traffic efficiency. The main concept of an AGD system is to optimize different driving parameters such as velocity or gear shifting strategy based on a prediction of the vehicle's behavior.

Assuming that the position of the vehicle is known, such data can be obtained from digital maps (containing planned route, slope of the road, distance to next intersection…). State-of-the-art AGD systems are using standalone on-board GNSS receivers and standard navigation maps. However, due to the limited position accuracy and the missing ability to determine the quality of the position estimation, such systems suffer from severe problems, especially in urban areas where multipath effects lead to wrong position solutions. Figure 1 shows a use case where the estimated car position indicates two possible routes, for which different driving styles are required. The AGD has to decide whether the car to slow down or to keep it at a constant velocity. If a wrong trajectory is predicted due to a false position estimate, the system is likely to perform an inappropriate action, such as decelerating on an unblocked highway or upshifting on a slope. The right part of Figure 1 shows the resulting behavior with the new EAGD positioning algorithm. The vehicle is now mapped to the correct lane, which leads to the appropriate action to keep a constant velocity of the vehicle.

2. OBJECTIVES

The overall aim of the GAIN project is to provide an "Enhanced Active Green Driving System" (EAGD) which significantly reduces CO_2 emission and fuel consumption. The project includes solutions for reliable vehicle localization in combination with an advanced integrity concept, communication and real time traffic information. In particular, the main objectives are:

- Reduction of CO_2 emission and fuel consumption
- Develop the Enhanced Active Green Driving system and prepare market introduction
- Use EGNOS/EDAS correction data for improved GNSS positioning accuracy and integrity information
- Allow multipath mitigation and positioning with integrity even under difficult receiving conditions like in urban areas
- Development, implementation and demonstration of EAGD system

3. GAIN PROTOTYPE

The product derived from the GAIN prototype is Enhanced Active Green Driving assistant (EAGD) with the aim to optimize the engine/vehicle energy spending by matching both static and dynamic travel constraints and information along the route planned by the driver. The most important feature implemented is the strategy to calculate a target "green" speed. The EAGD can operate as a "high authority" system operating as a "variable speed cruise control" and carries out the following strategies:

- Road scenario prevision (thru Electronic Horizon)
- Choosing the best compromise between CO_2 emissions reduction and a longer travelling time (the legal speed is the threshold)
- Optimal gear selection, choosing the best gear ratio in order to maximize the engine efficiency
- Enhanced Stop&Start & Free Wheeling management
- Kinetic Energy Eco Modulation Strategy (KEEM): switching on/off the engine when running at an average constant speed

3.2 Communication platform

GAIN communication is based on Vehicular Ad-Hoc Networks (VANETs). These are an emerging type of network, which is meant to improve the quality of transportation by enabling a broad range of applications: primarily safety but also services aimed at traffic management or enhanced driving comfort. It has to manage challenging conditions, such as mobility, scalability, reliability, determinism and capability of working according to a

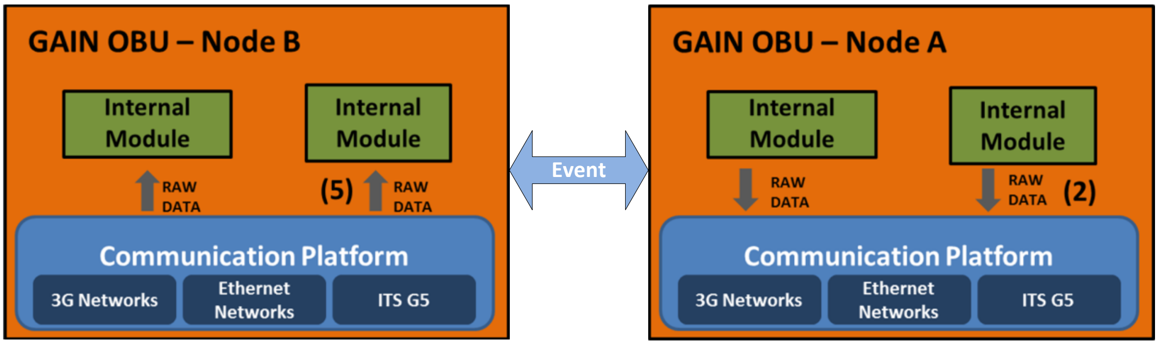


Figure 2: High level communication representation of the GAIN prototype.

completely decentralized paradigm. Thus, vehicular networks assist drivers in very different ways and each VANET application subtends distinct requirements which must be carefully set. For instance, safety services are strictly required to readily deliver warnings and imply critical performances, especially in terms of reliability and delays.

In GAIN, VANETs will provide continuously real time data from other nodes. Information shared between vehicles and fixed infrastructures are used by the AGD system to build a distributed knowledge of the networks (e.g., position and speed of other vehicles, dangerous situations, weather conditions). In this way, a more reliable and accurate decision can be taken, enabling for example important safety applications. Figure 2 shows the communication at high level representation. When a specific event occurs, the communication platform receives raw data from internal modules (e.g., weather/road sensors info, vehicle position) and creates corresponding messages to be sent outside the vehicles. All these characteristics fulfill the Standardization guidelines of IEEE 802.11p [2]. The role of this component from positioning point of view is the transmission of other vehicles GNSS raw observations and EGNOS correction information in order to perform relative positioning and to broadcast the 3D digital map and lane information.

3.3 GAIN Positioning and Integrity concept

The positioning component will generate an absolute and reliable positioning estimate in combination with a proper confidence measure. The ego vehicle position includes:

- Ego position and motion information (3D position, vehicle heading, velocity)
- Confidence measure (Horizontal Protection Level) for 3D position, heading, velocity
- Time stamp of estimate

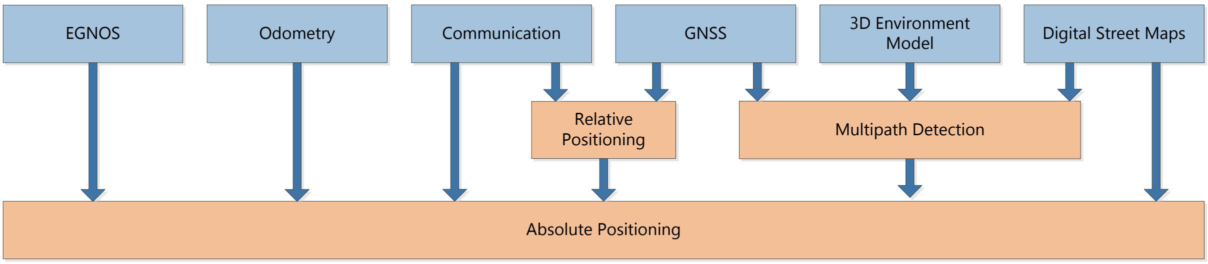


Figure 3: Architecture of the positioning component.

Recent efforts demonstrated that the SBAS integrity concept can increase the level of reliability of civilian GNSS-based tracking systems [4], but practical implementations are still rare. Although most commercial GPS receivers for car navigation are already able to decode and use wide area differential corrections, very few applications fully exploit the EGNOS integrity data, thus loosing important information that may be processed to alert users in case the GPS signal is degraded. In fact, the navigation system must be able to provide timely warnings to the application when the positioning is currently unsure. Since the actual position error is unknown to the application in practice, the upper bounds for these errors, called "Protection Levels," are compared to the alarm limit [5].

Figure 4 shows the GAIN system architecture, the integrity concept is applied to all components. It is important to note that integrity requirements are application-specific and the values assigned to these parameters depend on the specific application and are generally determined by institutions. Such values have already been established for many aeronautical and maritime applications, while for road applications, there is not a standard document available yet. Although the goal was not the definition of Alert Limit, the analysis of real measurements was invaluable for a first understanding of real users requirements and current limits of the GNSS technology [3].

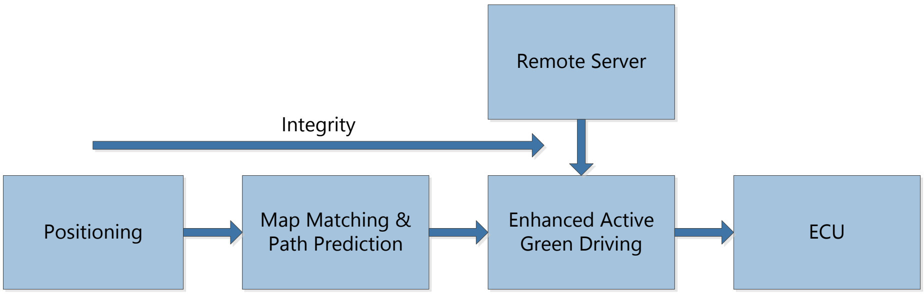


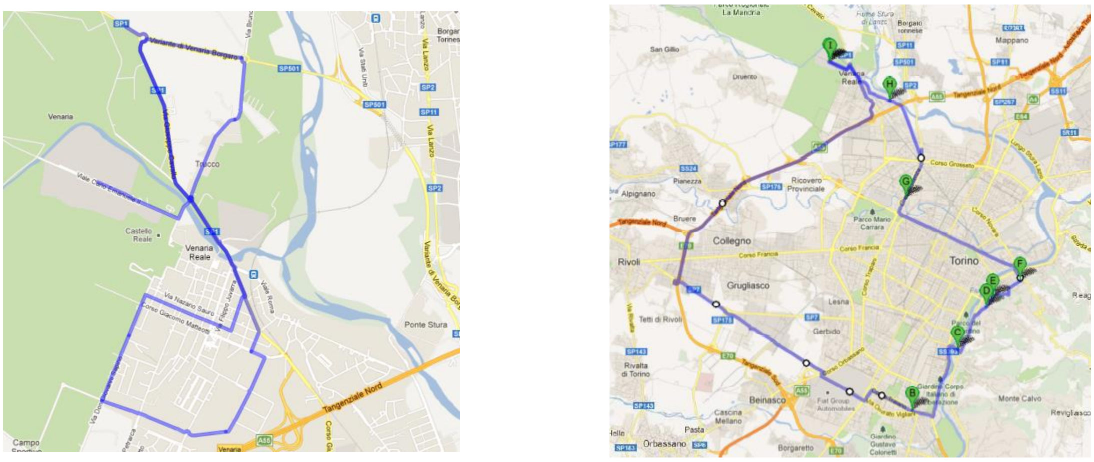
Figure 4: Proposed GAIN system architecture. The concept of position integrity is applied to all GAIN components and therefor available in the EAGD, as well.

4. POSITIONING PERFORMANCE EVALUATION

Within the GAIN project a refined positioning algorithm will be developed and integrated in the EAGD system in order to provide a robust positioning solution even in very demanding urban environments. It is a modular approach and delivers the best possible position solution and integrity estimation from the available components in a specific situation. The components of the positioning are introduced in this section. Due to the implementation of the GAIN prototype as an ongoing action the presented results are generated from simulations that were run so far. For the final paper the evaluation will be done with real data produced with the GAIN prototype. The final paper will include also the EGNOS/EDAS evaluation in combination with multipath mitigation.

The algorithm performance will be assessed through the analysis of real measurements, performed in different road user environments, providing statistical results in terms of accuracy and integrity, and in a wider sense of the performance of the use the proposed techniques – detailed in the following - for augmenting the reliability of GNSS positioning for road applications. The GAIN positioning will be stressed and evaluated in realistic scenarios. Therefore, several test sites as shown in Figure 5 have been chosen in order to fulfill the demands that are derived from the specified use cases.

For the evaluations in GAIN ground truth data will be recorded from a precise multi frequency NovAtel Span System with RTK and IMU. That ground truth delivers positioning accuracy within decimeter range and was used as reference in following evaluations in the paper as well.



a) Test site around Venaria, 15 km total

b) Test Site from Venaria to Turin and back to Venaria, 60 km total

Figure 5: GAIN test sites in Italy with Urban roads (deep canyons to force intensive multipath effects), Sub urban roads and open sky scenario (highway). Rounds, curves, slopes, stop signs, slopes and crosswalks are required as well.

4.1 GNSS Multi-constellation

Experiments conducted on multi-constellation positioning using simplified hardware configurations—typically a non-directional rooftop antennas a commercial GPS/Galileo receiver front-end and GNSS software receivers—show the use of multiple GNSS constellations (GPS and Galileo, e.g.) can contribute to the reduction of the positioning error [6] with respect to the case of a Stand-alone GNSS system [7].

It seems reasonable to expect that, when the number of Galileo operative satellites will increase, Galileo/GPS multi-constellation receivers will have important benefits in terms of robustness against interference, availability, reliability, integrity and continuity of service.

For these reasons, the current trend of GNSS receivers design, consists in facilitating the access to each different navigation system, fomenting multi-constellation receivers. In fact, by using the RF frequencies in common between the GNSS systems, the complexity of the receiver’s RF-front end can be considerably reduced with respect to multi-frequency receivers and even low-cost receivers for mass-market applications, typically used in road and pedestrian navigation in urban environments, can be able to process signals broadcast in a multi-constellation scenario. A detailed description on the entire multi constellation simulation can be found in [12].

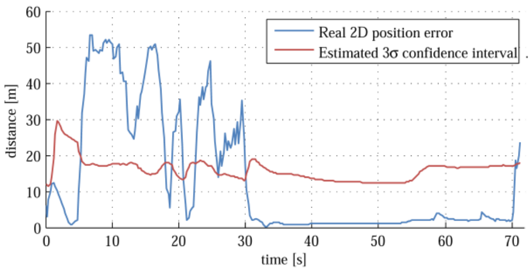


Figure 6: Positioning error and estimated 3σ confidence for GPS-only under multipath conditions.

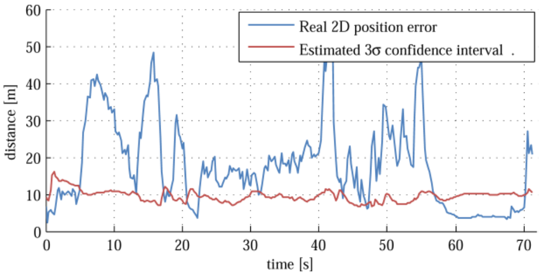


Figure 7: Positioning error and estimated 3σ confidence for multi constellation under multipath conditions.

For the multi constellation evaluation a test drive through the inner-city of Chemnitz was run in order to record GPS and GLONAS raw pseudorange measurements. Figure 6 shows the simulation results of the GPS-only solution with a multipath affected data set. Figure 7 shows the same sequence by considering satellites from the GLONAS and from the GPS constellation. Due to numerous satellites, the multipath effect has a greater influence on the positioning degradation. Almost all fixes are outside the estimated 3σ confidence interval. A noticeable advantage of multi-constellation positioning is not directly retrieved by applying straight forward position calculations. Any multipath mitigation strategy based on satellite exclusion will directly benefit from the enlarged number of available observations.

4.2 Tightly Coupling and Probabilistic Multipath Mitigation

The Probabilistic Multipath Mitigation (PMM) algorithm is introduced in [9]. Besides the accuracy of a navigation solution, the reliability and availability in terms of integrity are two major aspects of the positioning. Normally, GNSS observations which are subject to multipath and used throughout the localization process lead to an unmodeled bias in the final position estimate and therefore violate the promised protection/integrity level. Moreover, multipath effects in dynamic ITS applications are a rapidly changing phenomenon which makes it hard to detect and predict [10]. The algorithm can be used to autonomously increase localization accuracy and integrity without additional hardware sensors and has the biggest impact in strong multipath-affected situations. The algorithm is based on the idea of generalized probabilistic data association (GPDA) and the theoretical background is introduced in [11].

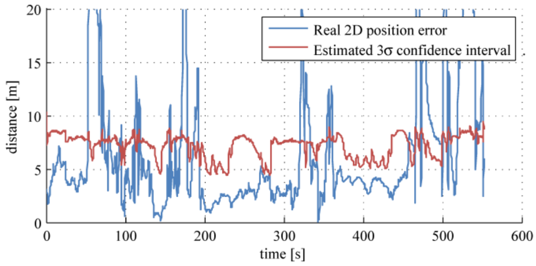


Figure 8: Position error and confidence interval for Bayes Filter result with Constant Velocity motion model [7], $3\sigma = 7.15m$.

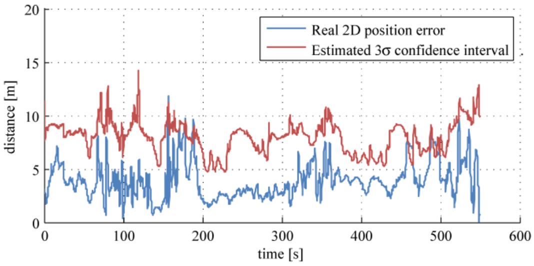


Figure 9: Position error and confidence interval for Bayes Filter result with Constant Velocity model and probabilistic multipath mitigation, $3\sigma = 7.96m$.

Figure 8 shows the result of a tightly coupled GNSS/INS Bayes Filter. There are many position estimations that are not within the calculated confidence threshold. The results of the PMM are shown in Figure 9. Here the number of position estimates within the confidence level is drastically reduced.

4.3 Digital 3D and Shadow Maps

In this section the results of the evaluation are presented. The detailed approach is described in [8]. First, the non-line of sight (NLOS) detection performance of the proposed algorithm is validated and compared to a reference system. Afterwards, the positioning performance—including accuracy and estimated integrity—is compared to a standard GPS-only positioning algorithm.

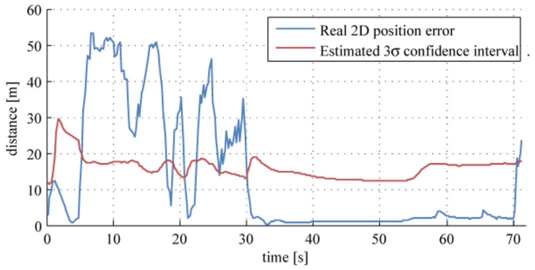


Figure 10: GPS localization without NLOS detection.

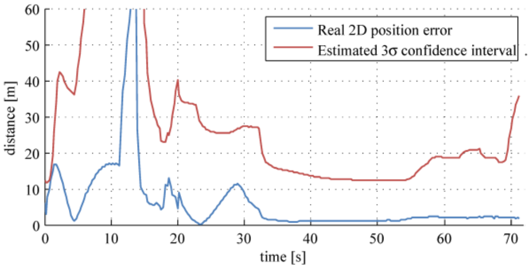


Figure 11: GPS localization with NLOS 3D detection.

In Figure 10 the positioning error and the estimated 3σ confidence interval for a GPS-only localization algorithm under multipath is shown. Figure 11 illustrates the same results for a GPS-only algorithm with integrated 3D multipath detection. It can be seen that with the multipath detection algorithm, the confidence interval is more dynamically, i.e. it adapts to local conditions. If the horizontal position raise, the positioning algorithm detects this and automatically increases the estimated covariance as well. As a result, the estimated confidence of the 3D based multipath mitigation is more appropriate than in the GPS-only case.

5. CONCLUSIONS AND OUTLOOK

This paper introduces the different aspects of the GAIN Positioning. The presented results were obtained from simulations of the algorithms based on real data obtained from different test drives. It was shown that the integration of the digital maps and multi constellation concept into the probabilistic multipath mitigation algorithm performs well under bad urban conditions. Furthermore, the integrity concept delivers reasonable estimations of the positioning accuracy. It was shown that the proposed approach as able to fulfill the demands of the EAGD system concerning accuracy and integrity.

The final paper will contain the results of the positioning performance evaluation of the GAIN prototype on the proposed test sites, while this paper contains preliminary results.

6. ACKNOWLEDGMENT

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