49. Internationales Wissenschaftliches Kolloquium
Technische Universität Ilmenau
27.-30. September 2004

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# A VIRTUAL VALIDATION ENVIRONMENT FOR THE DESIGN OF AUTOMOTIVE SATELLITE BASED NAVIGATION SYSTEMS FOR URBAN CANYONS

**Abstract**

Satellite based automotive navigation systems use range information to navigation satellites like GPS, Glonas and in the future Galileo to determine their location on earth. Range to satellites is determined by measuring the time difference between signals send by satellite and received by the automotive navigation system. To determine a 3D-position at sufficient accuracy with non-atomic clocks requires receiving at least 4 satellite signals at a time.

Typically up to 6 satellite signals are available in flat rural environment, providing sufficient information to determine the navigation position at an accuracy of 3 meters or less. However, in urban canyons, particulary between high rising buildings, in tunnels or on bridges, less than 4 satellite signals are available, at times non. The accuracy of automotive satellite based navigation systems in these environments depends on applicability and effectiveness of different techniques to reduce the navigation position error.

It is time consuming and costly to evaluate different navigation system designs for the variety of different urban environments. This paper describes a developed virtual validation environment for analysis and test of automotive navigation systems. In section 1, different techniques are introduced, how the accuracy of satellite based automotive navigation systems can be improved in different urban environments. Section 2 describes an universal virtual validation platform for navigation system designs, including a data driven 3D-scene, a navigation system model and a navigation satellite model. In section 3, the design of a specific navigation system examplifies the usage of the developed validation environment, by showing the influence of map matching on the navigation filter accuracy. Finally, section 4 draws conclusion about achieved results.

## 1 GPS Error Mitigation Techniques

On the basis of different developed techniques, it is in principle possible to enhance satellite based navigation systems in such a way, that even in critical regions, where less than 4 or non satellite signals are available, a high accuracy can be achieved.

Navigation filters, especially the Kalman filter, are the most common technique to reduce navigation position errors. The Kalman filter provides an extremely effective and versatile procedure for combining noisy sensor outputs to estimate the state of a system with uncertain dynamics. In connection with satellite based navigation systems, the noisy sensors may include GPS receivers, but may also include speed sensors and time sensors (clocks). The system state includes the position, velocity, acceleration, attitude and attitude rate of a vehicle. Additionally, the system state may include "nuisance variables" for modeling correlated noise sources and time-varying parameters of the sensors, such as scale factor, output bias, or frequency. Uncertain dynamics of the system state are given by unpredictable disturbances of the host vehicle and possibly unpretictable changes in the sensor parameters. To enable an optimum estimation of the system state, based on an optimum combination of all sensor information, the Kalman filter maintains two types of variables. First, the estimated state vector includes all variables of interest (e.g., position, velocity, etc.), additional "nuisance variables" and the state variables. Secondly, a covariance matrix defines a measure of estimation uncertainty. To obtain a new estimation of the system state, the Kalman filter uses an optimum weighting matrix, the Kalman gain, for combining new sensor data with a prior estimate [2].

Differential GPS (DGPS) is a technique to reduce the navigation position error by using an additional reference GPS receiver. In doing so, the exactly measured position of this reference station is compared to the positioning data, calculated by its GPS receiver. Resulting pseudorange corrections are transmitted in real time to mobile user's receivers. Provided that a user's receiver is able to process DGPS signals, the corrections are applied to the calculation of its own position [2, 3].

In opposition to navigation position errors, caused by missing satellite signals, reception of too many signals can also lead to high inaccuracies, in case of one satellite signal has been received twice or more. The ground and other objects (e.g., buildings, hills, etc.) near a GPS receiver antenna can easily reflect satellite signals, resulting in one or more secondary propagation paths. These reflected signals have always a longer propagation time and can significantly disturb the original direct path signal.
Such multipath errors cannot be reduced by DGPS, because signal reflections depend on the local geometry near each receiver antenna. But there are two other techniques to mitigate multipath effects. Spatial processing uses antenna design to isolate the direct path received signal. On the other hand, time domain processing operates only on the mulitpath-corrupted signal within the receiver [2].

Using an additional electronic vector map, especially in connection with route guidance systems, navigation system accuracy can be improved by the so-called map matching technique. Route guidance systems use electronic vector maps to calculate an optimum route from a start point to a desired destination, if necessary with alternative routes and automatic recalculation when the course deviates from the predicted route. In doing so, necessary information about position and motion of the vehicle are given by GPS or DGPS, wheel rotation sensors, magnetic compass and rotational speed sensors. If all of these information are available, the measured position can be combined with the covered route and projected onto the electronic vector map [3].
Map matching is only effective, while the underlying vector map is up-to-date. In cases where a predicted route cannot be used, for instance, if streets are blocked for construction, the navigation position error increases significantly, until an alternative route has been calculated. These effects can only be avoided, if updated electronic vector maps are online available and can be downloaded, for instance, using an UMTS connection.

In environments, where a limited reception of GPS satellite signals is a priori not preventible (e.g., tunnels), so-called pseudolites are deployed. To augment the GPS constellation, pseudolites are ground-based transmitters that can be configured to emit GPS like signals. With respect to the benefits of pseudolits, there effectiveness depends on a number of technical issues, like signal power level and data rate, deployment requirements, and user antenna location and sensitivity [1].

All described techniques use additional information to augment satelltite based navigation systems and/or navigation errors are reduced by including suitable mathematical error mod-

els. In this context, most of these techniques are a mixed blessing. If additional information are not available or erroneous and/or mathematical error models are incorrect, these techniques usually lead to a larger navigation position error than basic inaccuracies, caused by missing or disturbed satellite signals.
According to this, applicability and effectiveness of these techniques within a specific environment depends on if appropriate preconditions are satisfied in this environment.

## 2 Virtual Validation Environment

Due to the complexity of the described approaches for satellite based navigation systems, it is too expensive in time and costs to validate such systems only at a late design stage on the basis of hardware-in-the-loop tests. To enable an efficient validation at an early design stage, a computer-based simulation environment for validation of different navigation system designs has been developed.

Basically, this virtual validation environment consists of a data driven 3D-scene, a navigation system model and a navigation satellite model.
The virtual 3D-scene, implemented on the basis of OpenGL®, simulates representative environmental characteristics (e.g., streets, buildings, tunnels, etc.) in order to evaluate satellite based navigation systems. For a multifunctional usage with different scenes, all scene data (e.g., street map data, location and height of buildings, etc.) are loaded in XML format from an appropriate scene file.
Within a specific 3D-scene, an interactive controllable automobile can be "driven" through the virtual world, for instance, to validate the satellite signal acquisition time of a GPS receiver for full updates at street intersections, where 4 satellite signals are available. During simulation, this car is controlled by a Tcl/Tk widget, including a steering wheel and a combined slider for speed and direction.
Optionally, received as well as blocked satellite signals can be visualized while the car is "driven" through the streets, and in connection with the navigation filter, its uncertainty ellipse and a transparent "ghost" car can be displayed on the estimated car position.
The software tools MLDesigner and SatLab are used to implement the navigation system model and the navigation satellite model. MLDesigner is a design tool for modeling, simulation and analysis of complex systems [4]. SatLab is an animation and analysis tool for wireless mobile communication and navigation systems [5]. For data exchange, both software tools use the so-called SAPM (SatLab Access Protocol Module) interface.
The navigation system model consists of different interconnected MLDesigner blocks, implementing functional parts (e.g., navigation filter) of a specific satellite based navigation system design. Additionally, special interface blocks are used for communication with SatLab, the virtual 3D-scene, and the Tcl/Tk car controller widget.
For various simulation scenarios, the navigation system model defines also a set of system parameters, which can be individually set for a specific simulation. This set of system parameters comprises the simulation time scale, simulation date and time, the scene XML file and the location of the virtual 3D-scene on the world map. In connection with a specific navigation system design, additional system parameters can be defined, for instance the initial state of the navigation filter.
The navigation satellite model, implemented in SatLab, animates the 24 GPS satellites, according to their defined orbits. Each simulation step, depending on the specified time scale, the positions of the satellites are updated in SatLab and all satellites are determined, which are currently "visible" from the specified scene location. The positions of those satellites can be used as input for a specific navigation system design.

Figure 1 shows a snapshot of the complete virtual validation environment with the navigation system model, the navigation satellite model, a virtual 3D-scene, and the Tcl/Tk car controller widget.

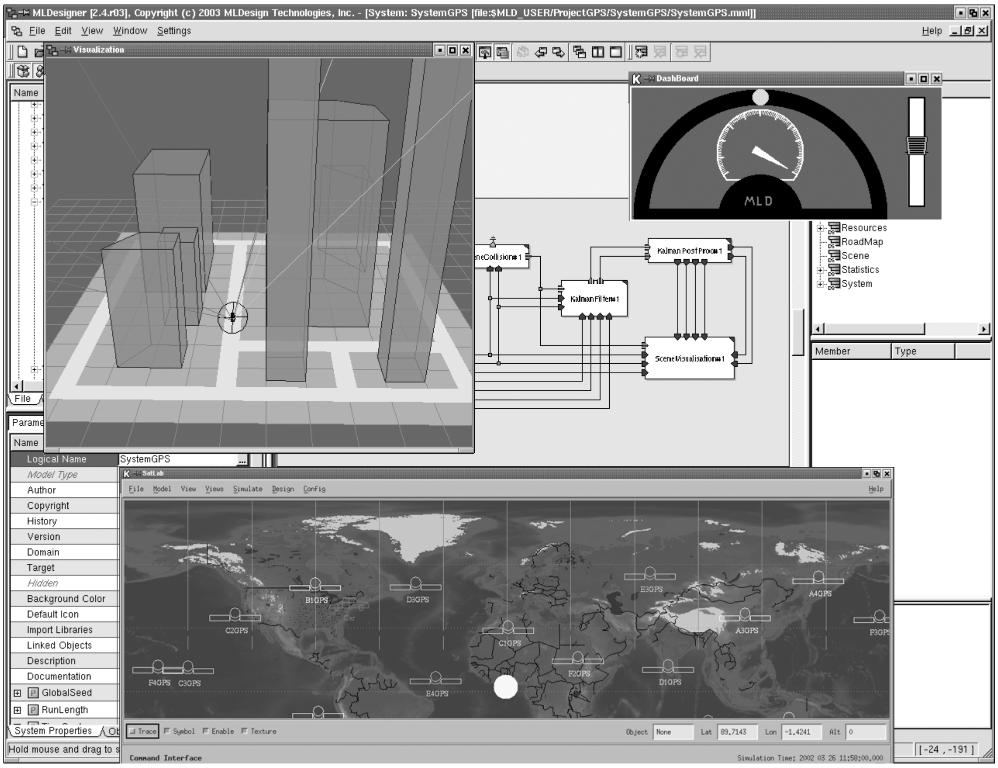



Figure 1: Virtual Validation Environment

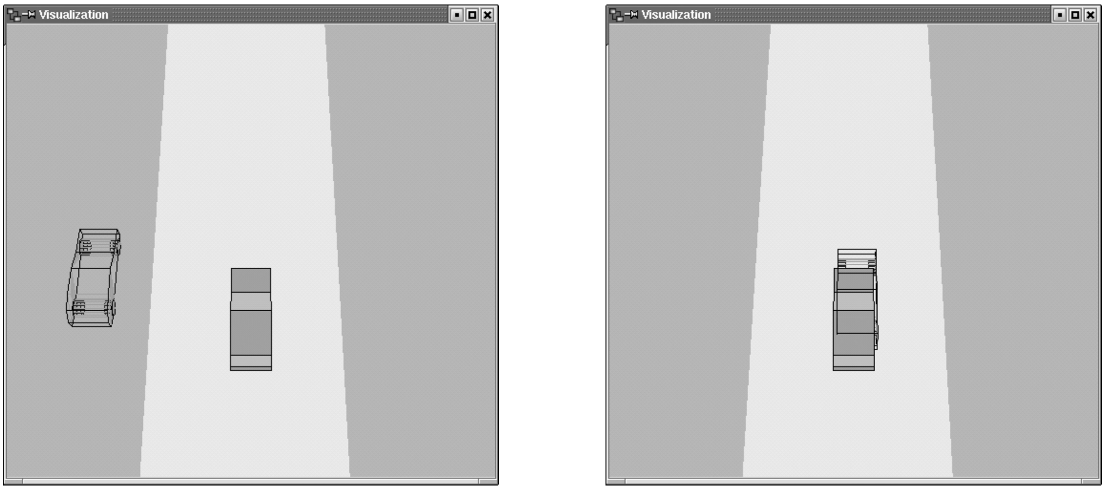
## 3 Example

As an example for the usage of the developed virtual validation environment for navigation system designs, this section describes a scenario to test the influence of map matching on the navigation filter accuracy.

During simulation, the virtual car is "driven" through a 3D-scene with high rising buildings. These buildings are used to simulate blocking of signals from global "visisble" satellites. For simplification, satellite signals, whose direct path is blocked by buildings, are not reflected and consequently not received by the car. Mulitpath effects are not considered in this example.
The underlying navigation filter is implemented as a Kalman filter, used to determine an optimum estimation of the car position, in cases when less than 4 satellite signals are received by the car. For map matching, an additional system parameter specifies, if information about the street map is used by the Kalman filter or not.

For each simulation step, the example navigation system model works as follows:
First, the navigation satellites are updated in SatLab and a list of all currently global "visible" satellites is determined. Next, all satellites, whose signal is blocked by buildings, are removed from this list. The positions of the remaining satellites are used by the Kalman filter to determine an optimum estimation of the car position. In case map matching is enabled, additional information about the street map is used for position estimation. Finally, the 3D-scene is updated and the transparent "ghost" car is displayed at the estimated car position.

Figure 2 shows the influence of map matching on the Kalman filter accuracy, when the car passes through a critical scene region, where many satellite signals are blocked by buildings. If no additional information about the street map are used by the Kalman filter, as displayed in figure 2(a), the estimation is highly inaccurate and the position of the "ghost" car can even be off the street. On the other hand, if map matching is enabled, as displayed in figure 2(b), the Kalman filter estimation is much more accurate and the position of the "ghost" car is always within in the current street segment.




(a) without map matching

(b) with map matching

Figure 2: Map Matching Influence

## 4 Conclusion

The simulation environment, presented in this paper, enables an efficient validation of satellite based navigation systems at an early design stage. Using this virtual validation environment, different approaches for improvement of automotive navigation systems can be modeled and simulated in MLDesigner. In doing so, required GPS satellite data are automatically given by an associated SatLab model. Simulation results are directly displayed within an XML-based virtual 3D-scene. An example navigation system design has shown, how the virtual validation environment can be used to evaluate the effectiveness of map matching in regions, where satellite signals are blocked by high rising buildings.

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**Trademarks:**