Demonstrating Tools and Results of a Measurement Campaign for Indoor GPS Positioning

Mikkel Baun Kjærgaard[1], Henrik Blunck[1], Torben Godsk[1,2], Thomas Toftkjær[1,3], Dan Lund Christensen[4], and Kaj Grønbæk[1]

[1] Department of Computer Science, Aarhus University, Denmark
[2] Danish Agricultural Advisory Service, National Centre, Denmark
[3] Systematic A/S, Denmark
[4] Alexandra Institute A/S, Denmark

Abstract. It has been considered a fact that GPS performs too poorly inside buildings to provide usable indoor positioning. We demo raw measurements and results from a measurement campaign which show that using state-of-the-art receivers GPS availability is good in many buildings with standard material walls and roofs: The root mean squared accuracy of the measured positions is below five meters in wooden buildings and below ten meters in most of the investigated brick and concrete buildings. Lower accuracies, where observed, can be linked to either low signal-to-noise ratios, multipath phenomena or bad satellite constellation geometry. A comprehensive analysis of the measurement campaign appears as full paper in Pervasive 2010, titled *Indoor Positioning Using GPS Revisited*. In this demonstration we present the campaign analysis results with an emphasis on visualization and animation. Another focus of this demonstration lies on depicting the visualization tools and methods chosen for empirically analysing GNSS indoor performance.

Applying the visions of ubiquitous computing to a variety of domains requires positioning with (i) pervasive coverage and (ii) independence from local infrastructures. Examples of such domains are fire fighting [1], search and rescue, health care and policing. Furthermore, also many other position-based applications would benefit from positioning technologies that fulfill both requirements [5]. One technology fulfilling (ii) is positioning by GPS. However, it has been considered as a fact that GPS positioning does not work indoors and therefore does not fulfill the coverage requirement (i). Due to recent technological advances, e.g, high-sensitivity receivers and the promise of an increase in the number of global navigation satellites, this situation is changing.

In 2005, LaMarca *et al.* [6] studied the availability of GPS with an off-the-shelf receiver for tracking the daily tasks of an immunologist, a home maker and a retail clerk. For the three studied persons, the availability was on average only 4.5% and the average gap between fixes was 105 minutes. To address these shortcomings they proposed fingerprinting-based positioning [4] as a solution. However, for the previously mentioned domains fingerprinting-based solutions are less suitable, given the requirement of fingerprinting collection, the vulnerability to hacking, that fires might alter the building and the unknown factor of whether or not fingerprinted base stations will be taken out by a fire.

We have conducted a measurement campaign at several indoor sites, including wooden and brick houses, a public school, a warehouse, a shopping mall and a tower block, to determine to what extent GPS is usable indoors and which performance to expect from it. Furthermore, we intended to link the measured performance to the type of errors affecting GPS as well as to local properties of the buildings like dominating materials and proximity to external walls and windows or surrounding buildings.

In our paper [3] to be presented at Pervasive 2010, we argue that the indoor performance of state-of-the-art GPS receivers is better than previously suggested. The results of the measurement campaign show that availability is good in many buildings except for large buildings with thick roofs or walls. The root mean squared accuracy of the measurements is below five meters in wooden buildings and below ten meters in most of the brick and concrete buildings. A low accuracy can be linked to low signal-to-noise ratios, multipath phenomena or bad satellite constellation geometry. We have also considered embedded GPS receivers in mobile phones which provided lower availability and accuracy than state-of-the-art ones. Finally, we consider how the GPS performance within a given building is dependent on local properties like building elements and materials, number of walls, number of overlaying stories and surrounding buildings.

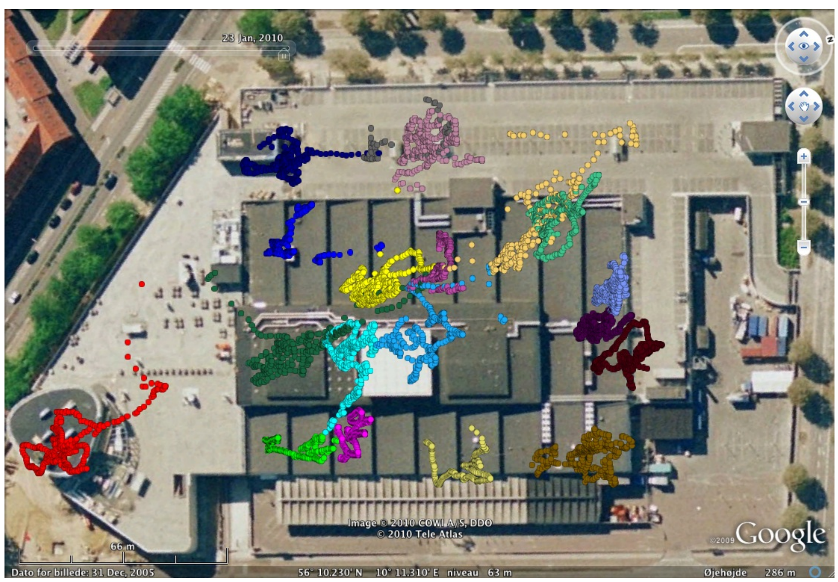

Fig. 1. Google Earth screenshot, showing data from 18 GPS measurement locations inside a mall.

In this demo we visually present and analyse the raw GPS measurements from our campaign to discuss the effect of local properties like building elements and materials, number of walls, number of overlaying stories and surrounding buildings. In the demo, the primary tool for visualizing the GPS measurements, as well the environments in which we carried them out, will be Google Earth. Specifically, we employ KML [8] to encode positioning data resulting from our measurements. Figure 1 shows a Google

Earth screenshot, in which the satellite image of a shopping mall is overlaid with positioning data gained from static GPS measurements of 5 minutes each at 18 locations within the mall.

Another tool used to determine and visualize the impacting factors of GPS positioning performance for individual locations are skyplots. Adapting the skyplot tool presented by Hilla [2] allows also for visualizing signal strengths and pseudorange errors for all individual satellites, the signal of which can be received by the receiver used. Figure 2 taken from [3] depicts two such skyplots. In the skyplots, the 3 concentric circles represent 0, 30, and 60 degrees elevation, respectively. Depicted are the location of the satellites, tracked by the receiver during the respective hot start measurement period. Individual satellites are identified by the id of the PRN code, they are sending, respectively. The individual positions over time of each shown satellite are depicted as "+" signs, where the color of the symbol indicates its signal-to-noise ratio, as experienced by the u-blox receiver at the respective measurement location and according to the color scale given in the figure. A green arrow trailing the orbit pattern of a satellite signals shows its direction of movement. The pseudorange error for each satellite and for each individual time instance of reception during the measurement period are then depicted in blue color according to the scale given in the figure and perpendicular to the respective satellite's direction of movement. Note that while a GPS receiver can only output pseudorange errors w.r.t. to the estimated position, they can be transformed into pseudorange errors w.r.t. the actual receiver position, given properly surveyed ground truth by means of, e.g. satellite imagery, building floor plans and laser ranging, as done by the authors.

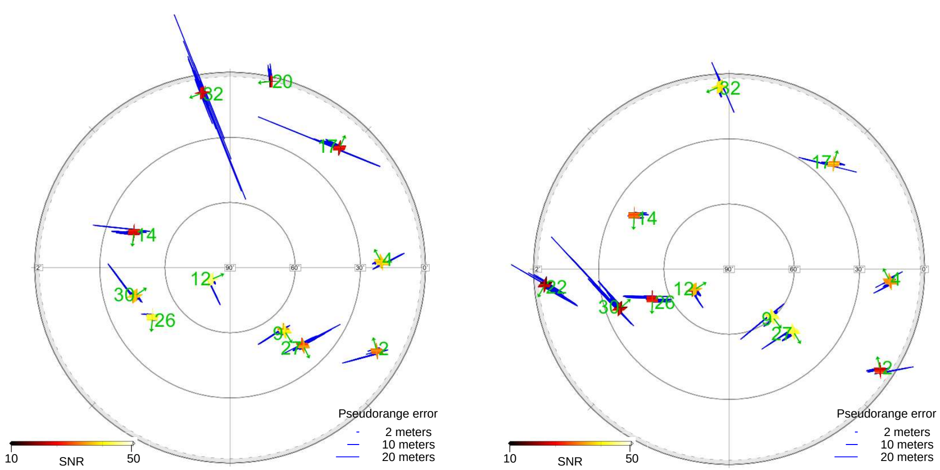

Fig. 2. Skyplots of measurements at two locations inside the warehouse.

To collect the measurements we use a u-blox LEA-5H Evaluation Kit GPS receiver. The u-blox receiver is specified to have a -190dBW (-175dBW) threshold for tracking (respectively, acquisition) and was connected to a u-blox ANN-MS patch antenna, providing 27dB gain and showing a 1.5dB noise figure. To obtain A-GPS assistance data [7], we connected the u-blox receiver to a mobile phone.

1 Acknowledgements

The authors acknowledge the financial support granted by the Danish National Advanced Technology Foundation for the project "Galileo: A Platform for Pervasive Positioning" under J.nr. 009-2007-2.

References

1. M. Angermann, M. Khider, and P. Robertson. Towards operational systems for continuous navigation of rescue teams. In *Proc. Position, Location and Navigation Symposium*, 2008.
2. S. Hilla. Plotting pseudorange multipath with respect to satellite azimuth and elevation. *GPS Solutions*, 8(1), 2004.
3. M. B. Kjærgaard. A Taxonomy for Radio Location Fingerprinting. In *Proceedings of the Third International Symposium on Location and Context Awareness*, 2007.
4. M. B. Kjærgaard, H. Blunck, T. Godsk, T. Toftkjær, D. L. Christensen, and K. Grønbæk. Indoor Positioning Using GPS Revisited. In *Proceedings of the 8th International Conference on Pervasive Computing*, 2010.
5. A. Küpper. *Location-Based Services: Fundamentals and Operation*. Wiley, October 2005.
6. A. LaMarca, Y. Chawathe, S. Consolvo, J. Hightower, I. Smith, J. Scott, T. Sohn, J. Howard, J. Hughes, F. Potter, J. Tabert, P. Powledge, G. Borriello, and B. Schilit. Place Lab: Device Positioning Using Radio Beacons in the Wild. In *Proc. 3rd Intl. Conf. on Pervasive Computing*, pages 116–133, 2005.
7. F. van Diggelen. *A-GPS: Assisted GPS, GNSS, and SBAS*. Artech House, 2009.
8. J. Wernecke. *The KML Handbook: Geographic Visualization for the Web*. Addison-Wesley Professional, 1 edition, November 2008.