An Integrity Navigation System based on GNSS/INS for Remote Services Implementation in Terrestrial Vehicles

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Abstract— **Nowadays, one of the most important applications of the navigation systems are the remote services. Applications such as tele-tolling, truck fleet control or antitheft devices suppose millions of users through the roads of the whole world. Particularly in Europe, the development of the GALILEO system and the efforts of the European Parliament in prioritizing the toll collecting systems based on GNSS and cellular networks (GNSS/CN), enlarge highly the european market of potential users. In that million users market, no particular exceptions can be treated in a realistic solution. The most part of the actual navigation systems relies mainly on the satellite navigation. Problems such as the deficit of precision, the lack of coverage or the service interruptions due to disturbances on the satellite network arouse the implementation of a more reliable solution combining GNSS and autonomous navigation systems. This paper is to present how an GNSS/INS integrated system offers the accuracy and quality assurance required in remote services. Both practical and theoretical researches about the possibilities of a single GPS receiver, EGNOS-SISNeT/SBAS position corrections improvements, the incoming GALILEO-GPS constellation and the use of a multisensor GNSS/INS integrated solution as a reliable navigation system for remote services applications are presented.**

I. Introduction

DIFFERENT remote services for vehicles such as traveller information, route guidance, automatic emergency calls, freight management, advanced driver assistance, etc. require a road side equipment (RSE) capable to offer an integrity position with low price. With this purpose in mind, developers had been focusing their efforts to the GNSS/CN. This solution allow low-cost positioning system, the posibility of increasing the accuracy by using the SBAS systems and bidirectional communication between the vehicle and the servide provider. However, today the GNSS systems do not provide the availability, accuracy and integrity necessary and some other technologies must be used. Main features the future on-board unit (OBU) of a vehicle must comply are:

1. low cost including easy installation, maintenance, etc.
2. Capacity for computing vehicle parameter like vehicle dimensions, truck class, weight, etc.
3. Integrate wireless communication for task such as e-pay, e-maintenance, etc.
4. Interoperability with others system.
5. Anticheating enforcement (difficulty to manipulate the OBU by a not allowed person).

As an example, just in the case of the eletronic-fee-collection (EFC) systems in Europe, the aim of a common, compatible solution seems to be a fairy tale. Despite of the efforts of the EU for a technical standardization, harmonization of national projects, and negotiations between operators, the reality is the next: A charging system is implemented in, Switzerland (LSVA-RPLP) using DSRC microwave 5.8 GHz. Germany planned other approach 2003 based on GNSS/GPRS. In Italy, haulers may use the Telepass technology (a different DSRC microwave, technology not compatible with the Austrian one). In France and Spain, as a possible future, the availability of a DSRC solution compatible with the Austrian one : “LIBER T” system. In United Kingdom, Belgium, Netherdlands and Czech Rebublic are interested in the deployment of a GNSS/GPRS solution in the future [1]-[5]. That is, too many different not compatible onboard equipment in the vehicles behind the windscreen.

According to the actual bibliography, the most reliable solution to the problem of localization is close to a positioning system based on the integration of a GNSS and another autonomous positioning system. In order to guarantee the proper quality of a positioning system in remote applications different approaches are being studied. All of them rely on an accurate GNSS position, either as the leading positioning information input, or as an aiding system, to determine vehicles movements along roads. In [6], a GPS receiver is complemented with odometry information and an electronic compass to estimate the position of an autonomous vehicle. In that work, some

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asumptions concerning GPS availability and velocity limits are done. It is worth mentioning the different versions of the NabLab positioning systems equipped by a GPS receiver, odometry and supported with a vision system and a laser range scanner for avoiding collisions [7]. In addition, in [8] both GPS receiver and inertial units are used. In Europe, the European Space Agency (ESA), is encouraging the use of the EGNOS/SISNeT position corrections while private companies as BMW offer their localization systems based on a single GPS receiver.

II. THE NAVIGATION SYSTEM

One of the main interests of this research is the use of satellite positioning systems to provide a more reliable positioning. An EGNOS prototype which provides a broadcast *Signal in Space* (SIS) is offered since February of the year 2000 as an EGNOS System Test Bed (ESTB). This prototype is used to support and test the development of the EGNOS system, to present EGNOS to potential users, to prepare to the EGNOS entrance and to test the possibility of expanding this system outside Europe. The ESTB provides users with a GPS-augmentation signal system a few meters accuracy positioning. A further aim of the European Commission is to increase the number of potential users of the GALILEO system in transport applications.

The poor coverage in built-up areas and tunnels and the undesirable propagation of the signal into many dispersed navigations trajectories are the main problems observed (both in the case of GPS and geo-stationary satellites). In order to minimize the problem of the poor visibility of the AOR-E satellite, corrections are sent by 2.5G and 3G mobile phone networks as a part of the ESA SISNeT project. The results of testing these corrections in our vehicle are also shown in this paper.

SISNeT can replace the geo-stationary augmentation signal, but it is not a solution for the lack of GPS coverage. A solution based on sensor fusion to maintain the integrity of the vehicle position is proposed. The EGNOS/SISNeT signal and an Inertial Navigation System (INS) are fused by a Extended Kalman Filter.

A. *The GNSS Positioning System*

Initially developed by RTCA for aerial transport, *Satellite Based Augmentation Systems* (SBAS) offer some interesting advantages to the ITS: Firstly, the availability of real time corrected position around a wide area of coverage. Next, the accuracy given by CEPs under 3m. and the possibility of integrity monitoring. Finally, WAAS, EGNOS and MSAS compatibility will provide a global accurate positioning system for ITS applications.

In this work, we have used a *High-End* GNSS sensor, Novatel OEM-3, capable to give a 20 Hz. rate differentially corrected positioning in kinematic mode. The sensor is configured to accept SBAS/EGNOS correction from geostationary satellite used by Egnos (AOR-E PRN 120 and IOR PRN 131). A GPRS/WLAN modem, Nokia D211 inserted by a PCMCIA slot to a Single Board Computer (SBC) has been used. This computer runs the user software application, developed by us, responsible to interact with the OEM-3 sensor and with the GPRS modem. In this way, the SBC gets a PVT datagram every epoch from the GNSS sensor, the PVT datagram is analyzed and when there's no EGNOS signal, the SBC switches to SISNeT to provide EGNOS correction frames (RTCA DO-229) to the GNSS sensor.

Some Egnos/Sisnet results are presented. The on-board unit has been installed in our test vehicle and some urban trajectories with and without SISNeT have been logged. In figure 1 trajectories along the city of Murcia are shown. The trajectory is superimposed in black points on a Navtech digital GIS map.

Fig. 1. Trajectory representation along the city Murcia superimposed on a *Geographic Information System* (GIS) map.

Figure 2 shows the same trajectory in a closer view. Mentioned problems such lack of coverage or spurious data, as consequences of insufficient number of satellites in view and a undesirable propagation, are now easy to recognize.

The incoming GPS-GALILEO constellation will approximately double the number of satellites in-flight. The possibilities of this new constellation are yet to see. A priori, the probability of satellites in view is increased, but in a practical approach, in built-up areas, specially in city environments, the possibilities of offering position with a system based on satellites are quite poor. In some tests developed downtown in Murcia where single-lane roads

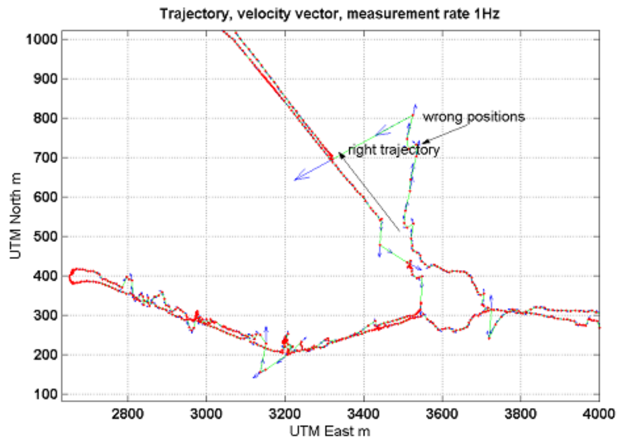

Fig. 2. A closer view of a trajectory along the city of Murcia. Problems such as spurious measurements or lack of coverage are very usual in city enviroments.

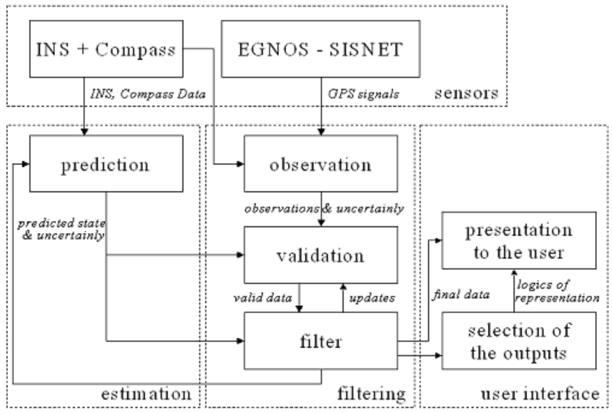

Fig. 3. Data fusion architecture. The filter implements an Extended Kalman Filter algorithm.

and six meters of wideness between buildings are usual the number of satellites in view was usually zero. These test results make us think that an autonomous positioning system is needed and disesteem the reliability of a solution exclusively based on GNSS for a integriy navigation system.

B. *The INS support*

The lack of GNSS coverage in city enviroments (even when SISNeT signal is used) is a real problem that cannot be solved with a global positioning system. A reliable solution for these periods wihout GPS signal is absolutely required to guarantee a complete information to the user. The nature of the inertial measurements (accelerations and rates of turn in the three coordinated axes of the body frame) complements perfectly the deficiencies of localization systems based on the GPS solution, without the typical odometry problems as the glides, the uncertainty about the effective wheelbase, unequal wheel diameters, etc. However, the need of a double integration process to obtain the position from the acceleration measures, is the principal source of error in a INS/GPS integrated system. Often updatings should be taken to zero the solution drift. Additionally, error models should be implemented in order to remove bias desviation from the measures. A test with no forces applied to the vehicle (except the assumption of the Earth's gravity) was carried out with a Crossbow VG-600, which provides the accelerations and the rates of turn in the three coordinated axes of the body frame. When error models hadn't been used, the position drifted quite soon, becoming –55 m. in 60 seconds without aided updates. When an exponential aproximation was implemented (see [9] for details) the position was retained under 70 cm. during the same 60 seconds without any aided update.

C. *The Fusion Architecture*

The data fusion architecture is shown in the figure 3. The filter implemented consists of an Extended Kalman Filter with a 18 variables state vector [10].

D. *GNSS/INS TEST RESULTS*

Figure 4 shows a typical situation in city environments. How intertial sensors support reliable position when not only spurious data from the GPS receiver are coming but also there is no GNSS signal during around 11 seconds and approximately 60 meters is observed. On this test, spurious measurements are determined as the result of applying a Nyquist certainty comparison depending on the vehicle velocity. When an spurious is detected, the filter rejects this measurement from and disable this sensor during this cycle.

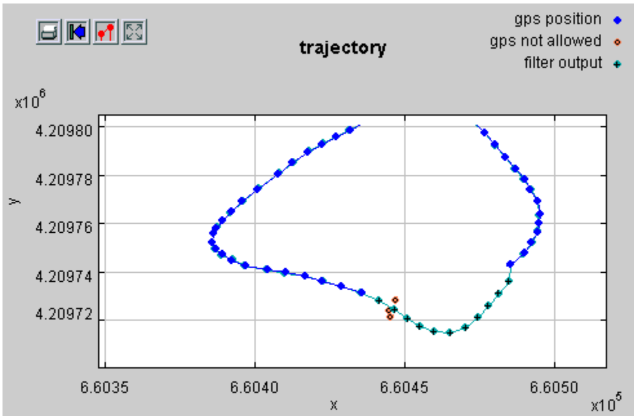

Fig. 4. A detail of a city trajectory when spurious GPS data are detected just before a coverage failure is shown. The output frecuency of the filter is 1 Hz. The Extended Kalman Filter output maintains reliable position when no gps is available. In this test developed in the Campus de Espinardo of the University of Murcia, the lack of coverage lasted around 11 seconds.

III. The Communication System

The presented navigation system has been tested out using the SatAnt test vehicle. The SatAnt vehicle is a platform equipped with a hardware architecture which provides the communication infrastructure required in our test (figure 5).

The hardware architecture consists of two blocks. The main CPU is in charge of sensor fusion, high level applications and user interface. A second CPU with less computational requirements is in charge of communications into the vehicle and with the base station. Both CPUs are

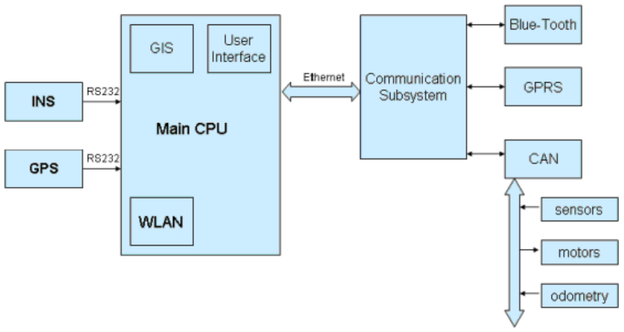

Fig. 5. The Communicartion architecture.

connected with an Ethernet bus. The main CPU is a standard single board computer based on a 32bit Pentium processor. For the second CPU it has been used a 8bit microcontroller in order to increase the I/O features of the whole system and to append more peripherals.

Communications out of the vehicle are carried out with GPRS wireless connection. This link is used to connect the vehicle with the base station and any other remote system. Inside the vehicle, a Blue-Tooth wireless link can be used to connect the vehicle with a laptop (or other mobile device such as PDAs, etc.). Additionally, a WLAN connection is available through the PCMCIA slot of the main CPU, bringing the possibility of communication with vehicles close to SatAnt.

Communications with the sensor system of Satant are carried out through a CAN bus interface. Different control and sensor units are distributed along the vehicle, and all of them are connected through a CAN bus with the communication CPU.

IV. Conclusions and Future Work

The presented results show how a GNSS/INS integrated system is an effective positioning unit for remote services applications. Applications such as a tele-tolling system (supported by different european goverments and in development by the main european vehicle manufacturers) require an accuracy and integrity not available with a single GNSS positioning system. Tunnels, built-up areas, trees and the multipath distortion provoke problems difficult to solve without an autonomous localization system, specially in city environments. In these applications, this enforcement of the solution is required to provide a realtime reliable position.

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