2012 International Conference on Indoor Positioning and Indoor Navigation, 13-15th November 2012

Investigation of Location Capabilities of four Different Smartphones for LBS Navigation Applications

Guenther Retscher
Department of Geodesy and Geoinformation
Vienna University of Technology
Vienna, Austria
gretsch@pop.tuwien.ac.at

Tobias Hecht
Vienna University of Technology
Vienna, Austria
e0206606@student.tuwien.ac.at

***Abstract*—The market of smartphones and other mobile devices shows very high increase rates nowadays, e.g. the Apple's iOS-based smartphone and tablet series have gained 15% of global market share, while the Android-based smartphones and tablets have a share of 52.5% [11]. The intelligence contained in smartphones relies very much on the integration of different low-cost and compact sensors. MEMS-based accelerometers and magnetometers (or digital compasses) are integrated allowing manifold scenario-awareness applications (apps). Apple began this revolution by equipping the iPhone with an accelerometer to switch its display automatically from portrait to landscape orientation. Now Apple has a storeful of novel apps that exploit the iPhone's accelerometer for gaming, health monitoring, sports training and countless other uses thought up by legions of developers. It is forecasted that 85% of all smartphones by 2013 will include GPS, over 50% will have accelerometers and almost 50% will have gyroscopes [6]. Using these sensors smartphones offer location and navigation functionalities. Accelerometers can be used to determine the current movement state of the user, e.g. standing, walking, or fast moving in a car or public transportation. In addition, the digital compass can provide the orientation of movement. The research study discussed in this paper investigates the use of GPS and other geosensors for navigation applications. The conducted field tests cover combined indoor/outdoor environments in urban areas in the city of Vienna, Austria. In the tests the navigation capabilities of four different smartphones are investigated, namely an Apple iPhone 4, a Samsung Galaxy SII, a HTC EVO 3D and a Nokia X7. One main objective of the presented tests is to assess the quality of the data provided by the sensors in these smartphones. The test results show positioning accuracies on the few meter level using either GPS or dead reckoned positioning solutions with calibrated accelerometer and compass measurements. Therefore the feasibility of using smartphones for positioning in LBS and other navigation applications could be proven.**

Keywords-indoor/outdoor positioning with smartphones, LBS, indoor navigation, trip recording, MEMS-based sensors, accelerometer, digital compass and gyro, WiFi fingerprinting.

The Austrian mobile phone operator A1 provided the smartphones for the field experiments.

I. Introduction

Smartphones provide communication convenience for people in their daily life but also offer location and navigation functionalities as well as opportunities to collect data for scientific research. Conventionally, for LBS navigation applications the location determination of the user relies mainly on GNSS. In challenging urban and indoor environments where GNSS signals are frequently blocked or not available a GNSS receiver may not be able to provide sufficient coverage for tracking of a user. In addition, carrying an additional GNSS receiver for applications such as trip recording may impose some additional burden to individuals. The use of smartphones has the advantages that no additional device has to be carried by the user and also a WiFi card as well as other additional low-cost sensors such as a digital compass and accelerometers are available. The integration of GPS/WiFi mobile devices, wireless communications and other positioning technologies, as well as geographic information and mapping systems are the basis for tracking applications. MEMS-based accelerometers in the smartphone can be used to determine the current movement state of the user, e.g. standing, walking, or fast moving in a car or public transportation. In addition, the digital compass can provide the orientation of movement. The measurements of the two geosensors (i.e., accelerometer and compass) can be used together for dead reckoning (DR) if GNSS is not available.

The field experiments in the research study discussed in this paper cover combined indoor/outdoor environments in a building and its surroundings of the Vienna University of Technology as well as in a residential area. In the tests four different smartphones have been employed, namely an Apple iPhone 4, a Samsung Galaxy SII, a HTC EVO 3D and a Nokia X7. In the selected test scenarios the quality of the data provided by the location sensors in the smartphones is investigated. The setup and procedure of the field tests is presented in section 2 of this paper, followed by a detailed discussion of the field experiment results in section 3. Finally, concluding remarks and an outlook are given in section 4.

II. FIELD EXPERIMENTS

Field experiments were conducted along pedestrian trajectories in the 4th and 10th district of the city of Vienna, Austria. Figure 1 shows the pedestrian route 1 in the 4th district which starts in front of an office building of the Vienna University of Technology (point A) and follows along Karlsgasse to the Resselpark and ends at point B, i.e., the entrance of the underground station Karlsplatz. A second part of the route leads back to point A along a different road (i.e., Wiedner Hauptstraße). The circular route is around 1.1 km long and consists of 24 reference points which have been surveyed using total stations and are therefore known in the Austrian Gauß-Krüger coordinate system. The 5- to 6-story buildings along the route have an average height of around 20 to 30 m. The route was reciprocated 15 times at different GPS satellite availabilities and geometric conditions (i.e., different values of PDOP (Position Dilution of Precision)). As an example, Figure 2 shows the satellite visibility mask for control point PP3 in front of the main building of the Vienna University. The mask has been obtained from measurement of the location and building heights from Google Earth. Figure 3 shows the number of available satellites and the corresponding PDOP values for point PP3 for one of the test runs on May 14, 2012, from around 9:00 to 11:40 a.m. As can be seen 7 to 8 satellites with a good PDOP are visible most of the time.

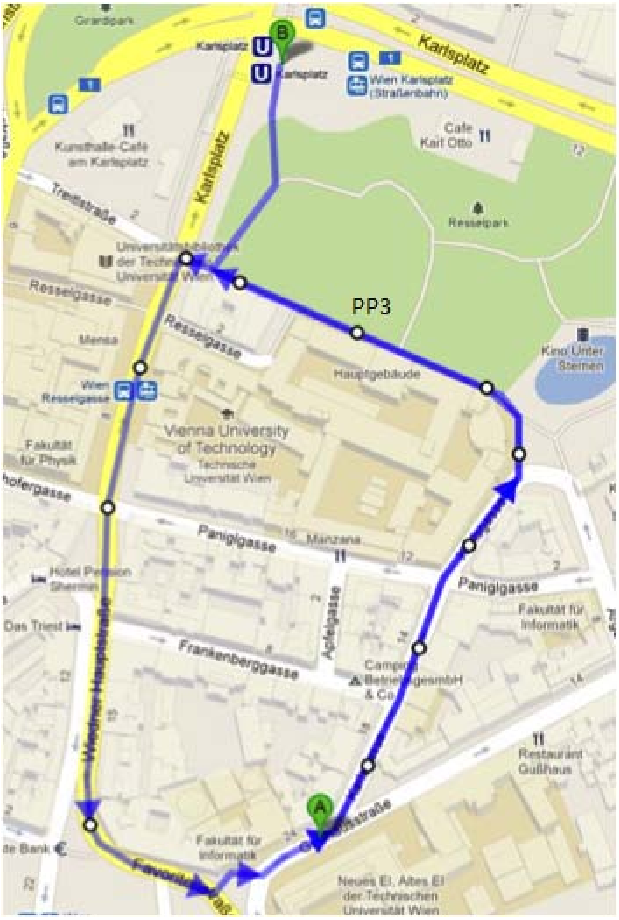

Figure 1. Pedestrian outdoor trajectory 1 from the office building of the Vienna University of Technology (point A) to the underground station Karlsplatz (point B)

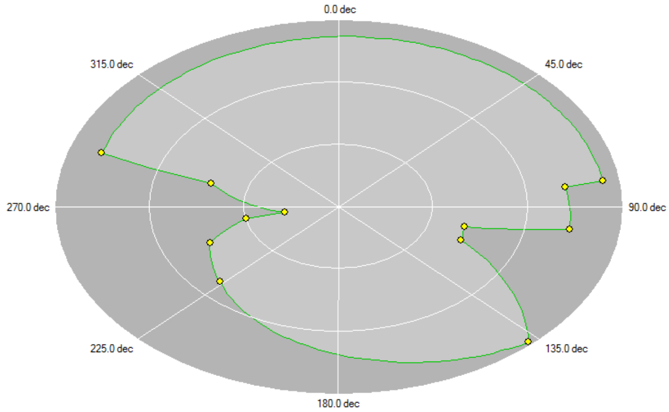

Figure 2. Satellite visibility mask for point PP3 in front of the main building of the Vienna University of Technology

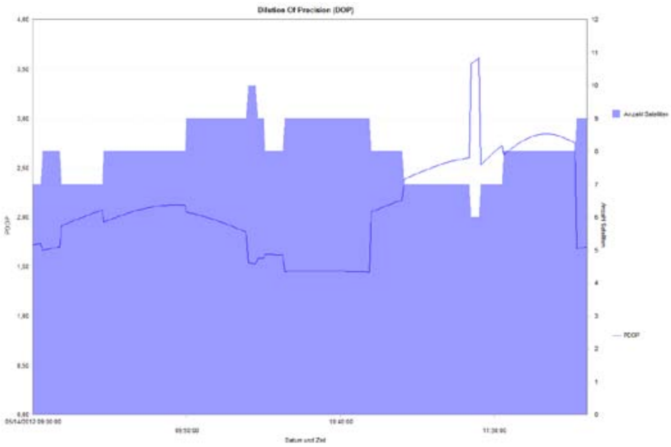

Figure 3. Satellite visibility and PDOP for point PP3 on May 14, 2012, from around 9:00 to 11:40 a.m.

In addition, an indoor trajectory starts in front of the office building at point A and leads up to the 3rd floor (where the offices of our Department are located) on staircase 1; then along the corridor to staircase 2; down to the ground floor and outside the building returning to point A. 26 reference points with known coordinates are available along this indoor route. Also a 3D building model for the two staircases and the 3rd floor has been created from the surveys with the total stations.

The second outdoor test trajectory in the 10th district of Vienna (see Figure 7) is around 300 m long and leads around a residential block with an average building height of 20 m (i.e., 4- to 5-story buildings). Different runs have been conducted to test the location capability of GPS and the other geosensors in the smartphones.

For the four different smartphones apps have been developed to be able to store the measured GPS positions and their accuracies as well as the measurements of the motion sensors, i.e., the MEMS-based accelerometers and the magnetometer or digital compass. In the following section the field test results obtained are discussed in detail.

To test the availability and the accuracy of the GPS sensors of the smartphones, an app was developed, that logged the values for longitude, latitude and altitude that were returned from the GPS receiver. The application was tested on a route with 50 reference points, of which 24 were outdoors and 26 were indoors. The GPS data of those points was logged and compared to the reference values.

For the implementation of an Inertial Navigation System using the measurements of the motion sensors, i.e., accelerometers and magnetometer or digital compass, another app was developed. The app uses a combination of the accelerometers and the digital compass of the smartphone to identify movements of the user. Starting from a known position the app calculates step by step the position changes. The application counts the number of steps based on the values received from the phone's accelerometers. For each of the three axes there is one returned value. In order to register movements in different directions that might occur due to different positions of the smartphone, those three values are combined to one single acceleration value. A step is detected when this value first gets higher than a defined threshold and subsequently below a second threshold. The direction or heading of the user is determined using the digital compass.

To use this application three different calibrations are needed, i.e., the calibration of the step-length of the user, the compass and the setting of the thresholds, which influence how sensitive the application is for step detection. The application was tested both in indoor and outdoor environments.

According to [4] the relevant information for the proposed localisation method is the occurrence of a walking step together with the movement direction. To detect the occurrence of a walking step, the data from the accelerometer sensor is used. The acceleration signal vector magnitude can be corrected by the offset due to gravity and then filtered using a simple averaging filter. Step events are then detected using an algorithm based on thresholds and some heuristics to ensure robustness. For every detected step, the corresponding heading information is also calculated. The heading can either be calculated by integrating the z-axis angular rate sensor data (parallel to the gravitational axis) or by using the x- and y-axis components of the Earth's magnetic field. Both methods, used alone, have drawbacks. Magnetic field sensors are very sensitive to disturbance from nearby metallic objects. In indoor environments especially, this can lead to large errors in heading calculations. Conversely, when integrating gyroscope data, along with needing a known start value, measurement errors can accumulate very quickly. Assuming that gyroscopes have a reasonable short term stability however, and that magnetometers are only disturbed over short periods of time, we can combine the advantage of both types of sensors by using a complementary filter with a fixed weight W. Test performed by Klingbeil [4] have shown that using a weighting factor W of 0.01 gives sufficient accuracy. So the filter relies mostly on the gyroscope data, but the magnetometers have still enough influence to compensate for gyroscope drift and unknown starting angles.

III. Discussion of the Field Test Results

In this section, the results of three different field experiments are discussed in detail, i.e., the test of the GPS positioning performance along the pedestrian trajectory 1, the investigation of the localization capabilities in an indoor environment and the test of the performance of the motion sensors along trajectory 2.

A. GPS Field Tests Along Combined Indoor and Outdoor Trajectory 1

The developed app for measurement of the GPS longitude, latitude and altitude was employed to test the availability and the accuracy of the GPS receivers of the smartphones. The application was tested on route 1 (see Figure 1) with 50 reference points, of which 24 were outdoors and 26 were indoors. The GPS data of those points was logged and compared to the reference values.

The variations of the different smartphones (in meters) from the reference points are shown in the Table I and II. As an example, Figure 4 shows the variations for the HTC EVO 3D, the blue dots are outdoors, the red dots indoors. As expected the performance of all smartphones is better in outdoor environment. As can also be seen from the tables the Samsung Galaxy SII and HTC EVO 3D performed slightly better in both outdoor as well as indoor environments.

TABLE I. Variations of the different Smartphones in Outdoor Environment (in meters)

Outdoor								
	Samsung Galaxy SII		**HTC EVO 3D**		**iPhone 4**		**Nokia X7**	
Availability	100%		100%		100%		100%	
	Lat/Lon	Height	Lat/Lon	Height	Lat/Lon	Height	Lat/Lon	Height
Min	0.38	35.76	1.04	26.87	0.78	0.00	1.85	34.26
Max	66.86	103.96	68.06	109.07	80.94	58.20	64.56	109.12
Mean	18.52	66.32	15.51	61.80	20.80	14.90	20.78	66.24
Median	18.54	64.02	13.84	58.89	16.28	11.94	17.75	62.46
Std Deviation	13.62	15.30	12.19	17.38	17.41	12.17	14.47	17.21

TABLE II. VARIATIONS OF THE DIFFERENT SMARTPHONES IN INDOOR ENVIRONMENT (IN METERS)

Indoor								
	Samsung Galaxy SII		**HTC EVO 3D**		**iPhone 4**		**Nokia X7**	
Availability	100%		30%		61%		21%	
	Lat/Lon	Height	Lat/Lon	Height	Lat/Lon	Height	Lat/Lon	Height
Min	4.99	0.67	32.85	17.64	36.52	0.07	13.54	12.79
Max	100.32	148.95	97.72	69.09	205.52	17.26	92.59	23.87
Mean	41.34	58.06	54.41	48.77	64.13	6.89	55.95	19.39
Median	40.79	58.06	54.31	46.33	55.64	6.01	57.11	19.33
Std Deviation	15.35	26.39	13.03	15.74	32.09	5.35	25.29	3.30

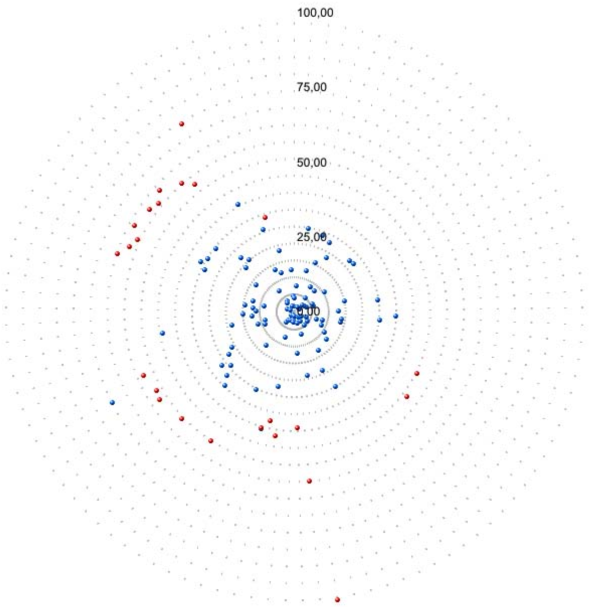

Figure 4. GPS deviations for the HTC EVO 3D along pedestrain trajectory 1 from the reference points in meters

B. Indoor Field Tests

In the office indoor environment the user started at a known position in the corridor and moved to various rooms on the same floor. The distances were between 50 and 100 m. In all the cases the correct room was detected, most of the time even the correct part of the room (see Figure 5 and 6).

C. Field Tests with Motion Sensors Along Trajectory 2

Test bed 2 is located in the 10th district of Vienna. The circular trajectory around a residential building block with a length of around 300 m has been repeated several times. Figure 7 shows a dead reckoned trajectory obtained from the measurements of the motion sensors of one very accurate test result along the route. As can be seen dead reckoning leads to good results if the accelerometer is used to count the steps of the pedestrian and the digital compass for heading determination. The step counts differ in maximum by ± 15 steps in comparison to the manually counted ones. The maximum deviations from the route lie in the range of 5 to 22 m for all test runs with an average deviation of 13 m. As said before, the motion sensors need to be calibrated in the beginning to be able to achieve such an acceptable result.

The application was tested on three different smartphones, but as they were calibrated independently, there was no significant difference between the smartphones noticed. The accuracy of the application depends mostly on a good calibration and on a consistent way of walking, so that the steps can be detected properly.

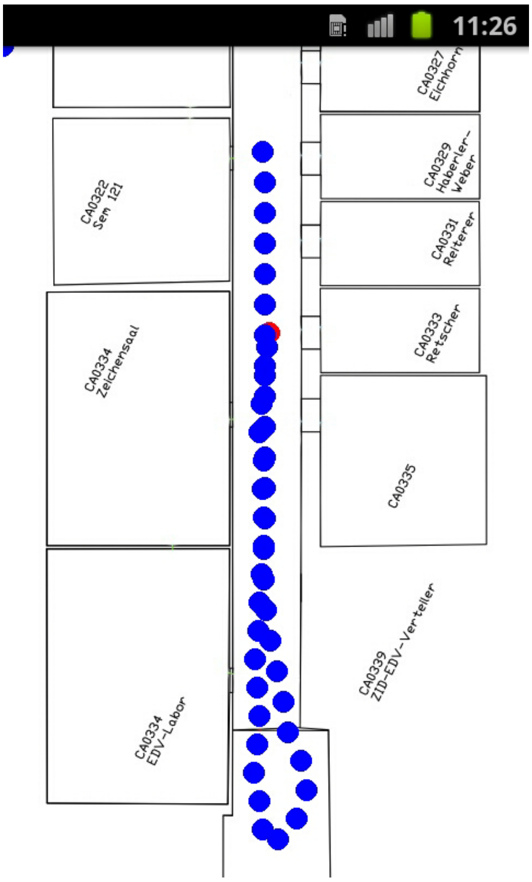

Figure 5. Indoor movements in an office building along the corridor using the motion sensors

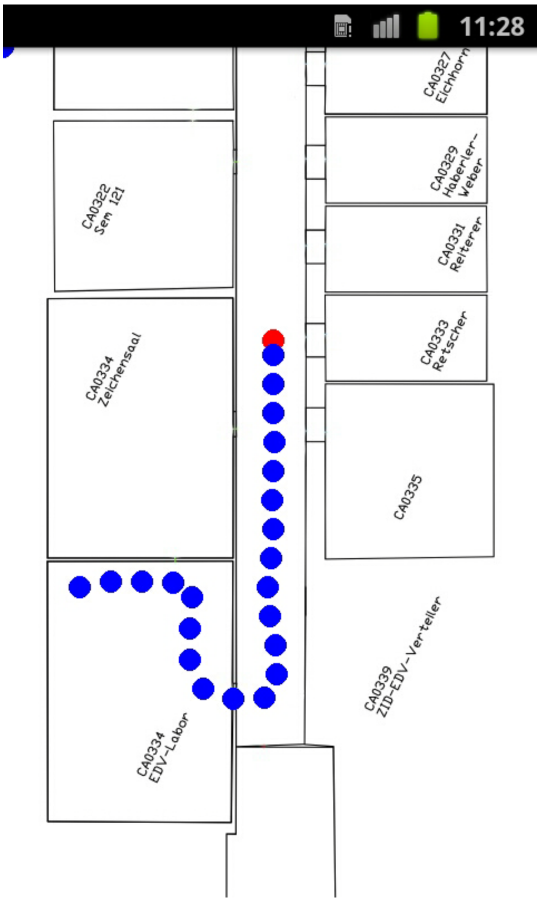

Figure 6. Indoor movements in an office building using the motion sensors

Figure 7. Measurements of motion sensors along pedestrain trajectory 2 in the 10th district of Vienna

IV. Concluding Remarks and Outlook

The location capabilities and performance of four different smartphones has been investigated in this study along different pedestrian trajectories in urban outdoor and indoor environments. The test results show the feasibility of using smartphones for tracking in LBS and other navigation applications. Further tests will be conducted in the near future along the trajectories at different environmental conditions, such as different GPS satellite visibilities and magnetic influences for the heading determination using the magnetometer. Furthermore the latest generation of Android smartphones will be included in the field testing such as the Samsung Galaxy SIII which also includes a barometer for altitude determination and a combined GPS/Glonass receiver. The major advantage of this new generation of smartphones is the increased satellite availability due to the combination of GPS with Glonass and the possibility to determine the correct floor in an indoor environment with the additional barometric pressure sensor. The new test results will be presented as soon as they become available.

Acknowledgment

The authors would like to thank the mobile phone operator A1 for providing the four different smartphones for the field experiments. The help of the students participating in the LBS course at the Vienna University of Technology, Austria, in the summer term 2012 for the data acquisition is also acknowledged. Some of the Figures use Bing maps and Google Earth for georeferencing.

References and Further Readings

[1] Asad-Uj-Jaman, “Sensors in Smartphones,” http://mobiledeviceinsight.com/2011/12/sensors-in-smartphones/. Accessed 11 July 2012.

[2] C. Hide, T. Botterill and M. Andreotti, “Vision-aided IMU for Handheld Pedestrian Navigation,” in Proccedings of the 23rd International Meeting of the Satellite Division of The Institute of Navigation, Portland, Oregon, USA, Sep 21-24, 2010, pp. 534-541.

[3] A. Kealy, M. Duckham, G. Retscher, G.W. Roberts and S. Winter, “Location Information Taxonomy for Location Based Services,” in Proccedings of the 6th International Symposium on Mobile Mapping Technology, July 21-24, 2009, Presidente Prudente, Brazil, 8 pgs.

[4] L. Klingbeil and T. Wark, “A Wireless Sensor Network for Real-time Indoor Localisation and Motion Monitoring,” 2008 International Conference on Information Processing in Sensor Networks, DOI 10.1109/IPSN.2008.15, pp. 39-50. http://www.cecs.uci.edu/~papers/cpsweek08/papers/ipsn08/3157a039.pdf. Accessed 9 October 2012.

[5] X. Li, J. Wang, A. Olesk, N. Knight and W. Ding, “Indoor Positioning within a Single Camera and 3D Maps,” in Proccedings of the International Conference on Ubiquitous Positioning, Indoor Navigation and Location Based Services, Kirkkonummi, Finland, October 14-15, 2010, 9 pgs. http://www.gmat.unsw.edu.au/snap/publications/lixun_etal2010a.pdf. Accessed 11 July 2012.

[6] D. Mala, “Growth of Sensors in Smartphones by 2013,” Satellite Technology Feature Article. http://satellite.tmcnet.com/topics/satellite/articles/105885-growth-sensors-smartphones-2013.htm, Accessed 11 July 2012.

[7] E. Mok, “Ubiquitous Positioning Technologies and LBS,” Location **2**(4), 2007, pp. 36-40.

[8] E. Mok and G. Retscher, “Location Determination Using WiFi-Fingerprinting Versus WiFi-Trilateration,” Journal of Location Based Services, **1**(2), 2007, pp. 145-159.

[9] E. Mok, G. Retscher, D. Wang, L. Xia, “Use of Smartphones for Tracking and Trip Recording,” in Proccedings of the 8th International

Symposium on Location-Based Services LBS 2011, November 21-23, 2011, Vienna, Austria, 137-152.

[10] E. Mok, G. Retscher and C. Wen, "Initial Test on the Use of GPS and Sensor Data of Modern Smartphones for Vehicle Tracking in Dense High Rise Environments," in Proccedings of the 2nd International Conference on Ubiquitous Positioning, Indoor Navigation and Location-Based Service UPINLBS 2012, October 3-4, 2012, 7 pgs.

[11] Premier Farnell UK Limited, "Sensors for Smartphone and Tablet," 2012. http://uk.farnell.com/smartphone-technology-applications. Accessed 11 July 2012.

[12] M. Quigley, D. Stavens, A. Coates and S. Thrun, "Sub-meter Indoor Localization in Unmodified Environments with Inexpensive Sensors," in Proccedings of the International Conference on Intelligent Robots and Systems IROS, Taipei, Tawain October 18-22, 2010, 8 pgs.

[13] G. Retscher, "Augmentation of Indoor Positioning Systems with a Barometric Pressure Sensor for Direct Altitude Determination in a Multi-storey Building," Journal of Cartography and Geographic Information Science (CaGIS), 34(4), 2007, pp. 305-310.

[14] Skyhook, "Wireless Positioning System (WPS)," http://www.skyhookwireless.com/. Accessed 11 July 2012.

[15] P. A. Zandbergen, "Accuracy of iPhone Locations: A Comparison of Assisted-GPS, WiFi and Cellular Positioning," Transactions in GIS, 13(s1), 2009, pp. 5-25.

[16] P. A. Zandbergen, "Comparison of WiFi Positioning on Two Mobile Devices," Journal of Location Based Services, 6(1), 2012, pp. 35-50.