SIMULATED GPS SPACE SEGMENT AND SENSOR FUSION FOR LANE-LEVEL ACCURATE LOCALISATION

The fusion of GPS signals and vehicle dynamics data makes it possible to localise vehicles with lane-level accuracy. As this sensor fusion is safety relevant, the functionality and robustness of all systems based on it should be verifiable as early as possible. IPG Automotive has developed a space segment with virtual GPS satellites for the CarMaker vehicle dynamics simulation. Integrated error models simulate GPS and sensor weaknesses in order to enable realistic, virtual road tests.

AUTHORS

DIPL.-ING. TOBIAS BUTZ
is Application Engineer, Test Systems & Engineering at IPG Automotive GmbH in Karlsruhe (Germany).

DIPL.-ING. UWE WURSTER
is Head of Test Systems & Engineering at IPG Automotive GmbH in Karlsruhe (Germany).

PROF. DR.-ING. GERT F. TROMMER
is Professor at the Institute for Theoretical Electrical Engineering and System Optimisation of the KIT, Karlsruhe Institute of Technology (Germany).

DIPL.-ING. MATTHIAS WANKERL
is a Research Fellow at the Institute for Theoretical Electrical Engineering and System Optimisation of the KIT, Karlsruhe Institute of Technology (Germany).

MOTIVATION

The growing number of onboard sensors in the vehicle will further increase safety, efficiency and comfort. New, more powerful assistance systems [1] can be achieved through multiple use of sensor signals and sensor fusion. The GPS receiver used for localising the vehicle plays an important part in this context. Due to the limited resolution and potential sources of errors the GPS (global positioning system) does not suffice as the sole data base to realise functions requiring lane-level accurate localisation of the vehicle. In addition, GPS localisation may fail due to satellite masking. However, when GPS data are combined with driving dynamics information from inertial sensors (INS) the strength of one sensor can compensate for the weakness of the other sensor. Apart from higher accuracy, additional redundancy is gained this way.

Advanced chassis control systems, driver assistance systems and predictive operating strategies can use this information base. As soon as safety-relevant systems are involved exacting demands in terms of functionality and robustness have to be met. Due to the complexity of networked systems and sensor fusion it is in the developer's interest to test the fusion architecture of a GPS-based and INS-based solution at an early stage, before the hardware is available. IPG Automotive has successfully addressed this requirement in its Space-Segment Model which simulates a segment of the sky with GPS satellites on their orbits around the earth. When the CarMaker vehicle dynamics simulation is extended by this model virtual road tests of functions/systems based on GPS-INS sensor fusion are made possible. Extensive error models allow the creation of test scenarios including realistic error modes.

FUNCTION AND GENERATION OF THE SPACE-SEGMENT MODEL

❶ shows the components of the GPS and the space segment it contains. The Space-Segment Model assumes the same function in the virtual road test. It provides simulated navigation data. In the test, the user segment shown in ① is represented by the simulated GPS receiver in the virtual vehicle. The control segment which in the real-world GPS monitors the constellation of the satellites (clock times, orbital data) is represented in the test by integrating current navigation data.

Whereas in the physical GPS the position and clock errors of the receiver are calculated based on the reception time of the satellite signal and the pseudo-ranges of at least four satellites, the position data of the virtual vehicle are known. Consequently, calculation differs in this case, ❷. Firstly, the position of the satellites in the coordinates system of the transmission time – the actual Space-Segment Model – must be calculated.

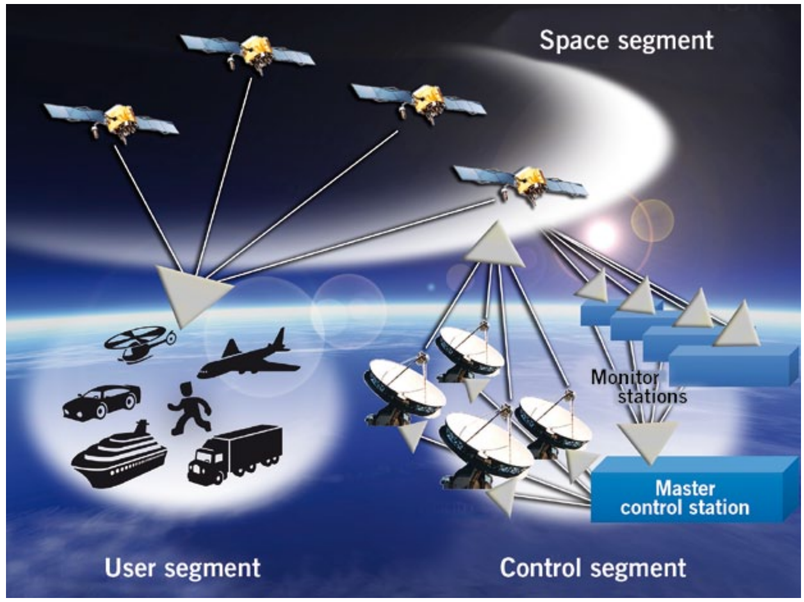
This part of the modelling is complex, as the position of a satellite in the coordinates system at the transmission time differs from its position at the reception time. The magnitude of the difference depends on the runtime of the signal, which depends on the position of the satellite. Consequently, the calculation is done as an iterative process of six single steps, some of which are repeated, until both the satellite position at the reception time of the signal and the signal runtime have been determined with sufficient accuracy. Subsequently, the data about the satellite positions and speeds required for the virtual road test are generated and handed over to the simulated GPS receiver.

As the satellite constellation of the model depends on place and time both must be defined prior to starting a virtual road test. This is done in a graphic user interface (GUI), ❸, where the elevation angle of the satellite up to which it is still "visible" by the GPS receiver is defined as well. Masking, for instance by high buildings or bridges, can also be activated in the GUI with the integrated masking model.

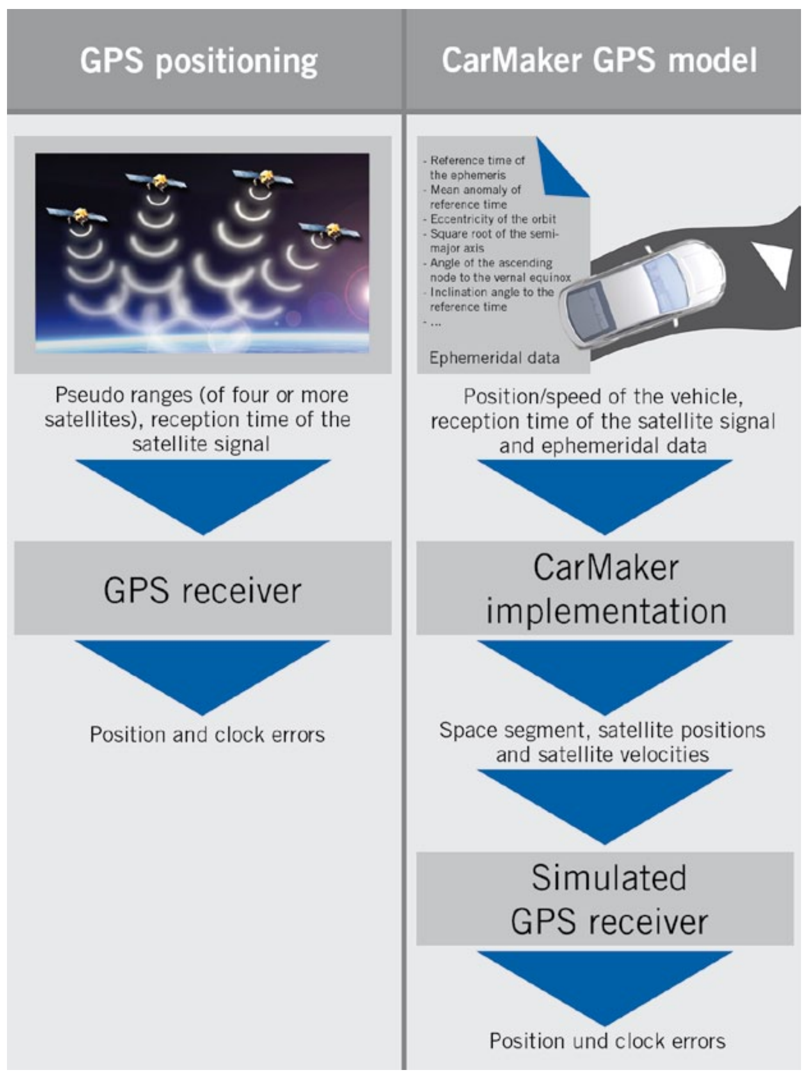
MODELLING OF REAL ERRORS AND INTERFERENCES

In order to obtain valid statements about a sensorfusion architecture it does not suffice to run the test in ideal conditions. In real-world driving, they are only available for a limited period of time as well. In fact, a sensor fusion of GPS and INS is influenced by a relatively large number of error sources and interferences. Consequently, the fault tolerance of the function to be tested in the vehicle is an important criterion for the subsequent safety and reliability of the function. Therefore, to achieve a simulation that is as realistic as possible, error models for the GPS sensors and the inertial sensors,which are operated via the GUI, have been implemented in the Space-Segment Model. ❹ provides an example overview of potential GPS error sources. As individual interferences and errors can be purposefully defined and activated the influences may be analysed both discretely and in terms of interactions. In case of malfunctions a drill-down to the root cause is possible. The fact that this analysis option is run in consistent external conditions makes the virtual road test a highly powerful tool.

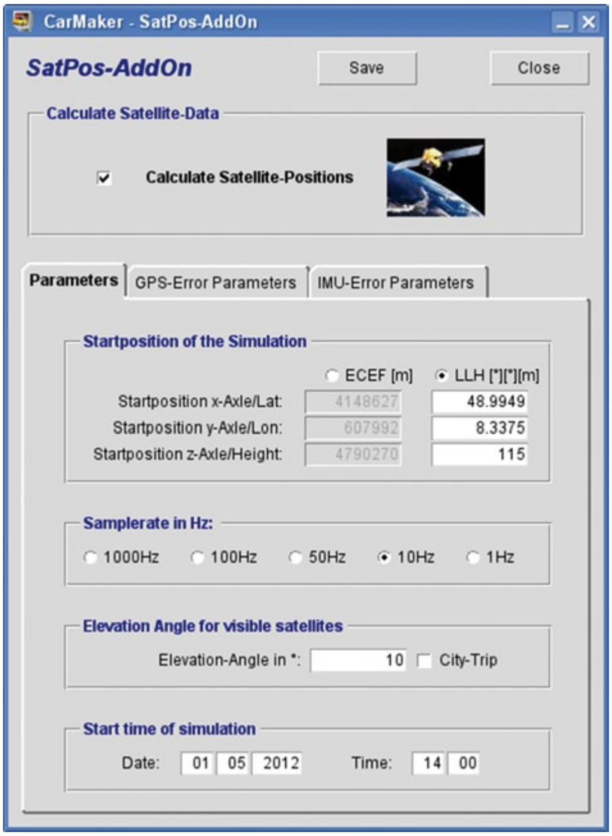
When looking at the various errors and interferences, it becomes obvious why GPS and INS complement each other well. The GPS sensor is relatively slow but on the whole delivers long-term accuracy whereas the inertial sensor delivers information on highly dynamic motions but only short-term accuracy due to its drift. Therefore, the sensor fusion provides a dynamic position signal in combination with long-term accuracy.



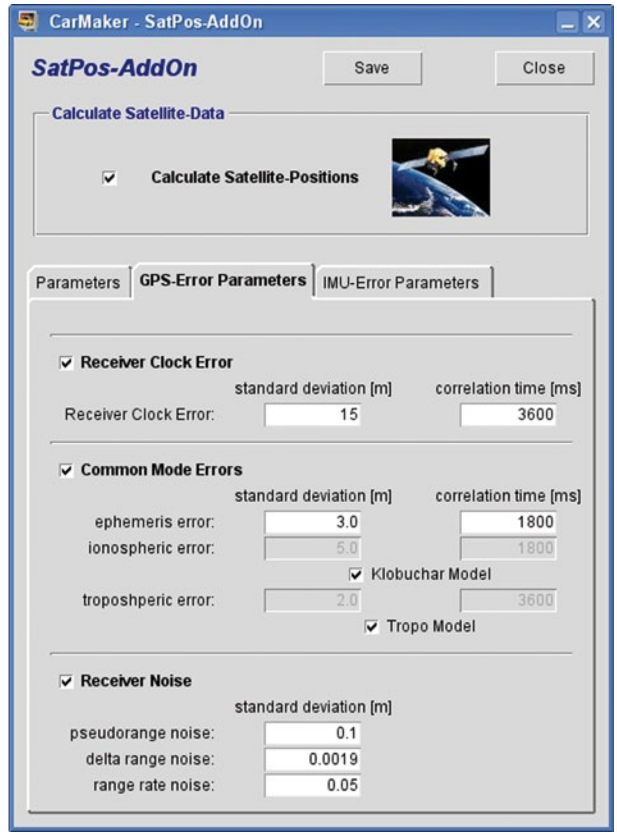
❶ The components of the Global Positioning System



❷ Comparison between normal GPS localisation and generation of the Space-Segment Model



❸ GUI for parameterisation of the data for a virtual road test



❹ GUI for parameterisation and activation/deactivation of GPS error sources

MODELLED GPS ERRORS

An overview shows the potential influences a real-world GPS sensor is exposed to. In addition to receiver clock errors, they include inaccuracies in the satellite orbit plus atmospheric influences and receiver noise. Inaccuracies in the satellite orbit (ephemeridic errors) are caused by the influence of gravitational forces. Such excursions from the required orbit are monitored on the one hand and corrected on the other. The exact orbital data are provided to the receivers as part of the ephemeridic data. Therefore, the influence of this error is a relatively minor one. More difficult to control are ionospheric influences (50 to 1000 km altitude) and tropospheric influences (up to 10 km altitude). In this case, the errors are due to runtime delays and the ray curvature caused by the free electrons in the ionosphere or air pressure and temperature in the troposphere. In addition, there is a random error that is caused by the measurement noise of the GPS sensor. In the GUI both types of errors, in other words random and time-correlated errors, can be discretely parameterised.

MODELLED INERTIAL SENSORS ERRORS

Inertial sensors are subject to errors and interferences as well. Bias errors, scale factor errors and sensor noise exert influences in a unit consisting of acceleration and rotation rate sensors (inertial measurement unit, IMU). The errors are also parameterised in the GUI. Bias is used to specify the origin distortion of the sensor and its apparent rotation rate in °/s or °/h or its apparent acceleration in mg at rest. The scale factor error quantifies the ppm rate of the difference between the rise in the sensor signal and the actual increase of the rotation rate. The sensor noise – depending on intensity – influences the quick acquisition of dynamic motions whereas the other errors tend to have a longer-term effect.

The sensor units can be divided into quality classes, depending on the extent of the errors. In entertainment electronics low-cost IMUs are often sufficient whereas more powerful and more precise IMUs are required in the vehicle. Cost-intensive inertial sensors for military and aviation applications form the top quality class. An exemplary sensor type with characteristic errors has been set up for each quality segment:

- Entertainment electronics: MPU-6000 by InvenSense
- Automotive: MMQ50 by Systron Donner
- Aerospace/military: SDI500 by Systron Donner.

To give the user maximum flexibility, the errors of other IMUs can be modelled in the GUI as well.This allows individual sensor clusters to be tested in terms of their suitability for a specific GPS and INS fusion architecture.

APPLICATION EXAMPLES

There are numerous possible uses for GPS/INS-based integration and fusion algorithms with lane-level accurate localisation such as lane-keeping and turning assistance, collision protection systems and many others. Combined with digital map material and car-2-car communication, sensor fusion for one enlarges the acquisition range of the sensors in the vehicle and for the other allows the position of the vehicle in which it operates to be transmitted to the receiver with the resultant higher accuracy.

In addition to safety-critical applications, the application fields for sensor fusion with GPS and INS components include efficiency improvements. A predictive driving strategy for example, which helps to avoid unnecessary load alterations due to road topography, intersections and traffic signs, benefits from lane-level accurate localisation. Hybrid electric vehicles (HEV) in particular profit from such a driving strategy in terms of optimising the alternation of the internal combustion engine and the electric motor or generator [2].

The spectrum of using GPS/INS sensor-fusion goes far beyond the passenger car sector though. It can also be used, for example, to develop new functions for commercial vehicles where the combination of GPS and INS chiefly serves to increase the productivity of work processes. Precision farming as a current trend in agriculture is a concrete example.

SUMMARY AND OUTLOOK

Whereas the CarMaker vehicle dynamics simulation previously consisted of the virtual elements of vehicle, driver, road, traffic, digital maps and environment/buildings, the Space-Segment Model now adds a GPS satellite system. In virtual road tests using this extended solution not only the functionality and robustness of fusion algorithms with GPS content can be tested, but also valid statements be made about the impact of this function on the full vehicle. Consequently, comprehensive analyses and evaluations of fusion algorithms are made possible long before the system is confirmed for production. In addition to validating its functionality and robustness, the possibility to perform a detailed error analysis contributes to early validation of system maturity.

RERERENCES:

[1] Butz, T.: Implementierung eines Satelliten-Space-Segment Moduls in IPG CarMaker zur KFZ basierenden Integration. Diplomarbeit, Karlsruher Institut für Technologie (KIT), Institute of System Optimization, 2011

[2] Schick, B.; Leonhard, V.; Lange, S.: Vorausschauendes Energiemanagement im virtuellen Fahrversuch. ATZ 04/2012, 114. Jahrgang

[3] Katriniok, A.; Reiter, M.; Abel, D.: Kollisionsvermeidung mittels Galileo. Wiesbaden: ATZelektronik, Jahrgang 6, Nr. 1, 2011

[4] Vietinghoff, A. von: Nichtlineare Regelung von Kraftfahrzeugen in querdynamisch kritischen Fahrsituationen. Dissertation, Universität Karlsruhe (TH), Fakultät für Elektrotechnik und Informationstechnik, 2008

[5] Schramm, D.; Hiller, M.; Bardini, R.: Modellbildung und Simulation der Dynamik von Kraftfahrzeugen. Berlin, Heidelberg, Springer, 2010