Monitoring the position integrity in road transport localization based services

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***Abstract*— Nowadays, a new generation of civil location based services (LBS) included in the intelligent road transport systems (ITS-R) field is emerging. The reliability of positioning sensors and the communication infrastructure will be the key to the success of such services. A recommended basic onboard equipment (OBE) can include a GNSS based sensor, an embedded computer, a communication equipment and some other aiding sensors. The current GPS based sensors, operating in standard positioning service (SPS) or differential GPS (DGPS) modes, supply the level of accuracy required by many services of interest. However, the solution availability and the integrity monitoring are the main problems for GNSS based road applications, where the cost plays a significant role. In this paper, an embedded software for monitoring the availability and integrity of a GNSS positioning system is presented. The software developed allows the study of the $\mathrm{HPL}_{\mathrm{SBAS}}$ (Horizontal Protection Level) parameter as a reliable integrity indicator of the positioning system performance. Its suitability for road applications, and the importance of the geostationary satellite visibility and the GPRS/UMTS coverage are analyzed in this paper. Finally, selected results of these investigations and their conclusions are commented.**

***Index Terms*— Intelligent Transport Systems, GNSS, Satellite Based Augmentation Systems, Horizontal Protection Level, Location Based Services.**

I. Introduction

The new generation of civil location based services (LBS), as a part of the intelligent road transport systems (ITS-R), requires positioning sensors with a high level of accuracy, availability, integrity and liability. Moreover, cost considerations must be done if a mass market implementation is pretended. After selective availability (SA) was disabled in the year 2000, and the satellite based augmentation systems (SBAS: WAAS, EGNOS, MSAS, GAGAN) were operative, most of the GNSS sensors in the market offer a good accuracy in locations where there is good visibility of the GNSS and GEO satellites. However, the lack of availability, specially in urban areas, is a known problem for the GNSS/SBAS. Although SBAS offers a slight improvement in the calculated position, another aspect considered as crucial for several road applications is the integrity of this position. Monitoring the integrity implies that the goodness of the positions received from the GNSS sensor can be known anytime. In several current road applications such as road pricing systems, or intelligent pay-per-use insurances, this issue becomes critical.

The use of SBAS systems allows the calculation of useful integrity factors, such as the HPL (*Horizontal Protection Level*) and VPL (*Vertical Protection Level*) parameters, as described in the RTCA DO-229 [1] specifications. In Fig. 1 the usefulness of the position integrity is shown. Here a typical ITS-R case is illustrated. The vehicle goes through the true path (green), but the navigation system indicator estimates that the trajectory is the red one. The difference between the erroneous and correct paths is the horizontal position error (HPE). Here the HPL parameter is vital in order to bound the confidence area of the GNSS sensor, providing a good estimation (i.e. $10^{-7}/hour$ probability) of the system reliability on the fact that the true position is within a circle around the computed position. The horizontal alert limit (HAL) can be defined as a proper upper bound for the HPL value. If $\mathrm{HPL} > \mathrm{HAL}$ the integrity alarm is triggered and the navigation system could switch to a secondary navigation sensor. Both HPL and VPL are commonly named as $\mathrm{HPL}_{\mathrm{SBAS}}$ and $\mathrm{VPL}_{\mathrm{SBAS}}$ in order to distinguish between the SBAS based computations and the receiver autonomous integrity monitoring (RAIM) algorithm factors.

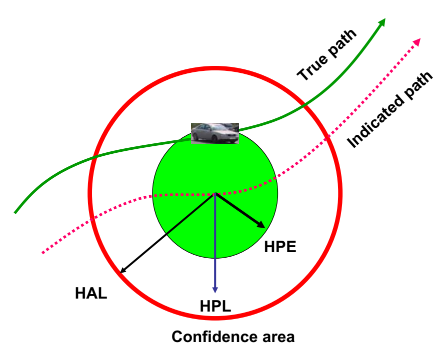

Fig. 1. Horizontal protection level

To improve the quality of the positioning performance of the vehicle, recent researchers propose a combination of inertial and GNSS sensors [2]. However, cost considerations must be done regarding the use of inertial units, and low cost sensors, based on micro-electro-mechanical (MEM) technology usually provide very low levels of accuracy. In [3] an alternative integrity parameter for the road applications and based on a combined GNSS/INS integrated system is proposed. Despite of the improvements of this approach not only based on the GNSS sensors, the strong dependency on the filter parameters encourages further investigations. [4] shows a positioning receiver implemented in software which monitors the EGNOS integrity. However this approach only deals with static non realtime scenarios. In [5], the authors describe the application of the EGNOS corrections broadcasted via Internet using the data saved in previous static or dynamic observations. The software proposed in that work, allows the simulation of the positions obtained in several operation modes, facilitating the inference in real results in a concrete environment.

In the same research line, the work presented is focused on monitoring position integrity and applying EGNOS online through cellular networks. An exhaustive study about the current state of WAAS and EGNOS can be found in [6]. Here, the tests carried out show a double vision of the SBAS performance. Firstly, an internal observation of the key factors in the SBAS operation is showed. Secondly, the performance at user level is evaluated. However, this study just points static environments and employs postprocessing calculations. This low level monitoring is not suitable for our applied road environment.

Our investigations have considered an European scenario, where the GPS/EGNOS availability is assumed as high, e.g. a vehicle along a highway. Preliminary works can be found in [7], where the evaluation is performed only on a static wide open scenario. In the current paper, an improved integrity algorithm applied to a dynamic environment is presented. Associated problems using the EGNOS/SISNeT technology available in Europe are also shown.

The rest of the paper is structured as follows. Firstly, the established basis of the preliminary work made in [8] are commented. In this paper, a prototype of sensorized vehicle takes into account the basic idea of calculating the HPL parameter as a reliability factor of the position. Section II presents some concrete items on the necessary calculations to obtain the HPL. In section III, the architecture of the designed system is explained. Section IV shows the results obtained in our HPL observation, and the usefulness of the integrity information applied to onboard vehicle services. Finally, main conclusions achieved in our work are presented.

II. Computing HPL

The calculation of the integrity parameters is based on the real time processing of the data broadcasted by EGNOS, which contains correction information for all pseudorange measurements. These data arrive to the user position by many types of messages coordinated through Issues of Data (IOD): types of messages 1, 2 to 5, 6, 7, 9, 12, 24 and 25 provide the fast and long term corrections, and UDRE, those due to ephemeris and clock errors. Messages 18 and 26 contain ionospheric corrections and GIVE. Finally, message 10 contains degradation parameters. Once these values are available, the integrity algorithm must proceed to evaluate the mathematical expressions described in [1], summarized in this section. In both the message processing and the HPL calculation, several considerations related to the road transport environment must be taken into account. The first of them is that an ENU coordinate system is used.

$$HPL_{SBAS} = K_H \cdot d_{mayor} = 6{,}18 \cdot d_{mayor} \tag{1}$$

(1) shows the calculation used to compute the HPL value. For the choice of the K_H constant, the RTCA standard differentiates between the *non precision approach* (NPA) and the *precision approach* (PA) modes of operation. In the present work, the mathematical expressions for NPA mode have been chosen due to the fact that the road environment does not require high levels of integrity (mainly directed to safety life applications). Moreover, the operation of EGNOS (ESTB), was not completely deployed during the trials, and the delay requirements associated to the precise mode might be counterproductive for the integrity calculations.

(2) shows all the errors considered to obtain the final estimation for the error variance in the pseudorange measurements of the satellite used (σ_i^2). Here, σ_{flt}^2 is the error variance caused by the imprecisions in slow and fast corrections, σ_{UIRE}^2 is the error variance caused by ionospheric effects in the transmission of the satellite signals, $\sigma_{i,tropo}^2$ is the error variance caused in a similar way by the troposphere and $\sigma_{i,air}^2$ is the error variance caused by the user receiver. [1] explains the process to obtain all these values in the implementation of a SBAS client. However some explanations are recommended regarding the temporization of the reception of messages, [10]. The last of these parameters, $\sigma_{i,air}^2$, requires a special mention and it is explained in the next section.

$$\sigma_i^2 = \sigma_{i,flt}^2 + \sigma_{i,UIRE}^2 + \sigma_{i,tropo}^2 + \sigma_{i,air}^2 \tag{2}$$

II-A. *GNSS sensor error variance*

The GNSS sensor contributes with the term $\sigma_{i,air}$ and is necessary to obtain a good estimation. For this purpose, we must consider the four classes of equipment described in [1]. In our case, we assume the class two for our equipment, hence (3) must be considered in order to obtain $\sigma_{i,air}$.

$$\sigma_{i,air}^2 = \sigma_{i,noise}^2 + \sigma_{i,multipath}^2 + \sigma_{i,divg}^2 \tag{3}$$

$$\sigma_{i,multipath} = 0{,}13 + 0{,}53 \cdot e^{-El_i/10} \tag{4}$$

The errors caused by multipath phenomena in the transmission of the satellite signals ($\sigma_{i,multipath}$) are estimated by (4), where El_i is the elevation angle of the line of sight between SV_i and the user antenna. However, there is not a fixed model for estimating σ_{noise} and σ_{divg}. The first of these values considers the errors caused in the operations made by the receiver and in the transmission of the signals due to thermal noise and interferences. σ_{divg} estimates the errors occasioned in the receiver filter, causing an ionospheric divergence. The standard establishes a feasible range for the sum of these two values, based on the elevation of the satellite.

(5) and (6) indicate the value to be considered in every edge, for conventional and SBAS satellites respectively. Because a value of this sum is needed according to the real satellite elevation, a linear interpolation has been assumed, considering the minimum level of signal at 5 degrees of elevation and the maximum at 90 degrees.

$$\sigma^2_{i,noise} + \sigma^2_{i,divg} \leq \begin{cases} 0{,}0225 & For\ min\ elevation \\ 0{,}0121 & For\ max\ elevation \end{cases} \quad (5)$$

$$\sigma^2_{i,noise} + \sigma^2_{i,divg} \leq \begin{cases} 1{,}8 & For\ min\ elevation \\ 1{,}0 & For\ max\ elevation \end{cases} \quad (6)$$

III. ARCHITECTURE OF THE PROPOSED SYSTEM

The onboard equipment (OBE) is a GNSS/EGNOS sensor and an embedded computer (PC) provided with cellular network (CN) communication connectivity. Fig. 2 shows the OBE block diagram. The PC software reads positioning data from GNSS sensor by the COM1 RS232 serial port. To calculate the integrity factors the SBAS/EGNOS messages come via two alternative ways: the GEO satellite and Internet. In the first case, an EGNOS capable GPS sensor provides the EGNOS messages via another RS232 port. When the line of sight between the geostationary satellite and the receiver is blocked by obstacles such as buildings, bridges or other vehicles, the application switch automatically to the second option, where the SBAS/EGNOS messages broadcasted via Internet by SISNeT [9] are received by the vehicle through a GPRS/UMTS link. The SISNeT version used (v3.0) supplies the possibility of demanding specific EGNOS messages, an interesting feature to allow a fast initialization of the system.

Once the SBAS/EGNOS messages have been received, each one enters the first step of software processing in the onboard computer. In the Message Processor stage some preliminary tasks are performed to transform the message into a generic format. In this way, for example, the SISNeT messages are processed to extract the specific field which contains the SBAS/EGNOS package. The task to be made now consists of identifying the content of the common fields to all messages and, after that, processing each type of message. A detailed description of each type of SBAS/EGNOS message can be found in [1]. Once each SBAS/EGNOS message is split into its fields, the SBAS Client will be in charge of processing it, maintaining the state of corrections and calculating the error estimations. These values are finally used in the Integrity Processor stage, which calculates and supplies the integrity parameters, available for the rest of applications.

IV. RESULTS AND PRACTICAL APPLICATIONS OF THE INTEGRITY PROVISION IN ONBOARD SERVICES

In the static tests, an exhaustive observation of the integrity have been carried out. Dynamic trials show the behavior of the integrity parameters in the location based services field. The software has been developed in Java, allowing portability among different platforms. This software has been designed to support a wide variety of receivers. In the tests presented

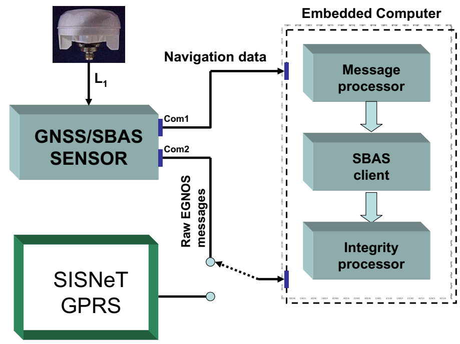

Fig. 2. System architecture

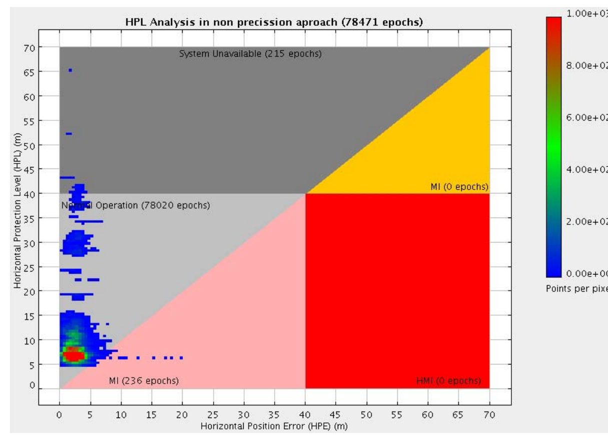

Fig. 3. Stanford graph of HPL results in a static environment

in this paper, a Novatel Millennium OEM3 has been used. For the static tests, the antenna was located over the roof of one of our external laboratories, whereas in the dynamic tests it was located over the vehicle. Finally, the Internet connectivity with the onboard PC was possible thanks to an UMTS Novatel Merlin U530 PCMCIA adapter, which allows GPRS/UMTS connections.

Fig. 3 shows a graphic of HPL values obtained as the result of a 24 hours test using our monitoring software in a static wide open environment. This graph presents the HPL value against the real position error considered with regard to the correct position of the antenna. It is visible how the 99.43 % of the values are located in the zone of normal operation, a 0.27 % of the values in the system unavailability zone, and just a 0.3 % in the misleading information zone. The most of the HPL values are located in the range from 5 to 15 meters.

In dynamic environments, several tests were focused on the reception of the EGNOS messages via SISNeT and the geostationary satellite. Fig. 4 shows the results obtained performing a route through the Campus of Espinardo of the University of Murcia. At the first glance, the results obtained in a dynamic environment differs from the one observed in a static location, where the visibility and the reception of EGNOS messages are much better. In this sense, taking into account the good conditions of all the satellites used in the GPS solution during the trials, the main factors to be considered in the analysis of the results are the visibility of the GPS and the geostationary satellites, and the quality of the GPRS connection. The impact occasioned by the lack of GPS signal availability due to the poor visibility of the satellites can be seen in the zone of 660.6 km. east (longitude) and 4209.7 km. north (latitude). However, the main problem caused by the surrounding buildings is not the loss of GPS satellite coverage, but the major latency in the GPRS connection and the loss of EGNOS satellite visibility. These two last effects can be seen in the upper and lower images of Fig. 4 respectively. When the GPRS connection gets worse or the GEO satellite is hidden, the ratio of the received EGNOS messages decreases, so the HPL value increases due to the degradation of corrections. It is worth mentioning how the operation of the integrity subsystem is better in the case of using the GEO messages extracted from the receiver, as can be seen in Fig. 5. Here, a cumulative distribution of the HPL values obtained in both GEO and SISNeT cases is shown. As can be seen, all the HPL values in the GEO case remain in the range between 5 and 15 meters, whereas in the SISNeT case, values nearby the 20 meters represent about the 12 %. In Fig. 6 the values obtained from the integrity subsystem are plotted in a histogram. The peaks in the HPL outcome using SISNeT are in the range from 200 to 450 meters. However, it is noticeable how the most of the values obtained in both the GEO and SISNeT cases are lower than 20 meters. Another fact of importance extracted from our results is the unavailability of the HPL. This can be clearly seen in Fig. 5, where the SISNeT cumulative distribution line begins at a value greater than 0. This is due to the fact that the unavailability of the HPL is expressed with a fixed value of -1.

Although the results presented show that the use of the GEO satellite as the source of the EGNOS messages seems to be a better option, some considerations of the environment where the tests were made should be taken into account. Although the visibility of the geostationary satellite signal in wide open areas is good, the results obtained in urban canyons encourage the use of SISNeT, being the visibility of the GEO satellite worse in built-up areas and the GPRS coverage better.

There are different manners in which this integrity information of the positioning system can be integrated in onboard services in vehicles. As a first approach, in our work we have developed the integrity monitoring tool presented in Fig. 7. In this software, the HPL value coming from the integrity subsystem is used to show graphically the state of this parameter. The user is warned when the HPL exceeds a preestablished threshold. Although this an interesting monitoring tool, the integrity information is specially useful in larger scope services. As an example, biohazard good haulers could be truthfully tracked while riding life-critical areas. Additionally, the HPL parameter could play a significant role as an estimator of the confidence level in road pricing systems, where a critical decision of the road ridden must be made. In Fig. 8 a screenshot of a navigation application developed in our group which uses the integrity information is shown. This software has been used in our research group for several works

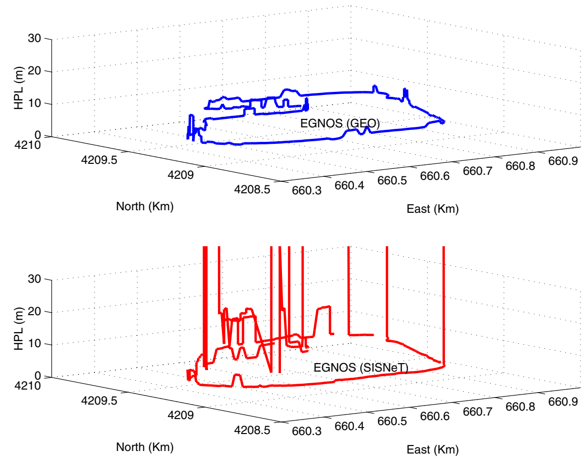

Fig. 4. HPL_{EGNOS} obtained with GEO (top) and SISNeT (bottom)

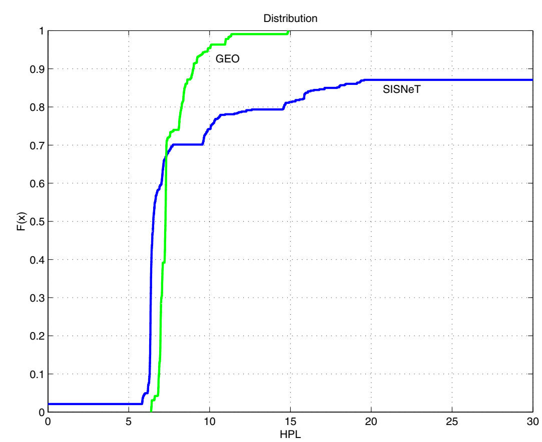

Fig. 5. HPL_{EGNOS} cumulative distribution for both cases

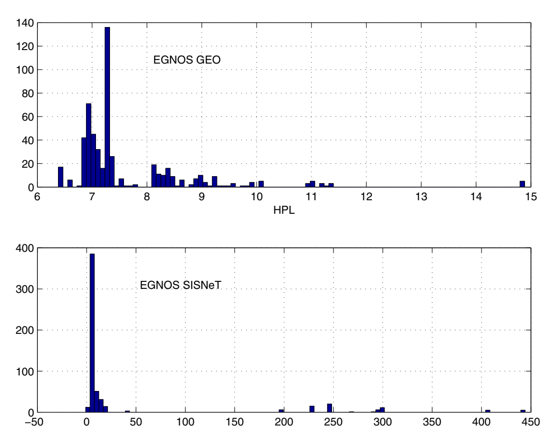

Fig. 6. HPL_{EGNOS} histogram for both cases

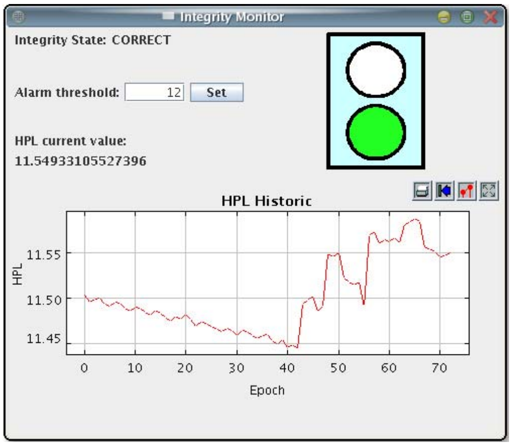

Fig. 7. Integrity Monitor service

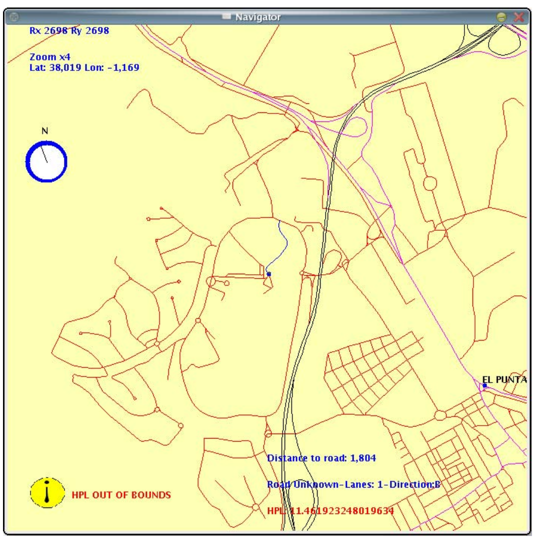

Fig. 8. Navigation service

with GIS and road pricing. It uses the integrity provided by the proposed architecture to warn the user when the position of the vehicle is not guaranteed, attending the HPL value.

V. Conclusions

In this paper, the integrity information provided by the broadcasted SBAS messages has been shown as applicable to the road transport environment, as compared with the traditional aviation purposes. Our software approximation executed in a standard PC has been presented as a valid system for decoding the integrity parameters HPL and VPL. In the proposed architecture two alternative ways of obtaining the SBAS messages have been presented. First approach is based on the possibility that the receiver provides the messages directly from the geostationary satellite, while second employs an Internet connection with a SISNeT server provided by the ESA. When using this last choice, current cellular networks play a key role in the performance of the integrity system, at the same level than the visibility of the geostationary satellite in the first case. The results obtained for the HPL parameter in the dynamic tests performed show how integrity values are better when the SBAS messages are received from the GEO in good visibility areas, as compared with the SISNeT option.

Regarding the location based services field, the investigations were focused on realtime warning of malfunctions of the underlying positioning system, and the usefulness of the integrity capabilities in the GIS navigation and electronic fee collection applications.

In the paper presented, the communication technology used has been GPRS, since the UMTS technology is not fully operative in the south of Spain. However, the use of UTMS is considered as a key factor in the future of LBS. Future researches will be focused on the exhaustive study of the influence of the communication delay and the loss of packets in the reception of SBAS messages when an Internet connection is used through a cellular network connection, against the reception of the messages via the GEO satellite.

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