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A FRAMEWORK FOR TESTING ITS APPLICATIONS BASED ON GNSS/EGNOS SENSORS

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ABSTRACT - In the last ten years, applications based on GNSS have become more and more useful in the transport market. Day by day, new researches contribute to the development of different comfort and security systems in the road transport sector. In this research a prototype of an intelligent vehicle, equipped with a set of sensors for satellite navigation and obstacle avoidance is presented. This prototype has been used as EGNOS-SISnet test bed for automatic driving and positioning. Finally, some positioning tests using GNSS/INS integration are shown.

INTRODUCTION - This paper presents the results of an evaluation of the EGNOS signal in the context of the MIMICS project (Mobile Intelligent Model incorporating Independent Control and Sensing) (1), financed by the Spanish Ministerio de Fomento which aims are to provide solutions in the field of intelligent transport systems, more specifically in the area of intelligent vehicles. The main objective is to develop a prototype of an intelligent vehicle in order to test different sensors integration, especially those related to location and awareness.

Different research groups from both universities and private institutions of the automobile sector have been working in the development of intelligent vehicles. Other important researches as NabLab vehicles (2), OSU vehicles (3), California PATH project (4), ARCO vehicle (5) and CHAUFFEUR project (6) are worthy of mention. This last project has been the inspiration of our MIMICS project since it tests an automated vehicle platooning.

One of the main interests of this research is the use of satellite positioning systems to provide a safer driving. 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 signal and an Inertial Navigation System (INS) are fused by a Kalman Filter.

FRAMEWORK

The MIMICS project involves an intelligent platoon, where a lead car guides a group of driversless cars. The prototype consists of a human-piloted lead car (Bombardier) and one autonomous following car (Comarth S1-50). The lead car sends commands and information to the following car. Using this information, the following car either mimic the lead car's behaviour or react to information. To increase the system's robustness, both cars operate cooperatively, transmitting information regarding their state, the lead-car driver's intentions, and any anomalous states of the second car.

SatAnt, the autonomous prototype (figure 1), has been also used to test the high integrity position system composed by GPS plus INS. This vehicle, with an automatic gear box, incorporates the following specially designed systems in a modified version of the original: electrically assisted steering, electronic accelerator and electrical breaking. The bodywork and dash were also modified to hold the sensorisation and monitoring systems, as was the interior distribution of components so that the actuators and electronics could be accommodated. The vehicle included a 77 GHz radar, an EGNOS satellite positioning receiver, electronic compass, inertial sensors, an odometric system based on the ABS sensors, and a 802.11b radio communication network.

Figure 1. Satant vehicle based on COMARTH S1

The hardware architecture (figure 2) has been organised in two layers, in which low level controllers and electronics (typically microcontrollers) communicate trough a CAN bus 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 interface 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.

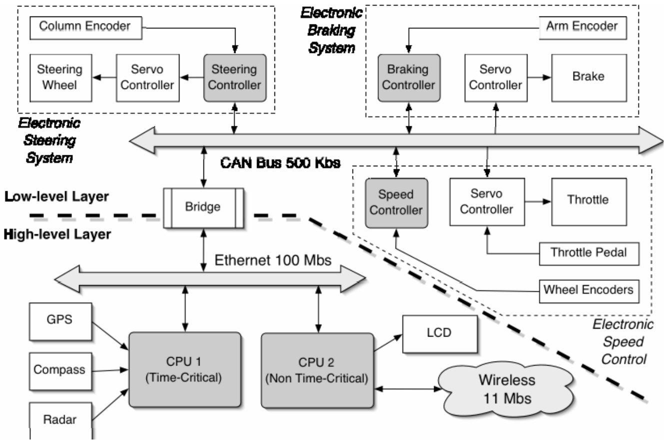

Figure 2. Satant hardware architecture

The software architecture is based on the ThinkingCap-II software. This framework is an architecture for developing mobile robot applications, and it is the extended combination of the ThinkingCap (7) and the BGA (8) architectures. This framework consists on a reference cognitive architecture that serves as a guide for making the functional decomposition of a robotics system, a software architecture that allows a uniform and reusable way of organising software components for robotics applications, and a communication infrastructure 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.

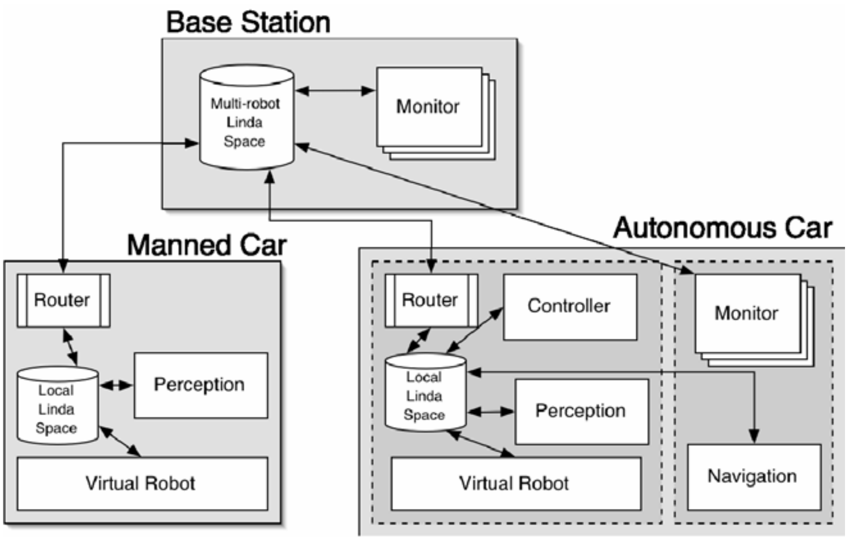

Figure 3. The MIMICS Application architecture.

The MIMICS application runs on the high-level layer of the hardware architecture of Satant vehicle, and it relies on the ThinkingCap II multi-robot architecture. This application consists on three different elements (figure 3): the multi-robot server supports the communication infrastructure of ThinkingCap II, the manned vehicle module implements the software of the lead vehicle, and the unmanned vehicle module implements the control of the autonomous vehicle. For monitoring purposes, displaying control and sensors information in both local (the car itself) and remote (base station) computers is possible.

AN AUTONOMOUS VEHICLE APPLICATION: THE MIMICS PROJECT

The aim of the MIMICS project is to develop an intelligent platoon of vehicles, where the leading vehicle (which is manned) acts as a guide for the following vehicles (which are unmanned). The controllers implemented in the Satant car for this purpose are explained.

Electronic Speed Control

The electronic speed control system consists on four different elements: the throttle pedal sensor, the servo actuated injector, the servo controller, and the speed controller. The servo controller and the speed controller are connected through the CAN bus. The speed controller is a hierarchical fuzzy controller that uses both the wheel encoders and road steepness information to decide the position of the injection servo in order to maintain a commanded speed. This command is named as *set-speed*. It is important to note that given the available engine power and the light weight of the whole vehicle, the plant presents high non-linearities. In particular, controlling both acceleration and deceleration are important issues. Thus, there are three basic controllers: one for uphill control, one for downhill control and the other for in level control. The selection of the active controller is performed by a high level controller whose input is the pitch/roll data. Depending on the values a combination of the basic controllers is executed. The output of the pitch/roll sensor used is quite noisy and a fuzzy IIR filter is applied to the sensor in order to smooth the signal. The servo controller receives both the throttle pedal sensor signal and the speed controller output and actuates the servo position accordingly. In the case that the throttle is actuated by a human operator, the manual input takes control over in any condition. All the electronics for both the servo control and speed control have been custom designed.

Electronic Braking System

The electronic braking system consists on the pedal actuator, a Maxon motor controller and the braking controller. The pedal actuator is a complex mechanical structure that allows parallel actuation of the pedal for both the human operator and the braking motor. The braking controller is in charge of applying braking patterns by sending signals to the motor controller through the CAN bus. A braking pattern is composed of three parameters: motor pressing time (to control the pressure applied to the brakes), motor standby time (to control how much time the brake is kept pressed), and motor releasing time (to control how fast the brake is released). The braking pattern command is named as *set-brake*. Both the braking controller electronics and the mechanical structure have been custom designed and built.

Electronic Steering System

The electronic steering system consists on a Delphi power steering column and a steering controller. The power steering column is directly attached to the steering controller. It includes a switch to engage or disengage the automatic control. The steering controller is a fuzzy controller that uses the steering column absolute position sensor to maintain a given wheel angle. The steering command is named *set-steer*. The steering controller has been custom designed.

A HIGH INTEGRITY POSITIONING SYSTEM APPLICATION

The robustness 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 mainly composed by a GPS-Egnos-Sisnet receiver and an Inertial Navigation System. Measurements from different natures will give us robust data to estimate the actual position of the vehicle. An Extended Kalman Filter data fusion algorithm has been applied.

The EGNOS/SISNET 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 the SatAnt vehicle and some urban trajectories with and without SISNeT have been logged. In figure 4 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.

An increase from 64.78% to 89.15% in the availability of corrected position is observed using Sisnet. However, in applications that require high precision PVT, many problems such as the position availability and the high resolution GIS cartography need to be solved.

The INS Device

The lack of GPS coverage in city enviroments (even when SISNeT signal is used) 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 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.

An Extended Kalman Filter (10) has been developed in our localisation system. 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 prototype for testing transport applications have been presented. The Satant vehicle, an autonomous car developed in frames of the MIMICS project is shown as a very useful framework to carry out a localization system design. The arquitecture of the vehicle, mainly relies on the TCII arquitecture, a modular software architecture for developing mobile robots applications. Two intelligent vehicles applications have been explained. First, the MIMICS project (Mobile Intelligent Model incorporating Independent Control and Sensing) financed by the Spanish Ministerio de Fomento. An evaluation of the EGNOS signal is discused in order to provide a solution in the field of intelligent transport systems, more specifically in the area of intelligent vehicles. Secondly, a high integrity positioning system has been tested using the Satant vehicle. Different sensors such as EGNOS/SISNET receivers, inertial sensors have been integrated in a Extended Kalman Filter. The synergism of these signals provide an accurate, high reliable solution required in an unmanned transport system.

Future researches on this area will aproach the localization system of the Satant vehicle 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. Finally, some measures from different natures, such as a vision system are being studied.

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