Editor: Alberto Broggi
University of Parma, Italy
broggi@ce.unipr.it

Mimics: Exploiting Satellite Technology for an Intelligent Convoy

Antonio F. Gómez Skarmeta, Humberto Martínez Barberá, Miguel Zamora Izquierdo, Benito Úbeda Miñaro, Felix Cesareo Gómez de León, and Luis Manuel Tomás Balibrea, *University of Murcia*

In this installment Antonio F. Gómez Skarmeta describes his team's project, a manually driven vehicle which, using GPS information, serves as the guide for a group of driverless vehicles. The vehicles that form the convoy are equipped with GPS receivers that enable precise self-localization and intervehicle communication.

In the last few years, GPS has spurred many automotive groups to launch many different applications including fleet management, road mapping, and intelligent highway monitoring. GPS can also offer superb facilities for automated vehicle guidance, as described in this article.

You are welcome to discuss and follow up on these articles and ideas in the IEEE ITS Council Newsletter, www.ieee.org/itsc or www.ce.unipr.it/itsc.

For further information and suggestions, feel free to contact me at broggi@ce.unipr.it; www.ce.unipr.it/broggi.

—Alberto Broggi

The Mimics (*M*obile *I*ntelligent *M*odel Incorporating *I*ndependent *C*ontrol and *S*ensing) project is developing a prototype of an intelligent convoy, where a lead car guides a group of driverless cars. The prototype consists of a human-piloted lead car and one autonomous following car. The lead car sends commands and information to the following car. Using this information, the following car can either mimic the lead car's behavior (for example, steer in the same direction) or react to information (for example, activate its brakes if the lead car is going to stop).

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. For this, the cars incorporate standard intelligent transportation systems technology and the latest in European satellite positioning and location technology.

Automating the convoy

For the lead car, we used two different vehicles: a Bombardier electric car and an internal-combustion-engine Comarth S1-50, to compare the different problems involved in each type of vehicle. (Implementing the electronics to handle information from different systems such as braking, steering, and acceleration was much more complicated for the Comarth.) In both cases, we equipped the cars with an Egnos satellite positioning receiver (we'll discuss Egnos in more detail later in this article), a tachometer, an electronic compass, and access to an IEEE 802.11b network.

For the automated follower, we used another Comarth S1-50 (see Figure 1). We added electrically assisted steering, an electronic accelerator, and electrical braking. We also modified the bodywork and dash to hold the sensing and monitoring systems, and rearranged the car's interior components so that the car could accommodate actuators and additional electronics.

The Comarth S1-50 has a factory-equipped control area network (CAN) for controlling the engine's operating parameters. However, the car has no additional electronic exchanges (CPUs for controlling car components) for comfort or passive safety features that a more luxurious car might enjoy. So, we installed our own system of data buses for the necessary additional exchanges and sensors.

To interconnect the microcontroller-based exchanges, we integrated the signals in the car's CAN. An Ethernet network, using a concentrator switch for intercommunication, connects the CPUs managing the high-level control applications.

To connect the CAN and Ethernet network, we used a board incorporating Dallas Semiconductors' TINI (Tiny InterNetwork Interface) microcontroller, which is programmable in Java. The TINI board acts primarily as an intermediary between the high-level control applications and the controllers for the car's low-level hardware (mainly the accelerator, brakes, and steering). It therefore acts as a translator between the Ethernet interface and the CAN bus.

We also installed these sensor and control modules in the car:

 1094-7167/02/$17.00 © 2002 IEEE

Figure 1. The automated Comarth S1-50.

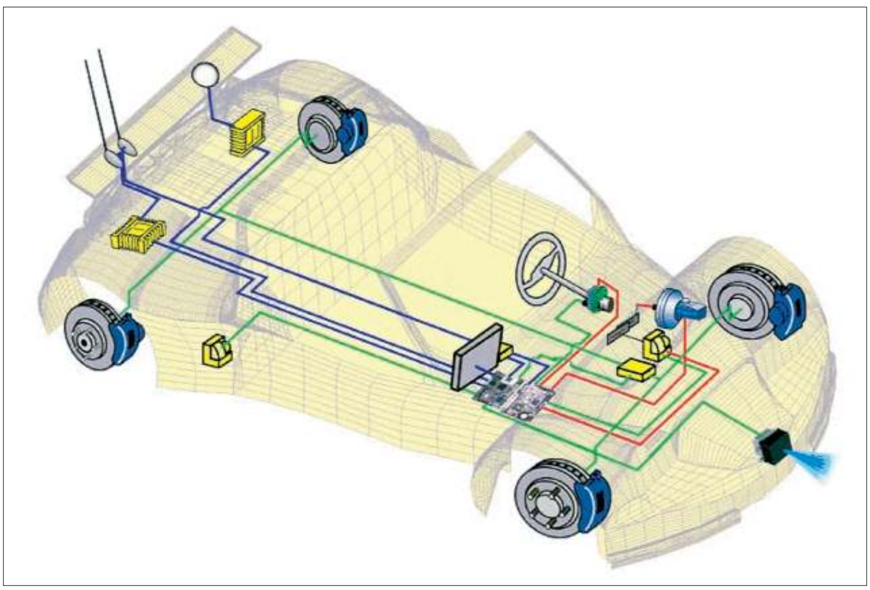

Figure 2. The automated car's interconnections.

- A Novatel GPS receiver with an Egnos corrector
- A Trimble GPS receiver with a Rasant corrector
- An electronic compass with inclinometer compensation
- An odometry acquisition module for the four wheels
- A 77-GHz radar sensor
- A steering control module
- A brake control module
- An accelerator control module
- A principal SBC-P111 control CPU
- An SBC-P111 CPU console with a 12-inch LCD thin-film-transistor screen
- A control module for an alphanumeric LCD
- An access point to an IEEE 802.11 network

Figure 2 shows the car's interconnections.

The GPS receivers, electronic compass, and radar have an RS-232 series interface, so we opted for a direct connection to the SBC-P111 gate. Because the radar did not fulfill the RS-232 standard, an adapter circuit was necessary.

Another important element is the IEEE 802.11 network established between the convoy cars to transmit control and positioning information from the lead car to the following car. In closed-circuit tests (on the university campus and race tracks), we established a third node as a base to receive information from the cars and to control the unmanned car. We set up the monitoring and control network so that it can be used both locally (in the car itself, using a screen and keyboard) and remotely (from any computer with Ethernet). Remote control was limited by the maximum reach of the 2.4-GHz ISM band.

The interchange of control messages and of positioning and state information over Ethernet used UDP connections. Such messages followed a protocol that took into account the need to keep messages from being too large and to not slow down the control cycles, while permitting clear differentiation between the messages.

Adapting satellite data

The European Space Agency's Galileo project (GNSS-2) aims to launch a group of satellites to provide the EU with an advanced positioning and navigation system under civilian control. The system should be operational in 2008.

Gallileo's predecessor, the Egnos project (GNSS-1), will boost the performance of existing GPS and Glonass systems. Geostationary satellites will augment GPS and Glonass signals by sending corrections to Egnos receivers. Egnos is part of the Eurocontrol Agency's Satellite Based Augmentation System project.

Egnos will function like the American Wide-Area Augmentation System. The idea is to replace many of the ground-based radio systems for air traffic control, such as ILS and VOR, thus improving the precision, reliability, and accuracy of GPS and Glonass. Therefore, Egnos will

- Correct in real time the error parameters observed at a network of reference stations situated throughout the cover zone
- Provide worldwide (or at least broad) coverage by means of geostationary satellites transmitting correction signals

The *Egnos System Test Bed*, the Egnos prototype, has been operating since February 2000. The ESTB provides a GPS-

Abbreviations

ABS	antilock braking system	**ILS**	Instrument Landing System
AOR-E	Atlantic Ocean Region-East	**ISM**	Industrial/Scientific/Medical
CAN	control area network	**LCD**	liquid crystal display
Egnos	European Geostationary Navigation Overlay Service	**LPS**	local perceptual space
		Rasant	Radio-Aided Satellite Navigation Technique
ESA	European Space Agency	**RTCA**	originally the Radio Technical Commission for Aeronautics
ESTB	Egnos System Test Bed		
EU	European Union	**SBAS**	Satellite-Based Augmentation System
Glonass	Global Orbiting Navigational Satellite System	**SIS**	Signal in Space
GNSS	Global Navigation Satellite System	**SISnet**	Signal in Space through the Internet
GPS	Global Positioning System	**TINI**	Tiny InterNetwork Interface
HPL	horizontal protection level	**UDP**	User Datagram Protocol
HAL	horizontal alert value	**UTM**	Universal Transverse Mercator
ICAO	International Civil Aviation Organization	**VOR**	Very-High-Frequency Omni-Range

augmentation signal that lets users calculate their position to an accuracy of within a few meters.

A further purpose of Galileo is to make money, so the ESA plans to make the system available for more than just air traffic control purposes. In this context, Mimics evaluates the ESTB's signal by using a Novatel receiver that can process the signal.

To analyze the Egnos data's precision, we placed the Novatel receiver in a static position but set it up as if it were operating in dynamic mode. By transforming the data received to local (Universal Transverse Mercator) coordinates, we assessed the data's dispersion and precision and calculated the horizontal-positioning error. We took care to select a suitable test site, from which both GPS and AOR-E satellites were visible. The navigation positions were registered at 1 Hz.

Figure 3 shows the absolute error and corresponding histograms for the 43,200 measurements made during Egnos correction. The absolute error takes the form of a group of points describing a 6 × 3-meter ellipse. The corresponding histogram shows

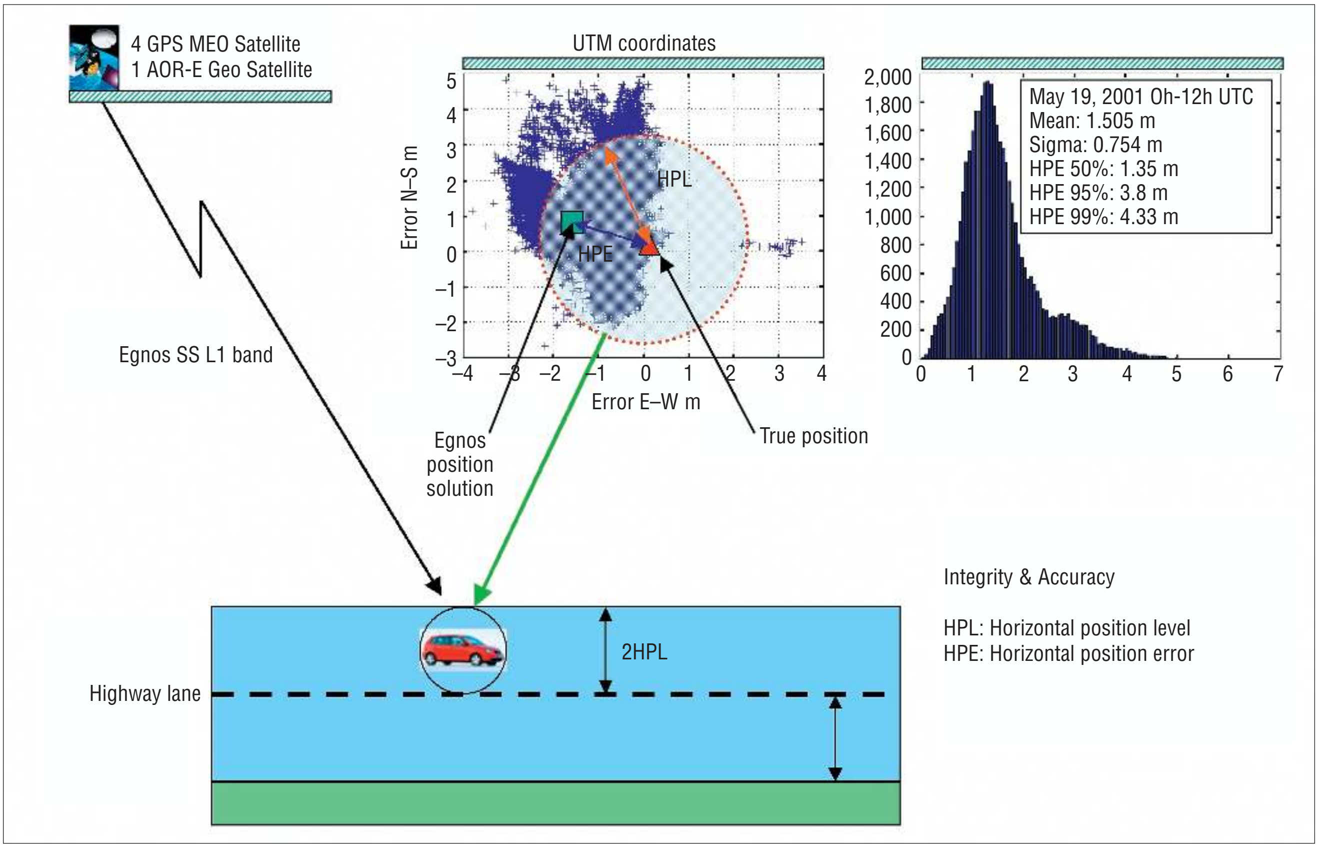

Figure 3. Analyzing the Egnos signal's accuracy (measured for a static point) for the Mimics autonomous car.

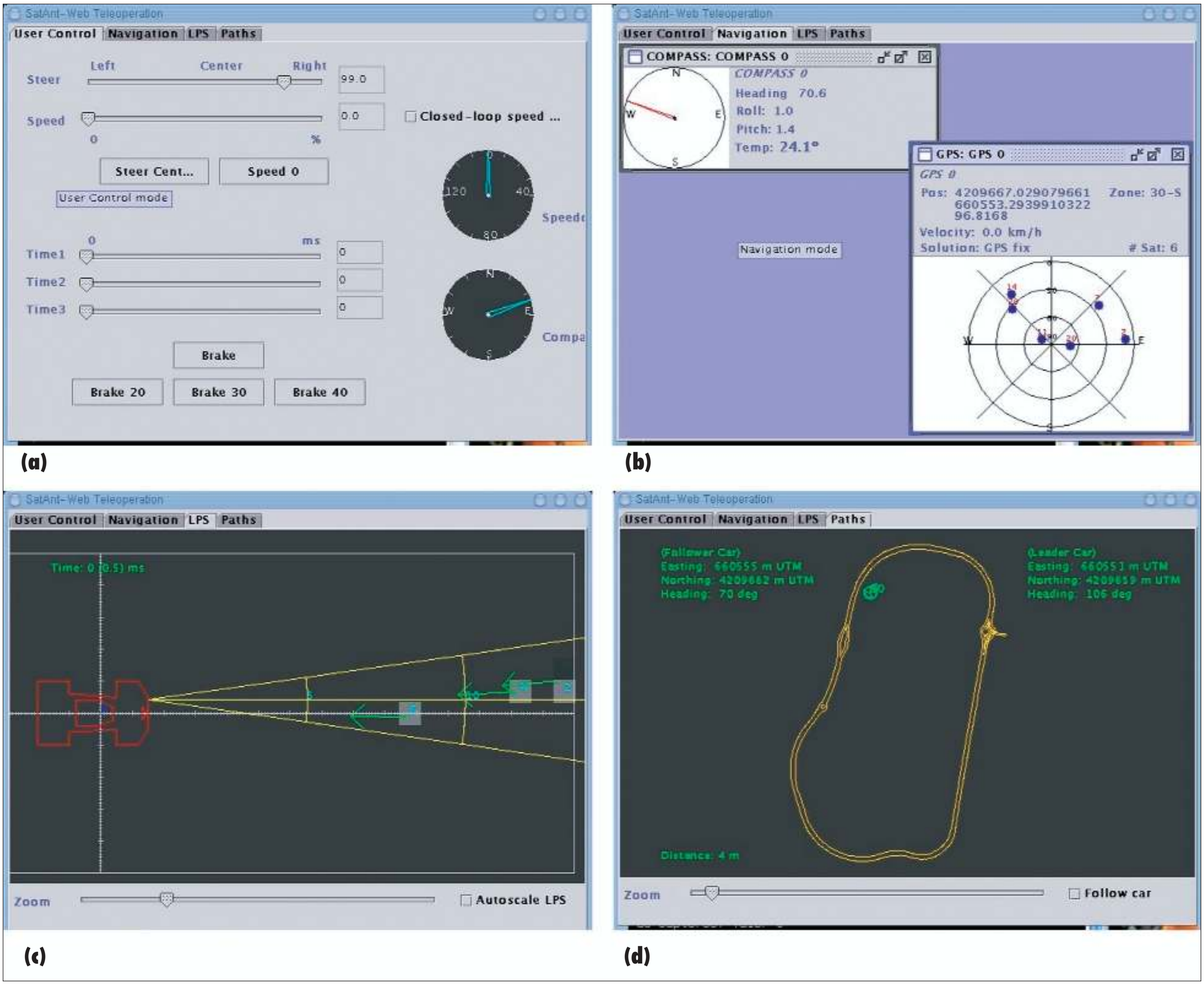

Figure 4. The navigation application: (a) the User Control window; (b) the Compass and GPS windows in Navigation mode; (c) the Local Perceptual Space window; (d) the Paths window.

that the error was approximately 3.8 m in 95 percent of the cases and within 1.35 m in 50 percent of the cases. This is a considerable improvement in accuracy, compared to GPS.

The main problem we observed was poor coverage in built-up areas and tunnels, along with the undesirable propagation of the signal into many dispersed navigation trajectories, both for GPS and geostationary satellites. To minimize the problem of the poor visibility of the AOR-E satellite, the SISnet project provides the option of sending the corrections over the Internet, which can be accessed through Global System for Mobile Communications or General Packet Radio Service technology. We also realized the necessity of redefining the criteria for calculating the horizontal protection level and the horizontal alert value to make this system viable for intelligent transportation systems.

These tests lead us to conclude that using several types of sensors to aid navigation will probably be the best solution for ITS, although cost will be a deciding factor.

Remote monitoring and control

To know the system's state at any given moment, we developed an application for remotely monitoring the car. This application also provides remote control of the car. Figure 4 shows several screens from the application.

The User Control window (see Figure 4a) shows the car's direction (given by the electronic compass) and speed, and provides remote control.

Figure 4b shows the Navigation mode. The Compass window (on the upper left) provides the heading and other data such as inclination (pitch and roll) and temperature. The GPS window (on the lower right) shows the position in UTM coordinates, the speed, the resolution quality, and the number of satellites whose signals are being received. This window can also depict the satellites according to their elevation and azimuth with respect to the car.

The Local Perceptual Space window (see Figure 4c) gives a picture of the space in front of the car, provided by the car's radar.

The Paths window (see Figure 4d) provides a georeferenced map of the zone through which the car is moving. ("Georeferenced" means that we used GPS information to precisely fix the map's coordinates.) It also represents the cars in accordance with the data sent by both cars' localization devices (compass and GPS). In this case, the cars are parked outside the University of Murcia's Information Technology Department. The application also permits zooming to show the position better.

The Mimics project provides a glimpse into the advantages that new technologies offer for road transportation. Mimics has focused on the kinematics of two cars assisted by satellite navigation systems and radar; more research is necessary within the wider framework offered by the concurrence of new information and communication technologies.

After evaluating Mimics' results, we've formed these objectives:

- Evaluate Egnos technology in a real and varied environment. This will include examining Egnos's associated services such as receiving correction signals through the Internet, which should overcome coverage problems in urban areas.
- Investigate how to increase safety through a control architecture that integrates the information received from various sensors to warn drivers of possible anomalous situations.
- Develop an integrated onboard system that manages internal data (CAN bus signals) and external information sources (for example, positioning or navigation information) and that presents information to the user via the in-vehicle screen.
- Discover ways to access information through different telematic services. One way would be to connect a user's PDA to the car's information system, to exchange navigation maps or other useful information.

Achieving these objectives will require 3G wireless networks and specific systems such as DSRC (Dedicated Short-Range Communications) at microwave bands (5 to 18 GHz). Development of new onboard electronic and software radio applications will also help meet these objectives. ■

Further Reading

J. Dahlgren, *ITS Evaluation Website: Report on Activities between October 1998 and July 1999*, Reports to Caltrans 99-C07, Int'l Fuzzy Systems Assoc., 2000.

Draft Standards and Recommended Practices for the Global Navigation System: Satellite-Based Augmentation Systems (SBAS), Appendix B, Int'l Civil Aviation Organization, Montreal, 1999.

ESTB SIS, User Interface Description, GNSS-1 Project, European Space Agency, Toulouse, France, 2000.

A.F. Gómez Skarmeta and H. Martínez Barberá, "A Fuzzy Agents Architecture for Autonomous Mobile Robots," *Proc. Int'l Fuzzy Systems Assoc. World Congress* (IFSA 99), Int'l Fuzzy Systems Assoc., 1999, pp. 713–717.

GPSCard MiLLenium Command Descriptions Manual, v. 4.501, NovAtel, Calgary, Canada, 1999.

N.J. Hotchkiss, *A Comprehensive Guide to Land Navigation with GPS*, Alexis Publications, Leesburg, Va., 1999.

E.D. Kaplan, *Understanding GPS: Principles and Applications*, Artech House, Norwood, Mass., 1996.

Minimum Operational Performance Standards for Global Positioning Systems/ Wide Area Augmentation Systems Airborne Equipment, Appendix A: Wide Area Augmentation System Signal Specification, Document DO-229A, RTCA, Washington, D.C., 8 June 1998.

J.C. Muñoz and C. Daganzo, *Experimental Characterization of Multi-lane Freeway Traffic Upstream of an Off-Ramp Bottleneck*, report UCB-ITS-PWP-2000-13, Calif. Partners for Advanced Transit and Highways, Richmond, Calif., 2000.

The NSTB WAAS: A Real-Time Wide Area Differential GPS Augmentation, Wide Area Differential GPS Laboratory, Stanford Univ., Stanford, Calif., 2001.

S. Shaheen and R. Uyeki, "CarLink Economics: An Empirically-Based Scenario Analysis," *Proc. 7th Ann. World Congress Intelligent Transportation Systems*, Ertico, Brussels, 2000.

P. Tran, J.-S. Wu, and J. Lewwellen, "The Sensitivity of Category I Precision Approach Availability to GPS Satellite Constellation," *Proc. Inst. of Navigation GPS-99*, Inst. of Navigation, Fairfax, Va., 1999, pp. 233–240.

J. Vermeij, A. van den Berg, and R. Farnworth, *Analysis and Validation of GNSS Performance*, Nat'l Aerospace Laboratory, Amsterdam, 1999; www.nlr.nl/public/hosted-sites/satnav/pub-eng.html.

Antonio F. Gómez Skarmeta is an associate professor in the Department of Information and Communication Engineering at the University of Murcia. His research interests are fuzzy modeling and hybrid systems, soft-computing techniques, intelligent systems, intelligent agents, distributed services, network protocols, and security. He received his MS in computer science from the University of Granada and his PhD in computer science from the University of Murcia. Contact him at Facultad de Informática, Apartado Correos 4021, 30001 Murcia, Spain; skarmeta@dif.um.es.

Acknowledgments

The Spanish Ministerio de Fomento and Ministerio de Ciencia y Tecnología (PROFIT) are financing this project. The authors thank Pedro Tena for his comments and valuable support.