Combined GPS-Galileo positioning for Location Based Services in urban environment

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Abstract

Position determination is one of the key-elements of Location Based Services (LBS). One popular approach to positioning for LBS is using a Global Navigation Satellite System (GNSS). With such a system, three-dimensional positioning is available anywhere on, and above the Earth, in principle without any local or regional infrastructure. On the other hand, as satellite based radio positioning relies on relatively weak signals, indoor positioning is a hard job, in particular without any aids. Also urban environment can pose a serious challenge to satellite based radio positioning. In this contribution, the availability of today's GPS positioning is analyzed using a three-dimensional model of the town of Delft in the Netherlands.

This contribution starts with a demonstration of the range of position accuracy using today's Global Positioning System (GPS). Different modes of kinematic and real-time positioning will be shown using a trial with a boat on the Schie-canal between Delft and Rotterdam. Standard GPS single point positioning with a simple handheld receiver offers 5-10 meter accuracy. With corrective information received from a geostationary satellite, the European Geostationary Navigation Overlay Service (EGNOS) comes down to the 1-meter level. Global Differential GPS, with a dual-frequency user receiver, reaches decimeter level accuracy, but currently only after a considerable initialization period.

Although accuracy is one of the main issues regarding GNSS, it is clear that availability is another point of concern with the LBS context. If you cannot rely on your positioning device all the time, the usage of the service will be limited. Therefore it is of great importance that within five years from now, the European Galileo system is expected to get into orbit, next to the US GPS. Doubling the satellite constellation is expected to be beneficial to position availability. The impact of the advent of Galileo on this aspect is analyzed as well, using the same urban environment.

1 Introduction

Position determination is one of the key-elements of Location Based Services (LBS). A Global Navigation Satellite System (GNSS) is an attractive way for worldwide positioning. Two importance aspects of such a positioning component in an LBS application are accuracy and availability. Depending on the mode of GNSS positioning the accuracy may range from 10 meter to a few centimeters. The availability is in particular of importance in urban environments. Due

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to obstructions of satellite signals by buildings, the ability to determine one's position is known to drop significantly in cities.

In the next section this paper first presents an overview of the accuracies that can be achieved with different modes of GPS positioning. Section three briefly discusses the LBS markets that are emerging with the advent of the Galileo positioning system. The availability of GNSS systems in urban environments is analyzed in section four. Using the (planned) orbit information of both GPS and Galileo satellites and a detailed 3D city model it is investigated to what extent the availability of GNSS positioning will improve once GPS and Galileo can be utilized simultaneously.

2 Positioning with GPS

This section intends to give a partial overview of the current range of GPS positioning modes. With a focus on position-*accuracy*, practical results are shown for standalone GPS, Wide Area Differential GPS (WADGPS) with EGNOS, and Global Differential GPS, the latter offering decimeter accuracy, in real-time, seamless all over the world.

The results shown - for the different modes of positioning – pertain to *real-time* operation (contrary to long site occupation times and post-processing of measurements). The results follow either from processing just a single epoch of measurements, or are the actual output of a recursive-processing scheme (for instance a running Kalman filter).

Kinematic experiment

All examples shown in the sequel are the results of a kinematic positioning experiment carried out by the Mathematical Geodesy and Positioning section in Spring 2003, with a small boat on the Schie-canal between Delft and Rotterdam in the Netherlands.

Figure 1: *The small boat, with several GPS receivers and antennas on-board, all collecting measurements simultaneously, was cruising the Schie-canal forth and back for an almost 3-hours period. The boat is depicted here at the little village De Zweth.*

For each of the examples in the following, GPS range measurements have been taken during the same 3 hours time span, at a 1 second interval. Generally, between 5 to 8 GPS satellites were used for the position solution.

For all receiver antennas on board, a so-called ground truth trajectory was established with centimeter accuracy, using both classical survey measurements on the boat - after the experiment - when it was moored again at the quay in Delft, and, high-precision GPS position solutions for three of the (high-end) receivers. The latter solutions were computed from dual-frequency precise carrier-phase measurements, with cycle ambiguities fixed, in differential mode using a nearby reference site (at 3-5 km distance).

Position accuracy measures

The position solutions obtained in the various cases are differenced with accurately known reference positions (ground truth trajectory). Subsequently, the 95th percentile value is determined empirically for the position differences, over the full time span, in each coordinate direction (each time in a local North-East-Height system); 95% of the position samples are within the values given. The 95th percentiles refer to the horizontal position error (North and East component together) and to the (absolute) vertical position error. For an introduction to position accuracy and its measures, the reader is referred to (Tiberius 2003).

2.1 Standalone GPS

Based on pseudorange code measurements of a single receiver, the position can be determined anywhere on Earth. Only the satellite signals are needed. The satellite position and clock error are obtained from the broadcast navigation message. This mode of positioning is referred to as single point positioning, or absolute positioning (sometimes also as point positioning). No auxiliary means are needed, as with Differential GPS.

In the kinematic test with the boat, a simple commercial handheld receiver was used (a Garmin GPS76 with a small external GA-27C antenna). Figure 2 shows the position error in all three components as a function of time.

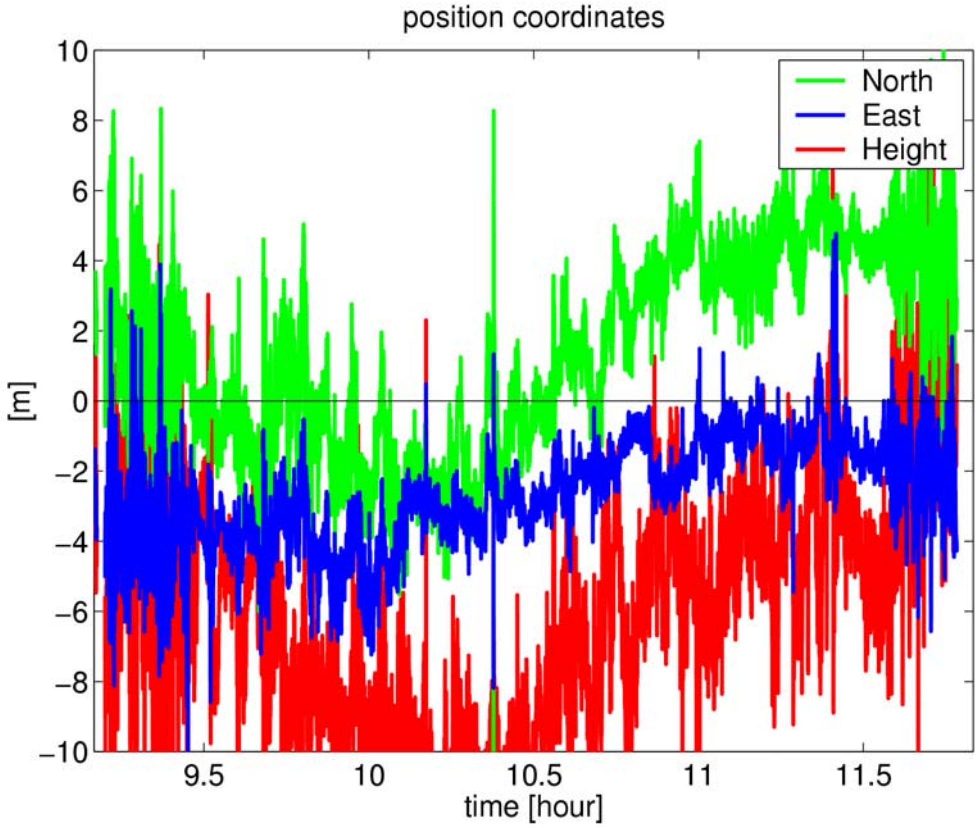

Figure 2: *Standalone GPS positioning errors.*

In particular the Height component is severely biased (mean is – 6 meter). The accuracy lies in the 5-10 meter range, see table 1.

mode	horizontal	vertical
standalone GPS	6.20	11.52
WADGPS	1.19	2.34
Global DGPS	0.34	0.60

Table 1: *Position accuracy of standalone GPS positioning, Wide Area Differential GPS positioning with EGNOS and Global Differential GPS. Given are 95th percentiles in meters.*

For more information about the standalone GPS positioning results, see (Le, Tiberius 2003).

2.2 Wide Area Differential GPS: EGNOS

Augmentation systems to GPS can improve the accuracy of standalone positioning. The European Geostationary Navigation Overlay Service (EGNOS) will, in the near future, as a Wide Area Differential GPS, cover the whole of Europe. Similarly, the FAA is developing the Wide Area Augmentation System (WAAS) in the US. Positioning with EGNOS is based on

Differential GPS, but instead of a single reference station, an integrated *network* of reference stations is deployed. The correction signal is broadcast from geostationary satellites. The user needs in principle additional equipment to receive the EGNOS signal, though there are already (relatively simple and cheap) handheld receivers on the market, which are WAAS (and EGNOS) capable.

In February 2000, the EGNOS System Test Bed (ESTB) became operational, and results of this prototype EGNOS are shown below. These results, *single frequency*, pertain to instantaneous positioning, once the current message with correction data and integrity information has been acquired. EGNOS is expected to become operational in 2004.

In the kinematic experiment with the boat, a high-end NovAtel OEM3 receiver with Leica AT502 survey antenna was used. Table 1 lists the position accuracy figures and figure 3 shows the position error in all three components as a function of time (the time series start late by some 50 minutes, due to unavailability of the ESTB signal).

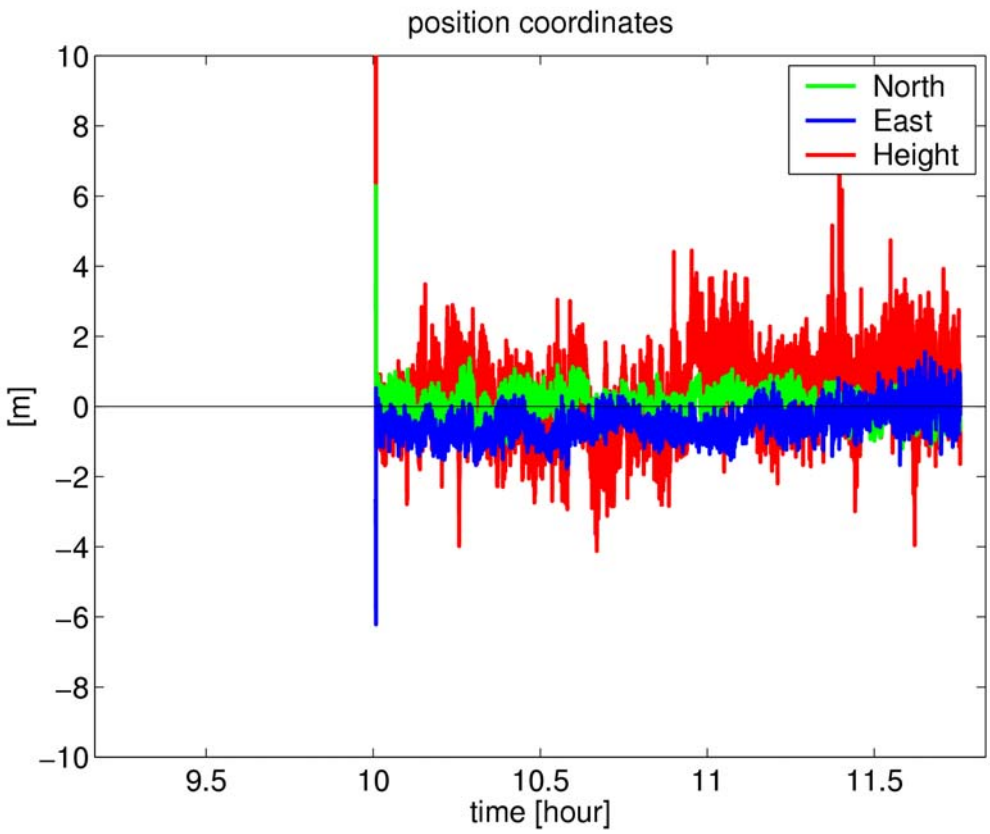

Figure 3: *Wide Area Differential GPS position errors with EGNOS.*

2.3 Global Differential GPS

Global Differential GPS (GDGPS) offers yet a higher class of accuracy, seamless all over the world. The results shown below are obtained with Internet-based Global DGPS (IGDG), which relies on a subset of NASA's Global GPS Network (GGN) with currently some 40 real-time stations. The data of these stations result in rapid service (real-time) GPS satellite orbits and clocks. Differences with the current GPS broadcast ephemeris are disseminated over the Internet in real-time (and commercially via geostationary satellites) and allow users, anywhere on Earth (i.e. truly global), to exploit the highly accurate satellite ephemerides in real-time.

The user needs to be equipped with a *dual-frequency* receiver (using the GPS L1 and L2 signals) delivering pseudorange code and carrier phase measurements. In addition a sophisticated modeling of these measurements is required. At present, dual frequency receivers are expensive, primarily because the current GPS L2 signal is not directly accessible for civil users, and the size of the high-end market is relatively small. The situation might change with the modernization of GPS (with a new civil signal on the L2-frequency and the first satellite to be launched in 2004) and the advent of Galileo. Dual-frequency receivers are likely to become much more affordable.

In the kinematic experiment with the boat an Ashtech ZXII-3 dual-frequency receiver was used, together with a choke-ring antenna. Table 1 lists the position accuracy figures and figure 4 shows the position error in all three components as a function of time (the initialization period, first 40 minutes, is left out of consideration for the accuracy figures). With Global DGPS decimeter accuracy can be achieved, though it should be noted that with a moving receiver, as in this kinematic experiment, currently a long initialization (convergence) time is needed (20-30 minutes) with continuous lock to the satellites' signals, to eventually reach this accuracy. Experimental results and further references on Global DGPS can be found in (Kechine et al. 2003).

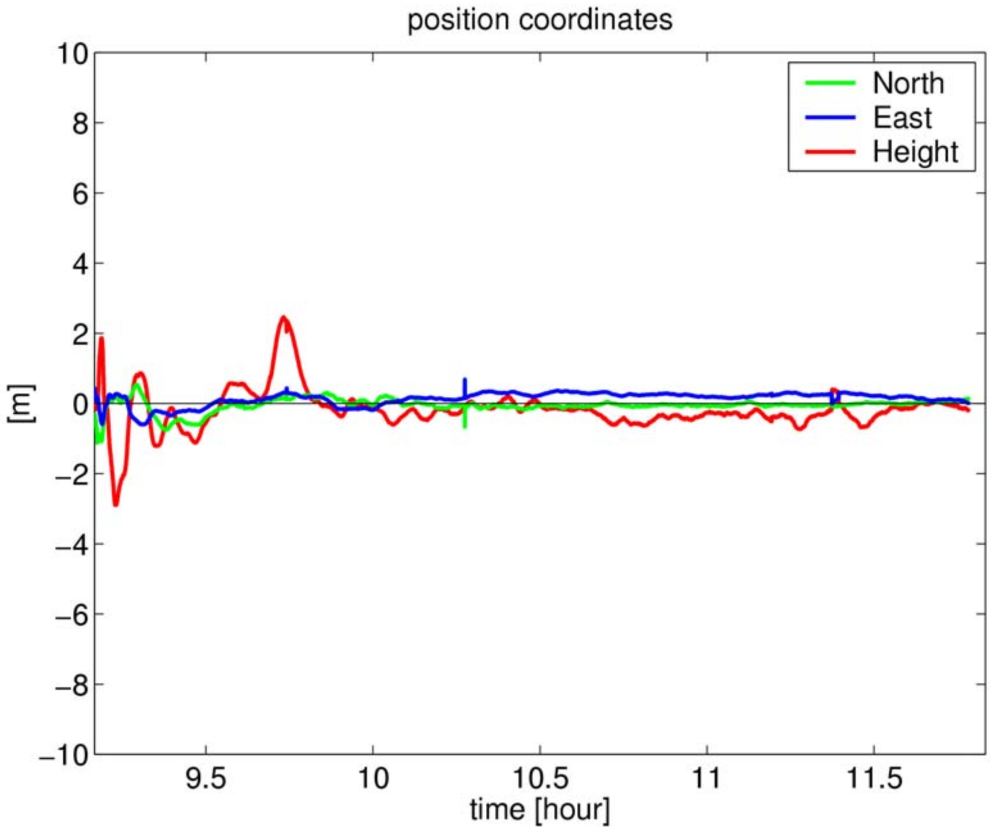

Figure 4: *Global Differential GPS position errors.*

3 Applications and examples

The 5-10 meter accuracy of GPS has pushed the development of the most important and well-known LBS: standalone in-car navigation systems. The (sub-) meter accuracy offers field inventory of all kinds of objects with hand-held Personal Digital Assistants (PDA) equipped with a GPS-module. The highest accuracy on centimeter-level is needed for Augmented Reality systems, in which information (as text and images) about the environment is projected directly within the view-field of the user. Although GPS can reach that level of accuracy other techniques could be applied besides GPS alone. An overview of tracking possibilities is given in (Zlatanova and Verbree 2004).

The current US GPS has been developed in a military context. The European Galileo, to be deployed by 2008, is set up primarily for civilian users. When integrated with telecommunication lots of new developments and services with Galileo in the area of LBS are foreseen. The LBS market is currently segmented into four categories:

- Information and navigation services, which provide data directly to end-users, in particular destination location and criteria for journey optimization.
- Emergency assistance, which provide the location of mobile users in case of distress and need for assistance.
- Tracking services, which provide location data.
- Network related services, where knowledge of user position improves communication services.

4 GNSS position availability

Compared to other positioning sensors for LBS, for instance using radio-signals for mobile communication of Wireless Local Area Networks (WLAN), a GNSS has the advantage of offering worldwide coverage. On the other hand, its weakest property is the requirement of, in principle, direct lines of sight to the transmitting satellites, which can be hard to realize particularly in urban environment, where typically most of the LBS applications will be used.

One cannot always take measurements to determine whether or not a GNSS is available within urban areas. One has to realize that visibility of the satellites is not only determined by the location of the observer and obstructions around him, but also by the moment of observation as the satellites are in orbit. Besides, the actual observation of the availability of GPS during a day at or nearby a busy road-crossing is impossible at all because of the traffic.

Simulation is the answer to these limitations. But simulation requests a proper representation of the reality, both of the space-segment as for the Earth-surface. The actual orbits of the GPS are known by the almanac, but in comparing Galileo and GPS the nominal constellation of GPS is put side by side with the (proposed) orbits of Galileo. We have calculated the elevation and azimuth angles for the 24 GPS and the 27 Galileo satellites for each minute during a full daytime for the test-area in Delft, at 52 degrees Northern latitude in the Netherlands. At a fixed location on Earth, the geometry of both GPS and Galileo basically repeat after 24 hours.

The old city of Delft has very narrow streets with built-up areas of around 8-10 meters, with famous Dutch roof shapes. A partial area of the city is modeled in three dimensions by airborne laser-altimetry. A typical example of this area is shown in figure 5.

Figure 5: *The 'Oude Delft' with the 'Old Church'.*

4.1 Creation of a three-dimensional city model by airborne laser altimetry

To make a realistic estimation of the GPS/Galileo availability an accurate three-dimensional model of the urban environment is required. Since a few years high resolution airborne laser scanners have become available (Baltsavias, 1999). The dense point clouds that can be produced by these scanners allow a semi-automatic extraction of building models. For 3D city modeling, laser scanning has become an attractive alternative to mapping in stereo photographs (Brenner and Haala 1998, Vosselman and Dijkman 2001).

To obtain the 3D model of a part of the city of Delft, data acquired with the TopoSys I scanner was combined with the cadastral data with all parcel boundaries. The parcels were labeled by hand in three different categories: building, street and canal. For modeling the buildings each parcel was treated individually. The strategy followed was to split each parcel into segments such that the point cloud within each segment can be represented by a simple roof shape, like a flat roof, gable roof, hip roof or gambrel roof. The segmentation was done by hand after an interpretation of the laser scanner data that is presented to the operator in different representations. Figure 6 shows the grey value encoded heights of the point cloud together with a perspective view on the point cloud that can be rotated interactively.

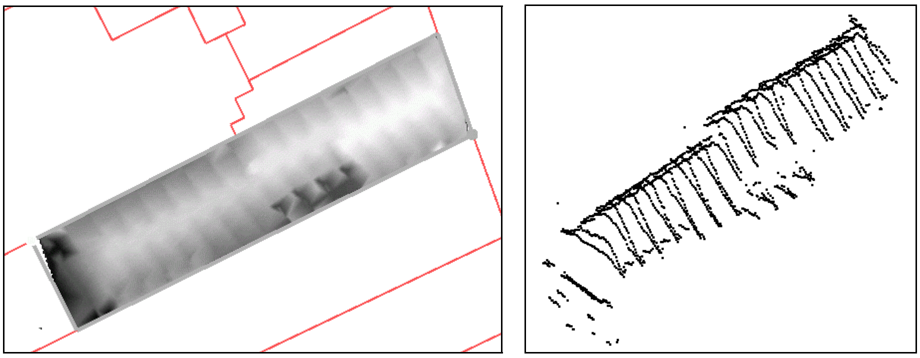

Figure 6*: Two representations of the laser data within a parcel used to decide on the optimal segmentation into segments.*

Figure 7 shows the segmented parcel and the building model that is reconstructed by fitting gable roof models to the point clouds in the different parcel segments. In this case the ridge orientation of the middle roof has a small error. This was caused by a small misalignment between two overlapping strips of laser data. In general, this procedure, however, allows a rapid 3D modeling of the buildings. The city model used in this project and shown in Figure 8 was reconstructed in about four hours.

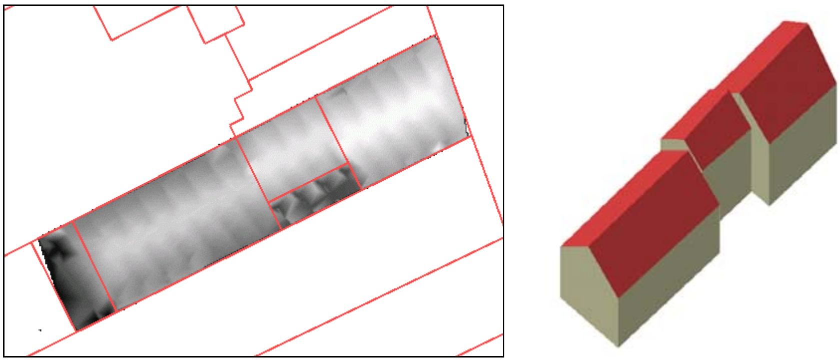

Figure 7: *Segmented parcel and the reconstructed roof models.*

The street surface of the city model was reconstructed automatically by filtering the point clouds that were located within the street parcels. Morphological filtering was applied to distinct between ground points and points on vegetation, cars, fences, and other objects. The water level in the canals was also reconstructed from the laser data by selecting the height corresponding to the first peak in the height histogram of the laser data (Vosselman 2003).

4.2 Representation of the ground surface

The 3D-city model of the old town of Delft is built up by a polygonal representation of the canals, the streets and the roofs. The quaysides and the walls - the connections between the streets and the canals at one hand and the connection between streets and the roof tops at the other - are thought to be vertical and modeled as vertical polygons. The visibility calculation however is based on a triangulated irregular network (TIN) that does not allow vertical polygon constrains. The solution to that problem is found in a minimal negative buffering of both roofs and canals polygons by 10 centimeters. These datasets are the input for the surface model of this part of Delft represented by a TIN. A height-rendered image of this TIN is shown in figure 8.

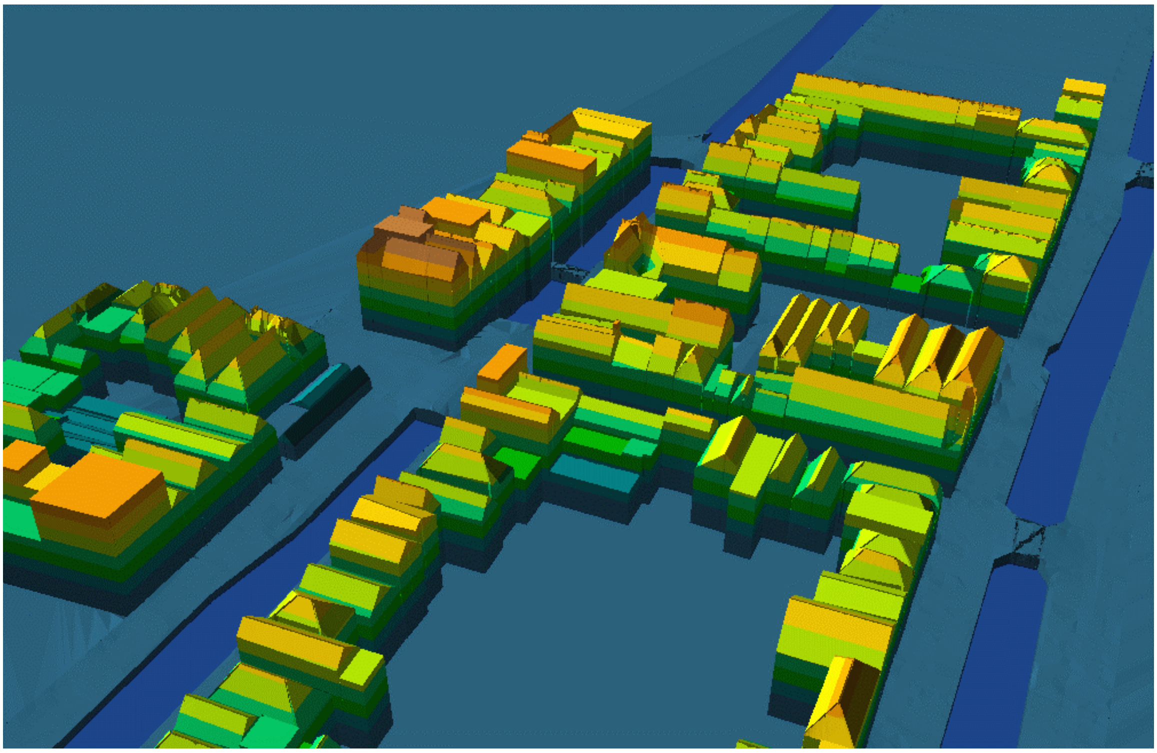

Figure 8: *Triangulated Irregular Network, rendered by height.*

4.3 Calculation of visibility and availability

Visibility Calculation – the Algorithm

The actual visibility calculation is performed within the GIS-package ArcView 3.2a with the extension 3D Analyst. The high-level scripting language Avenue allows fast prototyping of the algorithm with a proper visual feedback of the results within both 2D and 3D scenes.

The simulation of the availability of GNSS consists of two algorithms. The first one calculates the total of targets (satellite positions at a certain time) seen from the observation point by:

```
Count = 0
for each aTarget 'possible observable satellite
  if (aTIN.LineOfSightsAsShapes (anObserver, aTarget,
      ListOfShapes) = True) then
    Count = Count + 1
  end
end
```

Satellite signal propagation is assumed to take place along geometric straight lines. The request `aTIN.LineOfSightsAsShapes` returns not only whether or not `aTarget` is visible from `anObserver` across `aTIN` Surface, but also returns aListOfShapes containing `theObstacelePointZ` and the visible or invisible parts of the profile line. See figure 9 for the visual feedback of this calculation, with red the GPS visibility and within purple the Galileo visibility.

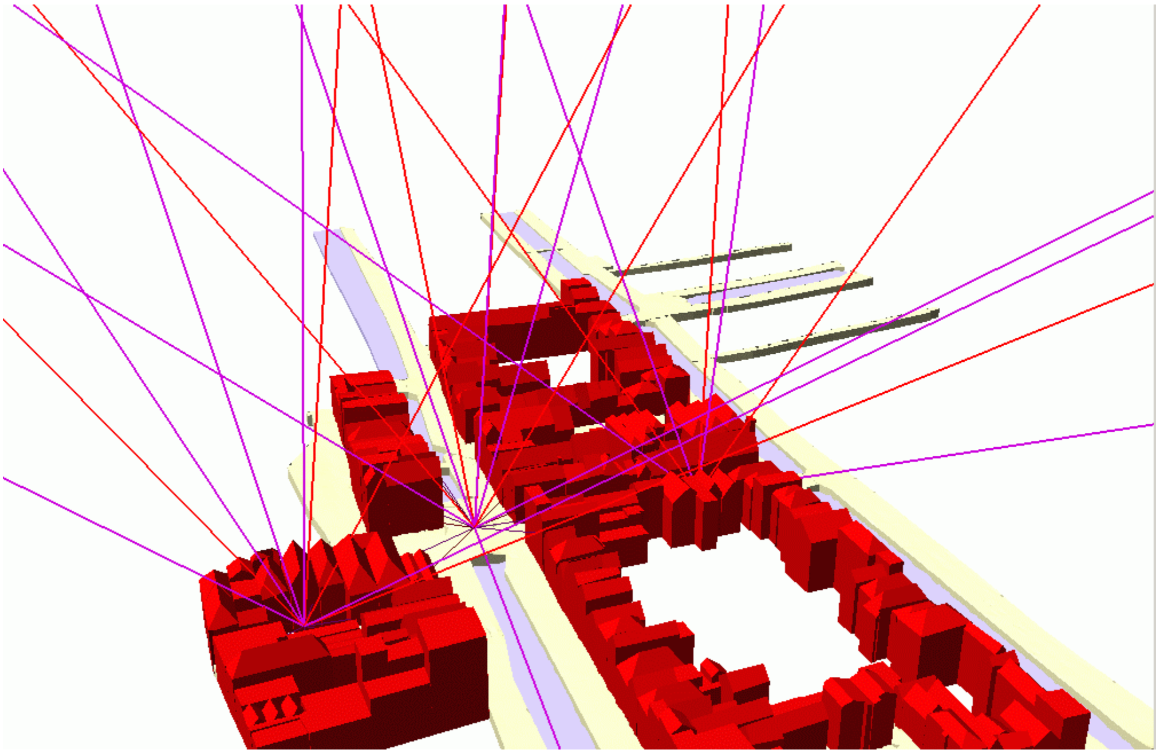

Figure 9: *Some examples of visibility of GPS and Galileo.*

Availability algorithm

The second algorithm calculates the availability of 'enough' satellites during a day time. We have chosen about 50 test observer points, with a height of 1.80 m above street-level. For each of these observer points the total number of visible satellites during a day time is calculated. During a day time means 60*24 = 1440 different constellations for both GPS and Galileo. Each Target (24 GPS satellites and 27 Galileo satellites) within these constellations is checked by the request: `aTIN.ObscuresTarget (anObserver, aTarget).`

For GPS and Galileo alone observing four satellites simultaneously is the minimum for a position fix, without any preliminary knowledge as a known height. In combination of GPS and Galileo this requirement for position availability holds true, but this demand can be extended with at least three GPS and two Galileo or two GPS and three Galileo satellites. Availability is analyzed here regardless the actual geometry of the visible satellites, which can have a large impact on the eventual position accuracy.

The percentage of 'valid' cases gives an indication of the availability of GPS, Galileo and the combination of both within urban areas. The percentage of availability is indicated by the legend as given in figure 10. The results of the test are shown within figures 11 (GPS), figure 12 (Galileo), and figure 13 (Combination).

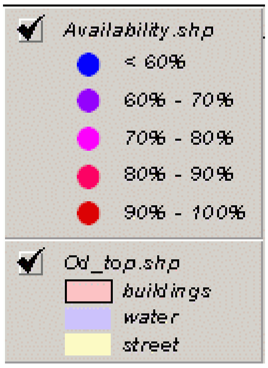

Figure 10: *Legend visibility (Blue – Red: <60% - 100% availability).*

Figure 11: *Availability GPS during a day time.*

Figure 12: *Availability Galileo during a day time.*

Figure 13: *Availability of GPS and Galileo combined during a day time.*

4.4 Simulation of GNSS availability - Conclusions

Out of these figures it can be concluded that the coverage of GPS alone is not sufficient within urban areas. But for navigation purposes it has to be stated that the visibility on street crossings is far better than within the street lanes. And decisions where to go are made at crossings. Besides, car navigations systems use map-matching and auxiliary sensors to keep the car on track. A second consideration should be made upon the required visibility of four satellites. If the height is known and steady (as in the streets) a position fix can be calculated out of the measurements to three visible satellites. This will improve the availability map considerably.

The calculated availability for Galileo alone is better than for GPS. The amount of proposed satellites (27 for Galileo compared to 24 for GPS) is due to this result. Again, the results will improve when relaxing the demand of four visible satellites to three.

The combination of GPS and Galileo is very promising. Not surprisingly with 51 satellites to choose from. Not all are above the horizon, but it is clearly shown that - besides very narrow streets - the availability of the combination is nearly 100%. This result is however a little optimistic, because we have not taken into account the obstruction by trees and obstructions other than buildings. As a compromise it is to be noted that both for Galileo and GPS the plain nominal satellite constellation was used. For GPS there are usually a few redundant operational satellites, and also Galileo is planned to have active spare ones.

Acknowledgements

Contributions to the examples of various modes of GPS positioning by colleagues Anh Quan Le, Rien Kremers and Maxim Kechine at the Mathematical Geodesy and Positioning section are greatly appreciated.

The laser altimetry data used in this project was acquired by Aerodata Int. Surveys using the TopoSys I scanner and processed by TopoSys GmbH. Kadata B.V. provided the cadastral data. The authors would like to thank all companies for their contributions.

Finally we would like to thank Elfriede Fendel for the review of this paper.

Biography

Edward Verbree holds an MSc in Geodesy from the Delft University of Technology. From 1997 he is member of the scientific staff of the section GIS-technology headed by prof.dr. Peter van Oosterom. His PhD research is on 3D topographical modeling and applications.

Christian Tiberius has a background in geodesy. He received his PhD degree from the Delft University of Technology in 1998 for his thesis on ‘Recursive data processing for kinematic GPS surveying’. Currently he is an assistant professor with the Mathematical Geodesy and Positioning section of prof.dr. Peter Teunissen. He is involved in several areas of GNSS positioning research as carrier phase ambiguity resolution, data quality control, analysis of geodetic-grade equipment pseudorange and carrier phase measurement noise, and evaluation of various modes of positioning and approaches of data processing.

George Vosselman is professor of Photogrammetry and Remote Sensing at the Delft University of Technology since 1993. He obtained his Ph.D. at the University of Bonn in 1991. His research interests are in image understanding, 3D reconstruction, laser ranging, and geographical information. He is chair of the ISPRS working group on 3D Reconstruction from Airborne Laser Scanner and InSAR data.

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