Performance of High-Sensitivity GPS for Personal Navigation at Schiphol Airport, The Netherlands

Dennis Odijk
Delft Institute of Earth Observation and Space Systems
Delft University of Technology, The Netherlands
Phone: +31 15 2787012, Fax: +31 15 2783711, Email: d.odijk@tudelft.nl
Frank Kleijer
OTB Research Institute for Housing, Urban and Mobility Studies
Delft University of Technology, The Netherlands
Phone: +31 15 2785154, Fax: +31 15 2784422, Email: f.kleijer@tudelft.nl

ABSTRACT

Schiphol Airport, located near Amsterdam, The Netherlands, is one of the main airports in Europe. To improve many of the daily processes taking place at this airport, positioning and/or navigation information is becoming more important. For example, both travellers and airline companies are interested in navigation of the traveller to his gate. Also security personnel and rescue teams may benefit from accurate navigation information. In this paper it is investigated whether GPS can provide accurate and reliable information for airport location-based services. Despite Schiphol Airport is a densely built area, we demonstrate by means of Lines-Of-Sight computations that for the almost complete outdoor area of Schiphol Airport sufficient GPS satellites can be received for positioning. This is also confirmed by collection of real GPS data outdoors in the urban Schiphol area. However, since many location-based services require positioning information indoors as well, tests with High-Sensitivity GPS (HSGPS) receivers were conducted inside the terminal buildings (departures and arrivals) as well as at two piers. With respect to performance of HSGPS we focused on two aspects, i.e. the accuracy and the availability of the position fixes. As a main conclusion it follows that indoor GPS positioning is not possible at many locations at Schiphol Airport, since the GPS signals get (strongly) attenuated or even blocked owing to the coating applied in the windows.

1. INTRODUCTION

Schiphol (or Amsterdam) Airport in The Netherlands is one of the main airports in Europe. At this airport, Location-Based Services (LBS) are becoming more and more important; not only for the Schiphol Group but also for the airlines (especially the home carrier KLM). For many of these LBS reliable and accurate positioning information is very crucial.

Positioning at Schiphol Airport may be done for various purposes: for navigation, tracking and tracing, or just for recording coordinates. It may take place both indoors in the terminal buildings and outdoors on either landside or airside. Accurate positioning may lead to more efficient airport procedures. Personal navigation is beneficial for e.g. security personnel, authority officers, fire fighters, and emergency services. Related to this is vehicle positioning, since many of these persons move around at Schiphol Airport. Personal as well as vehicle positioning of passengers may be beneficial for the airlines in order to anticipate on their time of arrival (tracking), but also for the passengers themselves (navigation). Tracking of luggage, both inside the terminal and on the platform, is important for logistic reasons, whereas tracking and tracing of airplane materials is especially important because of their high value. Registration of incidents is important to improve security.

For many of the above given applications it turns out that a position accuracy of 10 m is sufficient. Since this requirement corresponds to the typical accuracy of GPS standalone positioning (at least outdoors), in this paper it is investigated whether or not GPS positioning is suitable for LBS at Schiphol Airport. It is difficult to predict the performance of GPS positioning beforehand, because of Schiphol's urban environment on the one hand (especially near the terminals), and on the other hand, GPS signals are also required to be received indoors. The indoor reception of GPS signals is possible thanks to the (still ongoing) development of High-Sensitive GPS (HSGPS) chips. In addition, the use of GPS is very attractive, since no additional infrastructure is required (which is a great advantage with respect to other techniques), and GPS receivers are relatively cheap and small.

In this paper the performance of GPS at Schiphol Airport is examined by means of several experiments. In these experiments a HSGPS receiver is used to collect GPS data inside some main buildings of Schiphol Airport: Schiphol Plaza (shopping area and Arrivals), the Departure buildings and the C- and D-piers. Central issues with respect to the performance of indoor GPS positioning are *availability* and *accuracy*:

- Is the receiver able to receive a sufficient amount of signals to compute a position at all?
- Is this position of sufficient quality?

Next to indoor positioning, the performance of GPS outdoors in the urban Schiphol area is relevant as well for LBS applications. As outdoor GPS measurements at airside (along the piers) were not yet obtained at the time of writing this paper, the outdoor GPS experiments are restricted to the areas in front of Schiphol Plaza (at ground floor) and in front of the Departures areas (at the first floor). However, in order to get insight in the availability of GPS signals in the urban environment of Schiphol Airport in general, for a grid of points comprising the outdoor area of Schiphol Center, Lines-of-Sight (LOS) have been predicted

based on almanac data for the (positions of the) GPS satellites and using a three-dimensional city model of Schiphol Airport. As an outlook, the availability outdoors of future combined GPS and Galileo (based on constellation data) is predicted as well.

This paper is set up as follows. In Section 2 the availability of GPS (and Galileo) is predicted for outdoor Schiphol Center based on LOS computations. Section 3 describes the results of the indoor and outdoor GPS experiments, while Section 4 ends the paper with the conclusions.

2. GNSS AVAILABILITY OUTDOOR AT SCHIPHOL AIRPORT

A 3D city model of Schiphol Airport containing rooftops of terminals, piers, parking garages and other buildings was received from the Schiphol Group and used as basis for the GNSS availability predictions. Assuming a flat terrain for Schiphol Airport (which is close to reality for most of the area), for each point of a rectangular grid with 10-m spacing it was evaluated whether the (direct) LOS to a sufficient number of satellites for a position fix could be computed, taking into account the possible blocking of the LOS by obstructions extracted from the city model. For the positions of the GPS satellites almanac data were used, while for the Galileo

Figure 1. View on the urban area of Schiphol Airport

constellation a created almanac was used, see Verhagen (2002). These LOS computations have been carried out for a time span of 10 days (96 epochs with 2.5 hour interval) during December 2005. This 10-day interval has been chosen as to have a more or less homogeneous coverage of GPS (and Galileo) satellites. In the LOS computations an elevation cut-off of 10 deg was used. In the case of GPS or Galileo-only, a minimum of 4 satellites is enough to compute a position fix. However, in the combined GPS+Galileo case it is assumed that at least 5 satellites are needed, to account for a time offset between GPS and Galileo (although in practice this might not be needed if this offset is sufficiently small or when information on this offset can be retrieved externally).

Figure 2 shows the availability for the GPS-only and GPS+Galileo cases. Only if an availability lower than 95% was reached a red area was plotted. In black are shown the building blocks as well as areas for which no availability was computed because the cell centres fell inside building polygons. From these plots we can conclude that for the areas around the piers over 95% availability can be reached even in the GPS-only case. Only around high buildings with more than one blocking side availability is lower. In the GPS+Galileo case less than 95% availability is only reached for locations between (high)

buildings. More details on the prediction of GNSS availability in urban areas can be found in Kleijer et al. (2007).
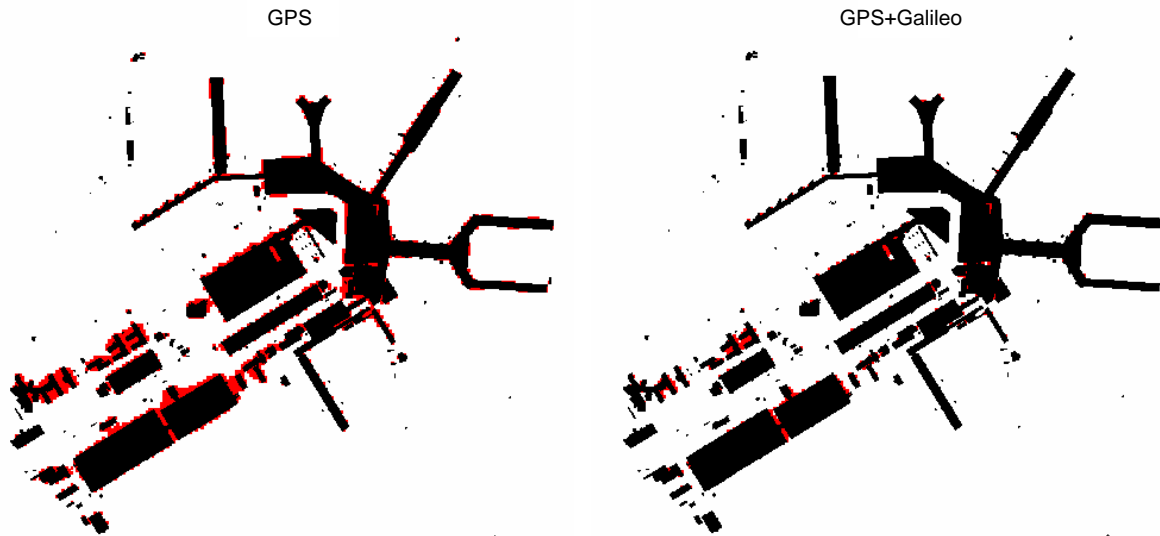

Figure 2. GPS availability (left) and GPS+Galileo availability (right) at Schiphol Airport (outdoors). Red: less than 95%; white: more than 95%.

3. GPS PERFORMANCE AT SCHIPHOL CENTER, INDOORS AND OUTDOORS

This section describes the results of experiments conducted as to test the performance of GPS at Schiphol Airport, both indoors and outdoors. The GPS experiments are restricted to Schiphol Center, and more specific inside and outside Schiphol Plaza (railway station, shopping and Arrivals area), inside and outside the Departures area and inside the C- and D-piers. In all experiments the same highly-sensitive u-blox receiver was used. In Sect. 3.1 we briefly discuss the characteristics of HSGPS measurements, while in Sect. 3.2 the experimental setup is explained in detail. The remaining subsections present the results of the experiments.

3.1 High-Sensitivity GPS Measurements

A traditional GPS receiver is designed for outdoor applications where sufficient (at least four) and unblocked LOS signals are available. In addition, the signal-to-noise ratio of these signals should be high enough in order to be acquired and tracked by conventional receivers. The time to acquisition of the signals is usually rather long (up to few minutes). A HSGPS receiver uses large computing power and sophisticated signal processing to acquire and track weak signals; see e.g. Van Diggelen and Abraham (2001) and Lopéz-Risueño and Seco-Granados (2004). The signals may be up to 1000 times weaker than with conventional receivers. This means that with HSGPS it is possible to receive signals indoor. HSGPS results showing this have previously been presented, e.g. by MacGougan et al. (2002) and Odijk and Tiberius (2006). The noise of HSGPS measurements can be large, dependent on the signal attenuation (Wieser, 2006). In addition, the signals may get contaminated by large errors as due to reflections to walls, glass, concrete and obstacles (multipath).

3.2 Experiment Setup

In all GPS experiments a highly-sensitive L1 receiver of the Swiss manufacturer u-blox was used, containing a LEA-4T module in an evaluation kit and a small patch antenna connected to the receiver kit. The receiver has 16 channels, measures at 1 Hz (thus with 1-sec interval), and its tracking sensitivity is -158 dBm. Good (relative) positioning results with u-blox receivers outdoors are for example described by Odijk et al. (2007). During the measurements at Schiphol the patch antenna was held in hand, while the u-blox receiver kit was connected to a laptop (in order to store the NMEA messages

Figure 3. Luggage trolley with u-blox receiver connected to laptop, while patch antenna is held in hand.

containing the position and status information) and carried on a luggage trolley (see Figure 3). This trolley was pushed forward with more or less constant walking speed. In addition to these kinematic measurements, at some points the trolley was not moved in order to collect GPS data in a static mode.

All GPS measurements were collected on 9 May 2007 in the following areas of Schiphol Center (see Figure 5 and Figure 6):

- inside and outside of Schiphol Plaza at the ground floor
- inside the C-pier
- inside the D-pier
- inside and outside the Departures Hall at the first floor

The quality of the GPS positions is not assessed in an absolute sense, since we do not have a ground truth available. However, an impression of the quality of the positions is obtained because some static measurements have been carried out. The (relative) precision of the positions kinematically obtained is assessed by plotting the positions on Google Earth background images. Because the absolute accuracy of Google Earth images is not very high, we cannot use these images in an absolute sense as ground truth for the GPS positions; they are only used for visualization purposes.
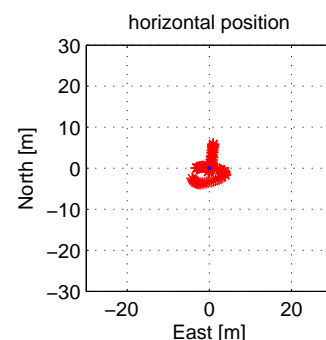

Figure 4. Static positions scatter outdoor (3 min)

3.3 Outdoor and Indoor GPS at the Ground Floor of Schiphol Plaza

The first experiment (from 12:27–12:48 UTC) started at the main entrance of Schiphol Plaza at street level with 3 minutes of static positioning, as to get insight in the position accuracy of the u-blox receiver. Figure 4 shows the horizontal scatter of these positions with origin the mean of the position fixes. It can be seen that all positions are well within 10 m of the mean,

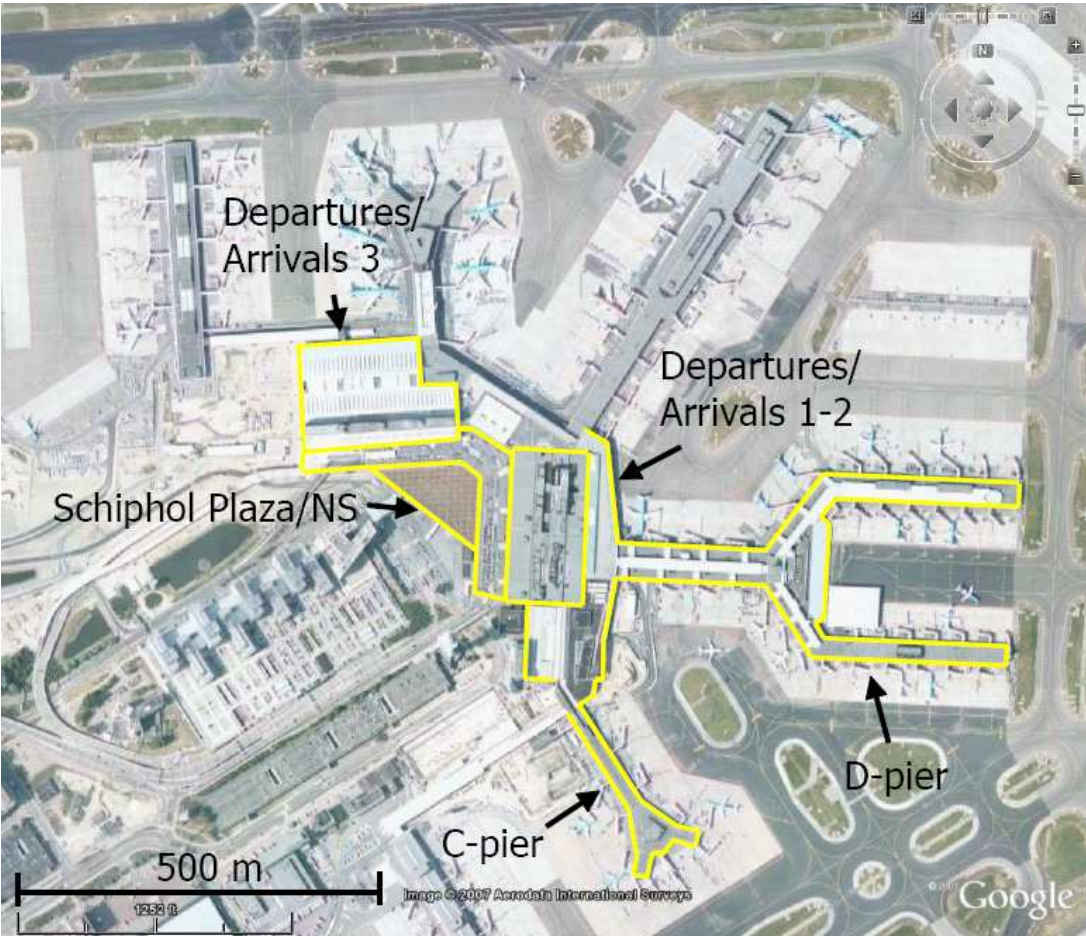and this corresponds to the typical GPS accuracy outdoors.

Figure 5. Google Earth image of Schiphol Center with contoured in yellow the areas where the indoor GPS measurements have been collected.

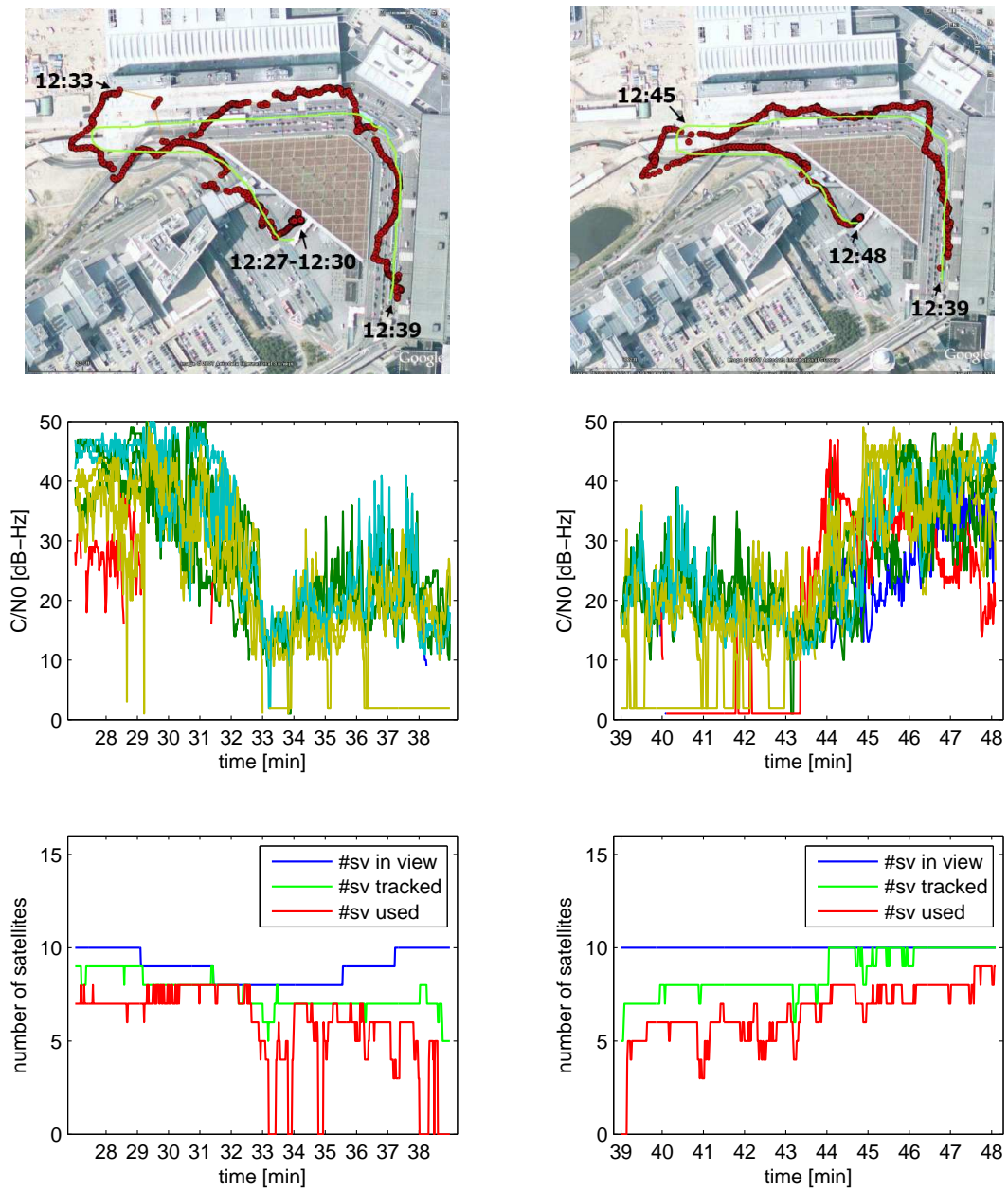**Figure 6.** Aerial view of Schiphol Center.

Figure 7. Position fixes (top; red dots), carrier-to-noise levels per tracked satellite (middle) and number of satellites in view, tracked and used for positioning (bottom) for the GPS experiment at ground floor near and in Schiphol Plaza. The left-hand figures refer to the first part of the measurements starting at the main entrance at 12.27 UTC, while the right-hand figures refer to the second part of the measurements starting in the shopping area (indoors) at 12.39 UTC.
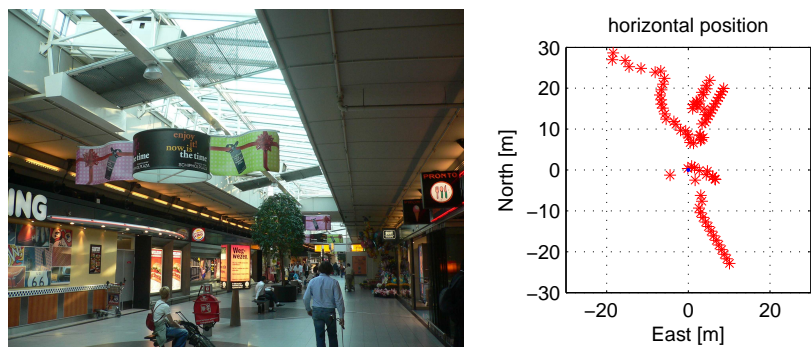

Figure 8. Shopping corridor in Schiphol Plaza with windows in the roof (left) and static positions scatter for the end of the corridor (right).

After the static measurements, with signals having carrier-to-noise ratios of up to 50 dBHz, the trolley was moved forward on street (see the green curve in Figure 7; top left) and along the way it passed several obstacles for GPS signals: a large pedestrian bridge and a viaduct. During these passes the number of satellites used for positioning (see the red curve in Figure 7; bottom left) never dropped to zero; it was still at 7-8. However, when walking underneath such an obstacle, there are jumps in the position fixes, see Figure 7; top left. Also the received signals were attenuated, see Figure 7; middle left. At 12:33 UTC the trolley went inside a shopping corridor in the Plaza building, see Figure 7 (top left) and immediately after entering only signals of at most 15-20 dBHz could be tracked, and unfortunately for some time intervals after 12.33 UTC no positions could be output by the receiver. After 12:35 UTC, when still inside the shopping corridor, suddenly stronger GPS signals were tracked and positions could be fixed all the time, see Figure 7; middle and bottom left. This good indoor behaviour can be explained from the penetration of GPS signals through the windows in the roof of this part of the shopping corridor, see Figure 8.

At the end of the corridor, at about 12:37 UTC, the trolley was held stationary for a couple of minutes. During some time of this stop the receiver was not able to generate position fixes, because at this place there are no roof windows at all sides. The positions that could be fixed are plotted with respect to their mean in Figure 8 (right). It can be seen that the spread in positions for this indoor location is much larger than for the outdoor location in Figure 4, due to deteriorating effects in the corridor such as multipath errors and signals only coming from one side (the windows), causing a bad geometry (high DOP).

After the static positioning the trolley was moved in the direction it came from. The complete track was walked again, but now in opposite direction, up to the location outside where the experiment started. The resulting positions, carrier-to-noise levels and number of satellites are shown in the figures at the right-hand side of Figure 7. Striking difference with the figures at the left-hand side is that when walking towards the exit of the corridor (where we entered the building in the other direction), the receiver is able to compute a position all the time. Being outside, it can be seen that mainly when the trolley is moved under the road viaduct the receiver outputs positions that deviate significantly from the walked track and also from the positions obtained in the other direction. Here possibly multipath errors play a role.

3.4 Indoor GPS at the C-pier

Other indoor experiments were conducted inside the C-pier (see Figure 5). This pier consists of one single floor. The trolley with the u-blox receiver was first moved with constant walking speed from the beginning of the pier at 13.44 UTC to the end of the (western wing of the) pier. As can be seen from Figure 9 (top; left) position fixes were output all time when moving on the C-pier. The number of satellites was relatively high; at least 7 for many fixes. In a second experiment use was made of two passenger conveyors present at the C-pier; see Figure 9 (top; right). The trolley was placed stationary on a passenger conveyor close to the beginning of the pier and after finishing this conveyor the one moving in the opposite direction was used in the same manner. This back-and-forth moving on these passenger conveyors was repeated for 5 times, each cycle (lasting for about 2.5 min) immediately following after the previous one was finished. This small experiment gives some insight into the repeatability of the kinematic indoor GPS positions. In Figure 10 the horizontal position fixes are plotted for each of the 5 cycles with respect to the mean position computed using the positions of all 5 cycles. The figures show that there are differences between the cycles;

however these seem to be restricted to at most 10 m (roughly assessed from the graphs).
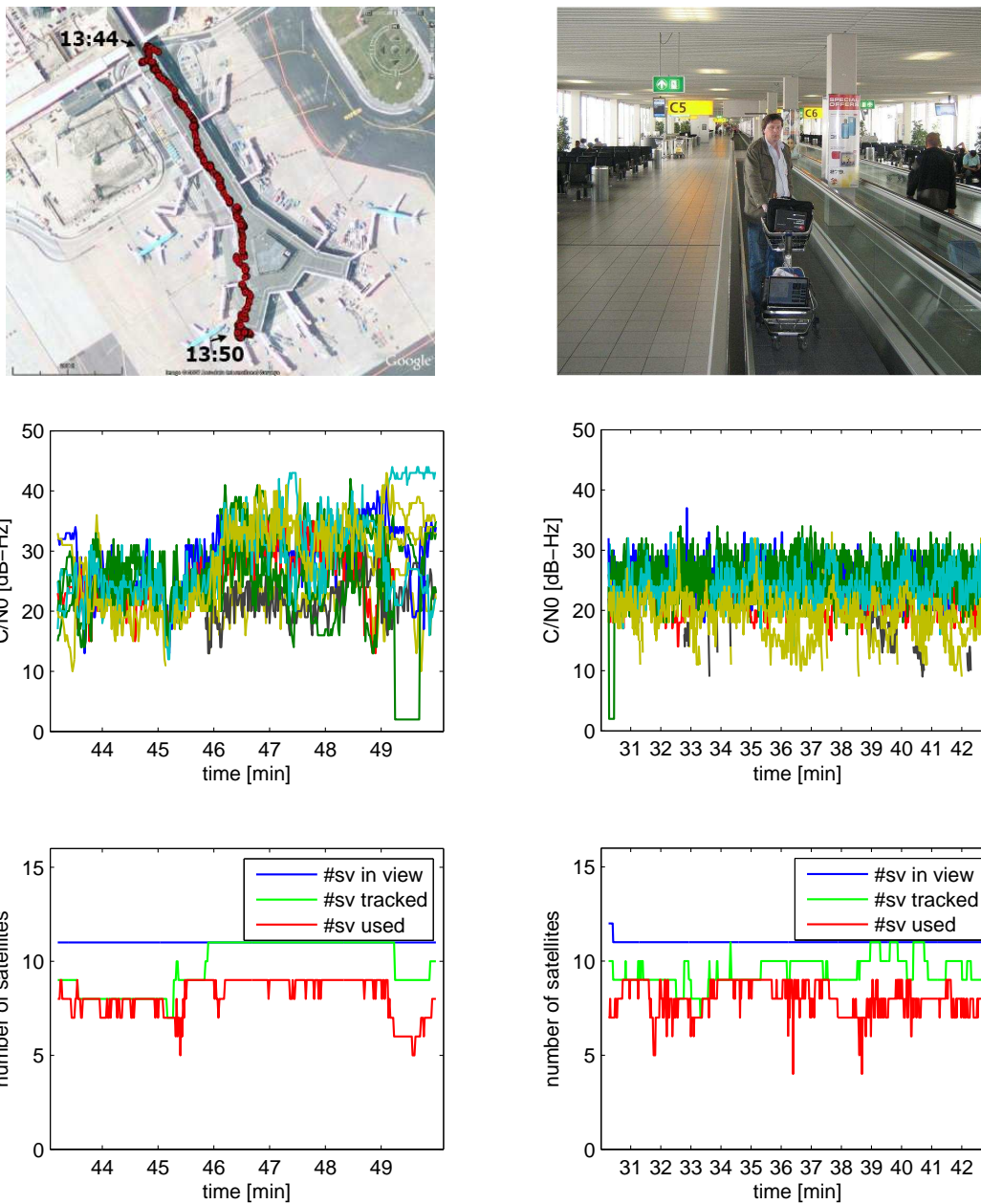

Figure 9. Position fixes (top left; red dots), carrier-to-noise levels per tracked satellite (middle) and number of satellites in view, tracked and used for positioning (bottom) for the GPS experiments at the C-pier. The left-hand figures refer to the walking experiment from the beginning to the end of the pier, while the right-hand figures refer to the passenger conveyor experiment.
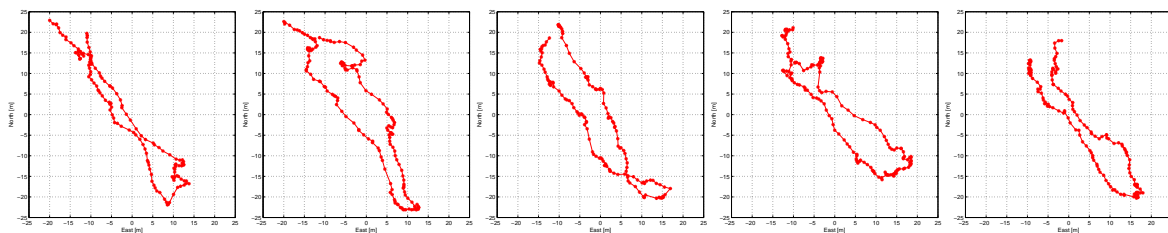

Figure 10. Horizontal positions (East vs. North) with respect to their mean (computed from all cycles) for the 5 back-and-forth passenger conveyor experiments. Note that the axes of all plots range from -25 m to +25 m and the applied grid size is 5 m.

3.5 Indoor GPS at the Top Floor of the D-pier

After the C-pier experiments, the trolley with the GPS receiver was moved to the larger D-pier (see Figure 5). This pier consists of a ground floor and a top floor. First the top floor was visited and the trolley was held still at the beginning of the pier for about 7 minutes. After that the trolley was moved with walking speed towards the end of the southern wing. At the end of the pier the trolley was hold for a couple of minutes and afterwards the trolley was moved back in the opposite direction towards the beginning of the wing, following more or less the same track.
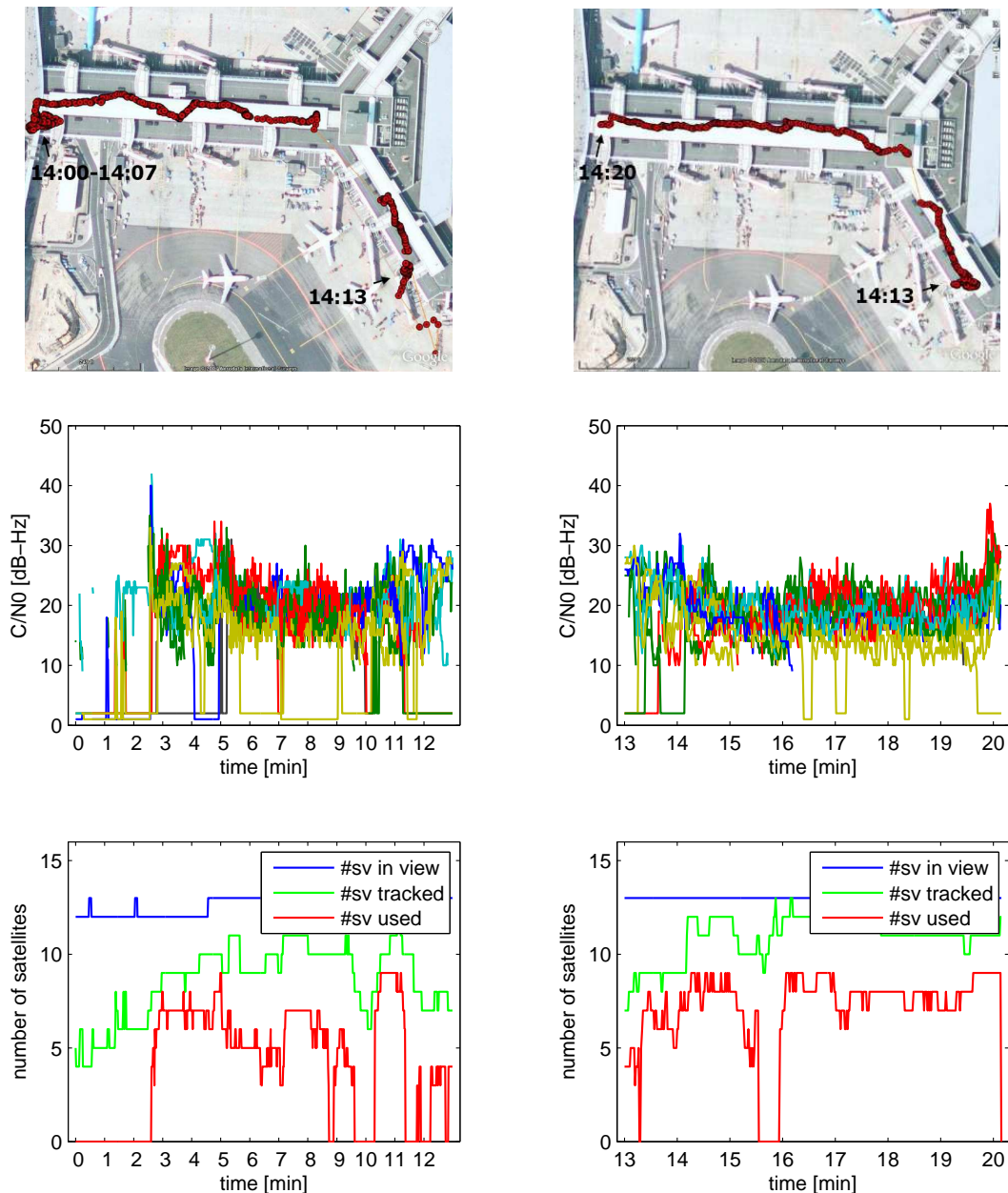
Figure 11. Position fixes (top; red dots), carrier-to-noise levels per tracked satellite (middle) and number of satellites in view, tracked and used for positioning (bottom) for the GPS experiment at the top floor of the D-pier. The left-hand figures refer to the first part of the measurements starting at the beginning of the pier at 14.00 UTC, while the right-hand figures refer to the second part of the measurements starting at the end of the southern wing at 14.13 UTC.

Figure 11 shows the results of the GPS measurements at the D-pier. Figure 12 depicts the static position scatter (with respect to the mean position) at the beginning of the pier. During the first minutes of this static positioning the receiver had to acquire signals again, as it arrived from a location where no signals could be tracked. Towards the split of the pier into a north and south wing and also after the split, the continuity of position fixes hampered, most likely owing to the presence of the building on the pier at the split; see Figure 11. During the walk in the opposite direction the receiver could not output position fixes for about the same locations (after the split when coming from the beginning of the pier). After about half a minute positions could be logged again, and this continued up to the beginning of the pier.
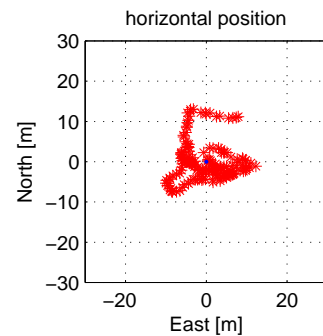

Figure 12. Static positions scatter at D-pier, indoors (3 min)

It was also tried to perform GPS positioning at ground floor level of the D-pier, but unfortunately this failed; no positions could be fixed at all. The cause for this failure is the (metal) coating that is applied in the windows of the D-pier. This coating is also applied at the top floor, but GPS signals here may be received since they are able to penetrate through the roof, while this is not possible at the ground floor level.

3.6 Outdoor and Indoor GPS at the First Floor (Departures)

The last GPS experiment has been carried out inside the Departures Halls 1-2 and 3 (see Figure 5) and outside in front of the Departures halls. Starting point of the measurements was outdoors close to the most southern entrance of Departures hall 1-2. Note that the street level here corresponds to the first floor of the Departures/Arrivals buildings (Arrivals at ground floor and Departures at first floor). For 4 minutes (15:10-15:14 UTC) the trolley was stationary in order to perform static positioning, see Figure 13 for the resulting positions. After that it was moved along the front of the Departures 1-2 building in northern direction (note that we walked under the roof outside), and then following the street along the corridor between the Departures 1-2 and Departures 3 buildings. Finally the front of the Departures 3 building was

Figure 13. Static positions scatter outdoors close to most southern entrance of Departures 1-2 (3 min)

followed (again under outdoor roof) in westward direction up to the last, most western, entrance, where the Departures 3 building was entered. Inside the Departures Hall 3 the trolley was pushed along the inner front of the building in east direction. The indoor GPS positioning was continued into the corridor between Departures 3 and Departures 1-2, and continued in Departures Hall 1-2 along the inner front. The experiment was ended at the most southern side of the building, close to where the experiment started outdoors.
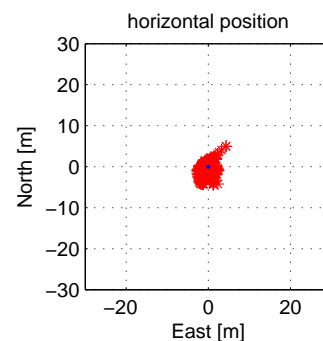
The results are as follows; see also Figure 14. Outdoors quite a lot of satellites could be tracked and used for the position computation, especially when walking along the Departures 1-2 building. Along the corridor and the Departures 3 building the number of tracked satellites had decreased, and also the carrier-to-noise ratios of the signals. Concerning the positioning results, Figure 14 (top; left) shows that for the tracks along the fronts of both the Departures

Halls 1-2 and 3 the position fixes seem to have a systematic shift in the direction perpendicular to the buildings; the positions seem to lie on the road (this shift is not visible for the track near the corridor between both buildings). A possible cause for this shift is multipath due to the overhanging roofs outside Departures 1-2 and 3. Such a roof is not present outside the corridor. After going inside Departures 3, the GPS receiver was not able to compute positions anymore. Only after entering the corridor, position fixes appeared; see Figure 14 (top; right). The cause of the too weak signals in the Departures 3 hall is –like in the D-pier– related to the coating in the glass of the windows. This coating does not seem to be present in the (small) windows of the corridor. When entering Departures Hall 1-2 from the corridor, positions could be fixed as well, however not for the complete walk along the inner glass front of this hall. Possibly not all windows in the Departures Hall 1-2 contain a metal coating.
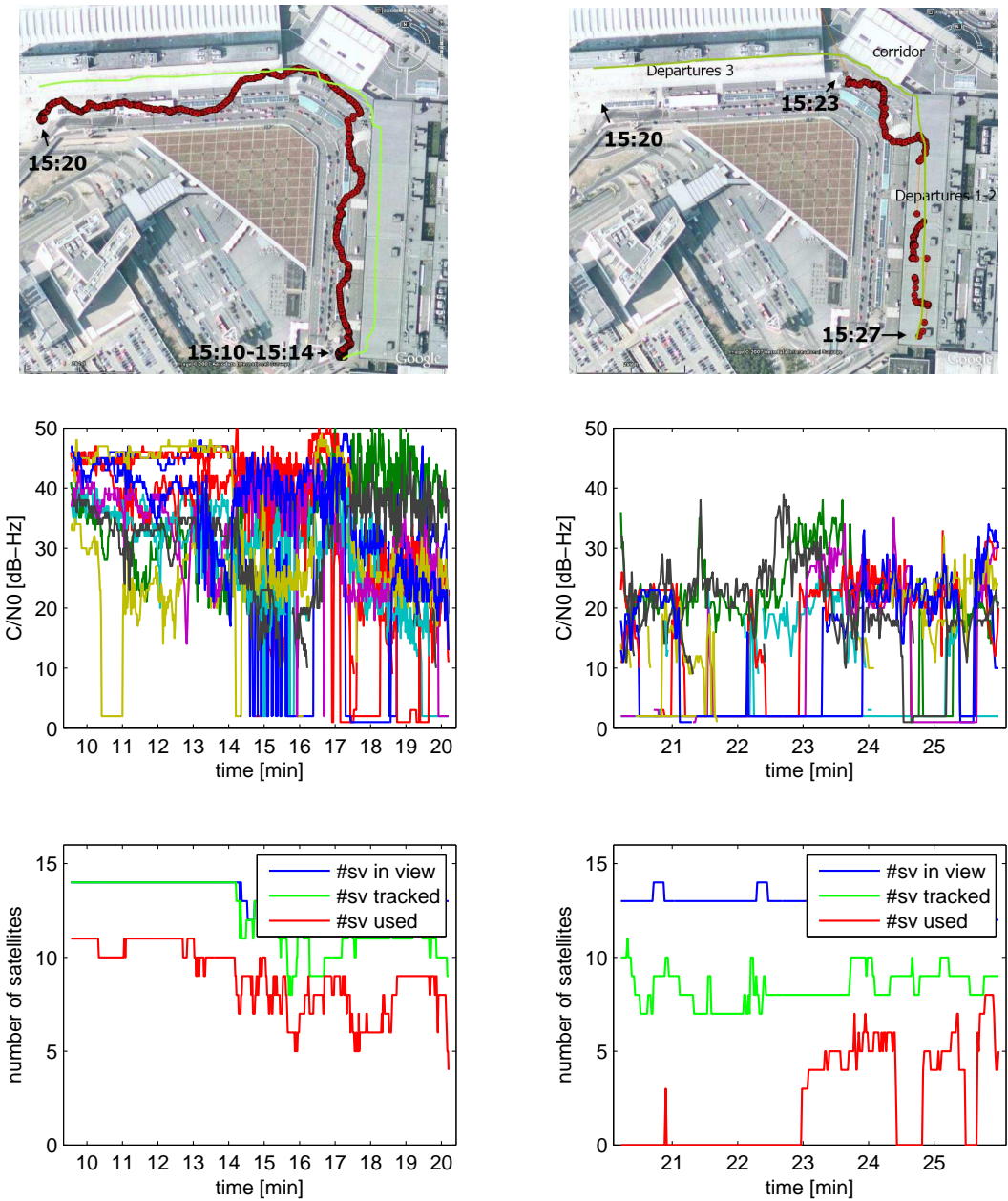

Figure 14. Position fixes (top; red dots), carrier-to-noise levels per tracked satellite (middle) and number of satellites in view, tracked and used for positioning (bottom) for the GPS experiment at the first floor near and in Departures Halls 1-2 and 3. The left-hand figures refer to the first part of the measurements outdoors along the fronts of the Departures halls, while the right-hand figures refer to the second part of the measurements inside the Departures halls.

Figure 15. Departures 1-2 with (partially) uncoated windows (left) and Departures 3 with coated windows (right).

4. CONCLUSIONS

For many LBS at Schiphol Airport reliable and accurate positioning information is required. In this contribution we have investigated whether this is feasible using GPS, by means of conducting experiments both indoors as well as outdoors. Advantages of GPS positioning are that no additional infrastructure is required and that it is relatively cheap. In the GPS experiments we used a high-sensitive u-blox L1 receiver and measurements were collected outdoors near Schiphol Plaza and the Departures halls, and indoors at Schiphol Plaza, the Departures halls, and the C- and D-piers. The main conclusion reads that although position fixes were obtained at many locations, and the u-blox receiver is able to track sufficient satellites indoors, often the GPS signals are too weak to be used for positioning. Hence, GPS positioning indoors at Schiphol Airport is still too unreliable. This is partly related to the applied metal coating in some of the windows in the terminal buildings. Outdoor GPS at Schiphol Airport is possible practically all the time and everywhere: for almost all locations for more than 95% of the time it should be possible to obtain a GPS position, even close to the piers. This availability is even more increased with an operational Galileo in addition to GPS. However, despite this good availability of GPS signals outdoors, one has to be aware for multipath errors close to and between buildings and piers. Having an operational Galileo system the indoor performance might improve as well, since Galileo signals will be (slightly) stronger than GPS signals. If Galileo and GPS signals are combined, this implies a doubling of the number of satellites, and the more satellites can be tracked for indoor positioning. In the meantime, for LBS at Schiphol Airport positioning information should not be based on GPS only; it should be a combination of several techniques, for example GPS integrated with INS; see e.g. Godha et al. (2006).

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