A PRECISION POSITIONING SYSTEM BASED ON EGNOS-SISNET/INS NAVIGATION FOR AN AUTONOMOUS VEHICLE

R. Toledo, M.A. Zamora, B. Ubeda, H. Martínez, A. Gómez Skarmeta
Department of Information and Communication Engineering
Facultad de Informática, University of Murcia
Espinardo 30071, skarmeta@dif.um.es, www.um.es
ph: +34 968 366 407 fax: +34 968 364 151

ABSTRACT

A solution for the problem of positioning in an autonomous vehicle is described. The use of a simple GNSS (Global Navigation Satellite System) do not guarantee continuous and accurate positioning, absolutely required for an autonomous car in practical applications such as urban public transport and road pricing systems. EGNOS and SISNET improvements complements perfectly with the inertial solution, since the periods without satellite coverage can be successfully served by the inertial device. An evaluation of Egnos, Sisnet and INS contributions to the simple GPS solution shows the benefits of the algorithm presented. On it, inertial measures are used both to predict and to validate observations from other sources. Additionally, It's briefly shown how error models can improve the inertial solution. A short description of both the hardware and software architecture of the autonomous vehicle (the SatAnt vehicle) is described.

INTRODUCTION

Nowaday GPS based tools are a usual navigation system. Day by day new applications emerge in the field of satellite navigation systems, some of them in the land navigation. Many of these new applications need accuracy and integrity above simple GPS standards. Urban transport and road pricing systems are examples of required integrity and accuracy

In Europe, some initiatives related to Road Pricing have emerged. Such solutions range from the ones given by the short-range commnunications technology (DSRC) to the ones based on satellite and cellular networks, known as GNSS/CN systems. Also hybrid systems, using both technologies, have emerged. We have focused our reseach in the GNSS/CN systems.

In Europe, several countries have seriously considered the introduction of these new road pricing systems [Jordan]. In Switzerland, a road pricing system became operative from January 2001. The system is based on microwave DSRC and GPS technologies, and a connection to the vehicle's tacograph. Other project related to road pricing is being developed in Germany. In this case the on-board unit is equipped with a GPS complemented with some sensors and broadcast beacons in places with bad reception.

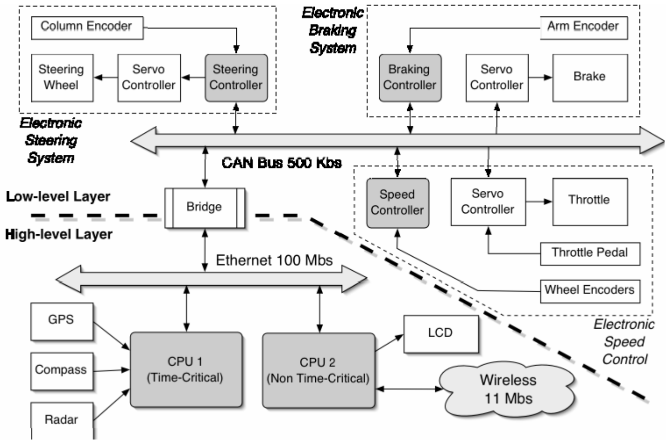
Next sections describe the framework of our autonomous vehicle, and the design and performance of the localisation system.

FRAMEWORK

A framework for developing mobile robot applications, the Thinking Cap-II architecture is used. This framework consists of a series of modules and services developed in Java and allows the distribution of these modules over a network. The framework consists on a reference cognitive architecture largely based on ThinkingCap [Saffioti] that serves as a guide for making the functional decomposition of a robotics system, a software architecture partially based on BGA [Martínez] that allows a uniform and reusable way of organising software components for robotics applications, and a communication infraestructure that allows software modules to communicate in a common way independently of whether they are local or remote. This framework has been fully implemented in Java.

The SatAnt vehicle, an autonomous vehicle that implements the Thinking Cap-II architecture will be our test vehicle. This vehicle incorporates a two layer hardware architecture that provides both modularity and flexibility. The SatAnt vehicle was developed in frames of the MIMICS project [Skarmeta], a two cars convoy application where the leading car is manned and the rest are being driven in autonomous mode.

The SatAnt vehicle has to be absolutely automatised in order to allow a computer to fully control it. Next, it requires enough processing elements and sensors to perform autonomous tasks.



a) The SatAnt autonomous vehicle b) Hardware Architecture

Figure 1. The SatAnt vehicle.

The SatAnt vehicle (Fig SatAnt a)) is based on a COMARTH S1-50 two-seats sport car, which has been heavily modified to allow it to be controlled by a computer based system. The weight of the whole vehicle is 700 Kg and the engine provides 90 h.p. which gives a high power to weight ratio and allows high accelerations. The modifications include an automatic gearbox, electronic assisted steering system, electronic speed control, and electronic braking system. For safety reasons, all electronic systems have been designed in such way that they allow both manual and automatic control, and at any time the electronic systems can be disengaged. Both the frame and the outer shell has been modified to accommodate for the non standard equipment.

The hardware architecture (Fig. SatAnt b)) has been organised in two layers, in which low level controllers and electronics (typically microcontrollers) communicate trough a CAN bus [Lawrenz] operating at 500 Kbs, and high level electronics (typically microprocessors) communicate through an ethernet bus operating at 100 Mbs. The design goals for the hardware architecture were modularity and scalability, in such a way that adding a new module did not interfere with the existing ones. The low level microcontrollers are in charge of close-loop controlling the actuators and sensor data acquisition. The high level microprocessors are in charge of running all the intensive computations software, bridging the two layers, and communicating the vehicle with off-board equipment through wireless links.

The software implementation runs on the high-level layer of the hardware architecture of the SatAnt vehicle. It relies on the TC-II architecture previously introduced. In the commented MIMICS application it consists of four different types of elements:

- Multi-robot Server. Given the nature of the communication infrastructure of the TC-II, all the information shared by the different elements is exchangedthrough and stored in a multi-robot Linda space. There should be only one instance of this element.
- Manned Vehicle. This is the element that will serve as a guide for all the autonomous vehicle. There should be only one instance of this element.

- Unmanned Vehicle. This is the element that will follow a leading vehicle, whose identifier is a priori set by the system designer. Thus, the leading car can be either a manned or unmanned vehicle. It is possible to have more than one instance of this element.
- Monitor. For monitoring purposes it is possible to receive all the information received at the information server. The monitor element displays this information and allows the operator of the system changing some parameters and monitoring the internal state of the different elements. It is possible to have more than one instance of this element.

DESIGN OF THE LOCALISATION SYSTEM

The robutness and performance of the autonomous system relies strongly on the high accuracy and integrity of its localisation system. In order to support a reliable solution the positioning system will be composed by a GPS-Egnos-Sisnet receiver, an Electronic Compass and an Inertial Navigation System. Measurements from different natures will give us robust data to estimate the actual position of the vehicle. Heterogenous data fusion algorithm are being tested.

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.

Unfortunately, nowadays SBAS cannot offer a good availability in urban areas due to the blockage of GEO SIS produced by tall buildings. To increase the availability of EGNOS SIS, the *European Space Agency* provides identical information by Internet: SISNeT project.

Usually. there are three possibilities for each epoch:

a.- There is a valid corrected position.
b.- There is a valid position but not corrected because the GEO satellite is obstructed by some obstacles such as tall buildings.
c.- There's no position, because visible satellites are not enough to calculate the position.

A solution to solve the case b using the SISNeT signal has been tested. In the case c, only increasing the availability of visible satellites will solve the problem. The future European positioning system, the GALILEO project, will add 30 satellites to the actual GPS constellation.

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 an 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 case b happens, the SBC switches to SISNeT to provide EGNOS correction frames (RTCA DO-229) to the GNSS sensor.

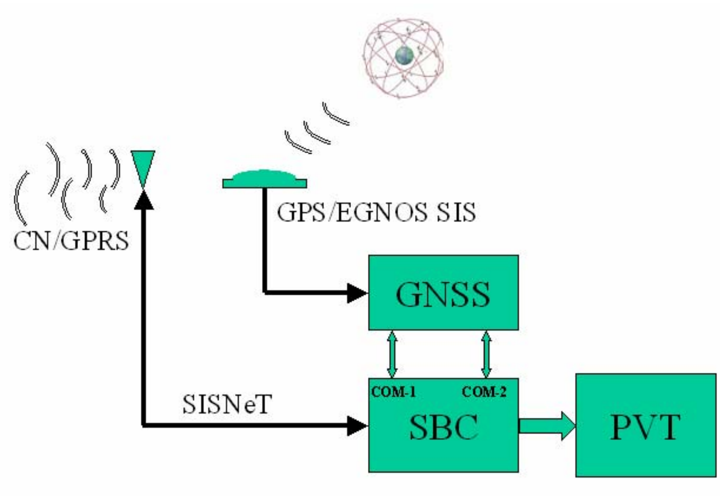


Figure 2. GNSS configuration.

The INS device (a Crossbow VG600 vertical gyro) provides the accelerations and the rates of turn in the three coordinated axes of the body frame. Integrating these measures, position and pose are obtained. Tilt sensors are included for the initialization. The tilt sensors, in addition to the electronic compass, will supply the pose information when the vehicle is stopped due to the drifts errors in the inertial measures as a consequence of the integration process. Different error models are implemented to correct these drifts errors. The better those error models are, the longer inertial solution will be reliable in unaided mode. For this reason, a complete study of different error models has been carried out.

The aim of the structure of the localization system is to be appropiated for different filtering algorithms (Figure [loop]). The most extended solution for a non-linear system as ours is the Extended Kalman Filter. This architecture suits it perfectly without desestimating a multihypothesis algorithm as a more robust, reliable future solution.

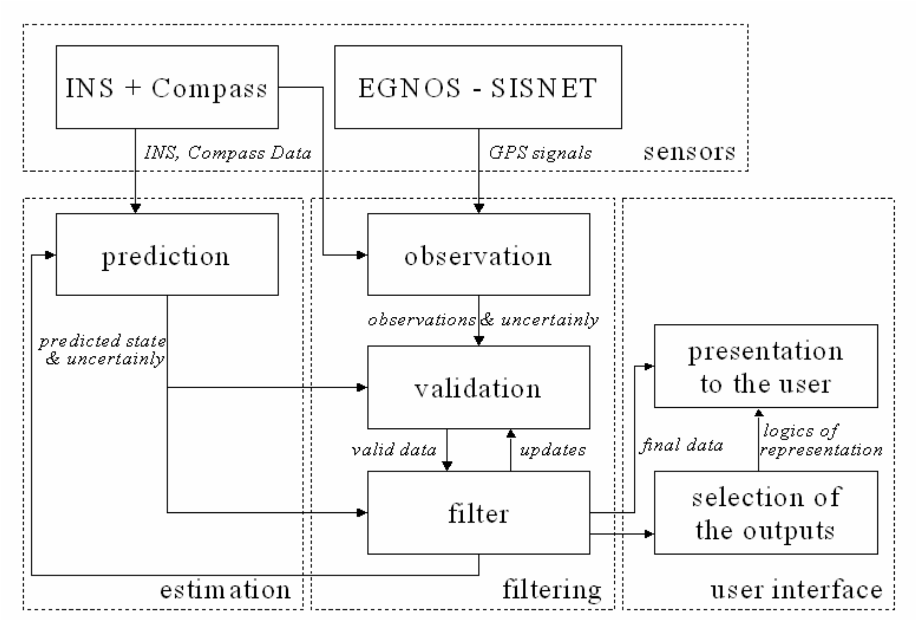


Figure 3. Structure of the positioning system.

PERFORMANCE OF THE POSITIONING

Evaluating Egnos/Sisnet improvements

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

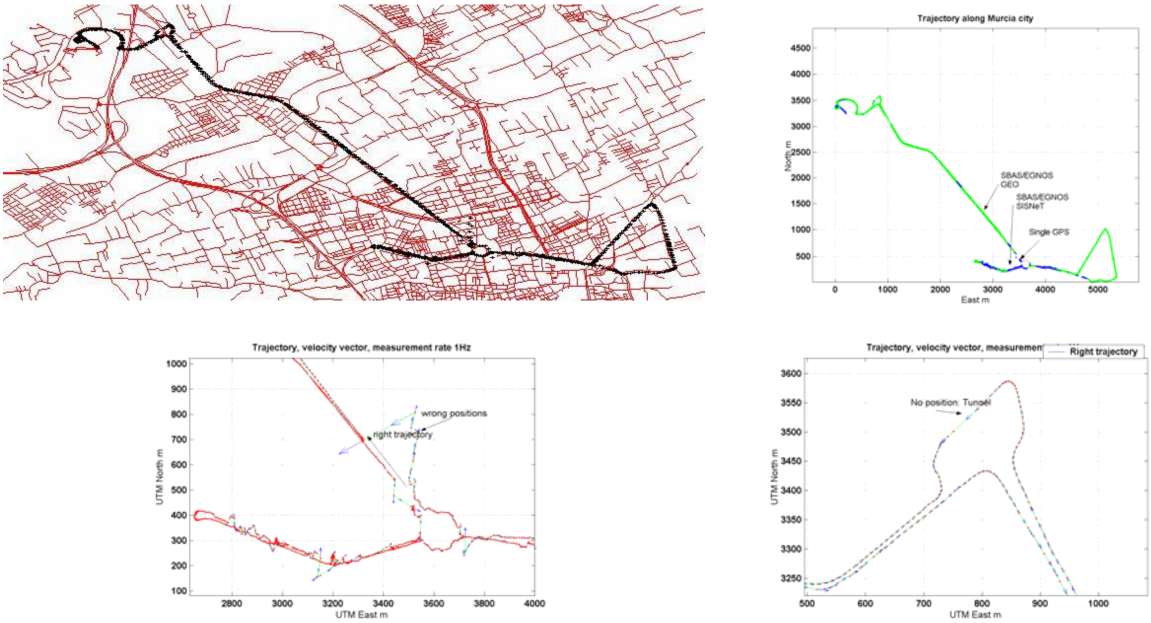


Figure 4.- Trajectory representation.

Table I

Epoch Number	No position	Single GPS	Sbas/Egnos GEO	Sbas/Egnos SISNeT	Distance Estimate
2777	105 [3.78%]	196 [7.05%]	1799 [64.78%]	677 [24.37%]	20.07 Km

We see that SISNeT suppose one increase from 64.78% to 89.15% in the availability of corrected position. That is, about 24% in this specific case.
However, for applications that requires high precision PVT, many problems need to be solved: Increase de availability with INS and dead reckoning sensor, elaborate digital cartography GIS with high resolution, elaborate a integrity definition valid for ITS, etc.

INS contributions

The lack of GPS coverage in city enviroments is a real problem that cannot be resolved 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 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 gravity was carried out. 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 [Barshan] for details) the position was retained under 70 cm. during the same 60 seconds without any aided update.

In our application, the SatAnt vehicle must rely on a accurate positioning system to navigate in autonomous mode. The use of a multisensor positioning system based on an INS device with accelerations and rates of turn in the three coordinated axes of the body frame and EGNOS/SISNET signals ensures robust and accurate position information even where no GPS coverage is available.

CONCLUSIONS AND FUTURE WORK

A description of a positioning system based on GPS (improved by the Egnos-Sisnet signals) integrated with an INS solution has been developed in this paper. Applications such as an automated tolling system or the localization system for a convoy of urban autonomous buses require a robust and continuous accurate positioning. As it has been shown in this paper, the use of inertial measures covers the lacks of a navigation system based on satellites. Egnos and Sisnet are able to improve substantially the GPS PVT datagram (position, velocity and time), using the geostationary satellite (in Egnos mode), or the GPRS technology (in the Sisnet option). Additionally, a short description of both the hardware and the software architectures of an autonomous vehicle, the SatAnt vehicle, is shown. The SatAnt vehicle is presented as a very useful framework for testing positioning systems results. The TC-II, a modular software architecture fully developed in Java, allows a simple distribution of its modules over a network.

Future researches on this area will aproach the GPS/INS integrated solution to the market. The development of the MEMs (Micro-Electro-Mechanical) technologies and its application to the IMUs (Inertial Measurement Units) is decreasing inertial devices prices day after day. In addition, the final implementation of the GALILEO project (fully operated and marketable in the year 2008) will bring more accuracy and reliability to the navigation systems based on a global navigation satellite system.

ACKNOWLEDGEMENTS

This research has been supported by the Fundación Séneca and the Ministerio de Fomento and the Ministerio de Ciencia y Tecnología (PROFIT FIT-160300-2003-41) of the Spanish Government .

REFERENCES

[**Jordan**] *A Study of Road Pricing Systems based on GNSS/CN*. J.G. Jordán, F.R. Soriano, P. Catalá and S. Montes. 10th World Congress and Exhibition on Intelligent Transport Systems and Services. Madrid, Nov 2003.

[**Skarmeta**] *MIMICS: Exploting satellite technology for an intelligent convoy*. A.G. Skarmeta, H. Martínez, M.A. Zamora, B. Úbeda, F.C. Gómez and L.M. Tomás. IEEE Intelligent System. N. IV. V17, pp. 85-89. 2002.

[**SMZUCA**] *Egnos (GNSS-I) Evaluation for ITS Application in a Vehicle Driving Support System*. A.G. Skarmeta, H. Martínez, M.A. Zamora, B.Úbeda, J.P. Cánovas and D. Alonso. Satellite Navigation System, Policy, Comercial and Technical Interaction. Kluwer Academic Publisher 2003.

[**Saffioti**] *Team Sweden. RoboCup 2000: Robot Soccer World Cup IV*. A. Saffioti, M. Bomanand, P. Buschka, P. Davidsson, S. Johansson and S. Wasik. 643-646. Springer, 2001.

[**Martínez**] *A Framework for Defining and Learning Fuzzy Behaviours for Autonomous Mobile Robots*. H. Martínez and A.G. Skarmeta. Intl.J. of Intelligent Systems, Volume 17(1): 1-20. 2002.

[**Lawrenz**] *CAN System Engineering. From Theory to Practical Applications*. W. Lawrenz. Springer-Verlag, 1997.

[**Barshan**] *Inertial Navigation System for Mobile Robots*. Billur Barshan and Hugh F. Durrant-Whyte. IEEE Transactions on Robotics and Automation, Vol II, No. 3. 1995.