Combined Out- and Indoor Navigation with Smart Phones Using Intelligent Check Points

Hannes Hofer, Guenther Retscher

Department of Geodesy and Geoinformation, Research Group Engineering Geodesy, TU Wien, Vienna, Austria

Abstract. Apart from a GNSS receiver, smart phones are nowadays equipped with further components, such as inertial sensors, a digital compass and a wireless module, which can be used for navigating. The aim of this work is to combine the data of these components in order to improve the accuracy of positioning in both outdoor and indoor areas. The idea behind is to intelligently choose check points along the user's trajectory and recognize them by using the wireless module by using a WLAN fingerprinting strategy. The inertial sensors and the digital compass were used to detect changes in positioning.

The combination of the methods is an obvious solution. In this work a new approach is developed where fingerprinting is used to recognize certain points – referred to as check points – when they are passed and an inertial navigation system is used to calculate the positions between them. These check points are placed in an intelligent way so that they must be passed and can distinguished well by the fingerprinting algorithms. In this work we present the results by using fingerprinting algorithms to recognize these intelligent check points (iCPs).

Keywords. Wi-Fi positioning, location fingerprinting, training phase, reference points, intelligent check points, inertial sensors, sensor fusion

1. Data Recording and Analyzing (DAAS)

For investigation of the iCP approach a data recording and analyzing system (DAAS) was developed. The DAAS is composed of an Android App and a MATLAB framework. The arrangement of the components is shown in Fig-

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ure 1. The Combined Positioning System App CPS is able to record RSS values and orientation data on selected locations with the *"CPS Kompass WiFi-Scanner"*. Along a trajectory the *"CPS Sensor-WiFi-Recorder"* can be used to record continuously RSS values and sensor data.

The recorded data can be imported to the MATLAB framework and the positioning can be simulated with different approaches off-line. With the DAAS databases for different phones and test trajectories can be build. As a specific simulation can make use of the same data different approaches can be compared. A next step is the further development of a new App version so that the data of the magnetic field sensor and the gyroscope can be combined with the received signal strengths (RSS) values.

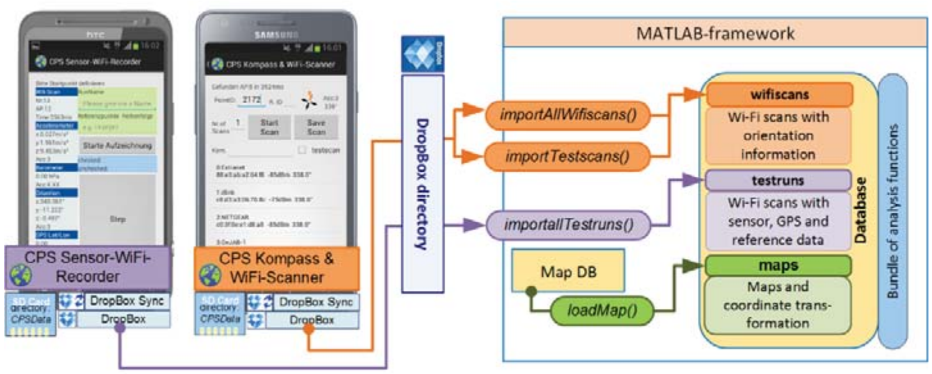

Figure 1. DAAS - arrangement of the components.

2. Wi-Fi Fingerprinting

To calculate a position with the wireless modules, the RSS of Access Points (APs) of an already existing wireless network can be used. A common strategy is to scan for the RSS values on a definite grid of positions and save the scans in a database. For the positioning a scan with the wireless module must be carried out. The detected RSS values are used to find the position in the database where they fit best. In this work the wireless fingerprinting algorithms with a nearest neighbour strategy were implemented.

For this purpose, RSS values were recorded for 49 positions to simulate the calibration and position phase. The DAAS was used to simulate the nearest neighbour fingerprinting algorithms and recognize iCPs without moving. The aims were to find the best averaging strategy for RSS values and to investigate whether better results can be achieved if the orientation of the smart phone is considered additionally. Results of the tested variants of the fingerprinting algorithms can be seen in Figure 2.

The overall best results were achieved by using the arithmetic mean for averaging and if minimal RSS values are assigned for Access Points which are not always found by a scan.

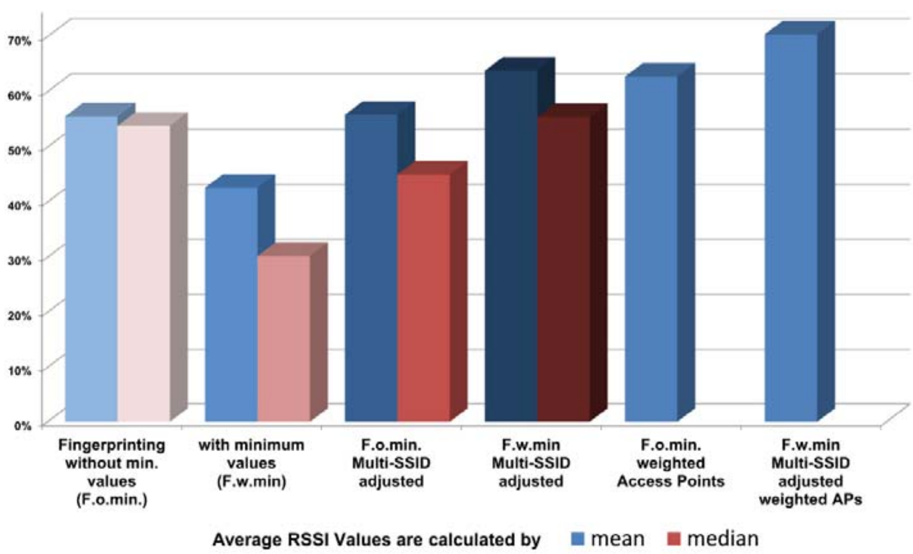

Figure 2. Recognition rates (RR) of Wi-Fi fingerprinting of the tested 49 positions – variants.

By considering of the orientation no significant improvement could be achieved, but the wireless scans in the training phase can be reduced significantly, because wireless scans must be done on less positions and only in necessary orientations. Furthermore, future investigations concerning fingerprinting are dealing with a meaningful selection of Access Points so that their RSS values are well distinguishable for each location in the database.

3. Inertial Navigation (IN)

The inertial sensors and magnetometer embedded in the smart phone can be used to identify the orientation of the phone and use it as a digital compass. By combining the data of the orientation and the accelerometer a change of the position can be recognized. Then a travelled distance can be traced based on inertial navigation. To recognize a position, change a step detection algorithm was implemented. This algorithm analyses the accelerometer data and a detect a step when a peak is found and a defined threshold is exceeded. An example of the accelerometer data and the detected steps is shown in Figure 3.

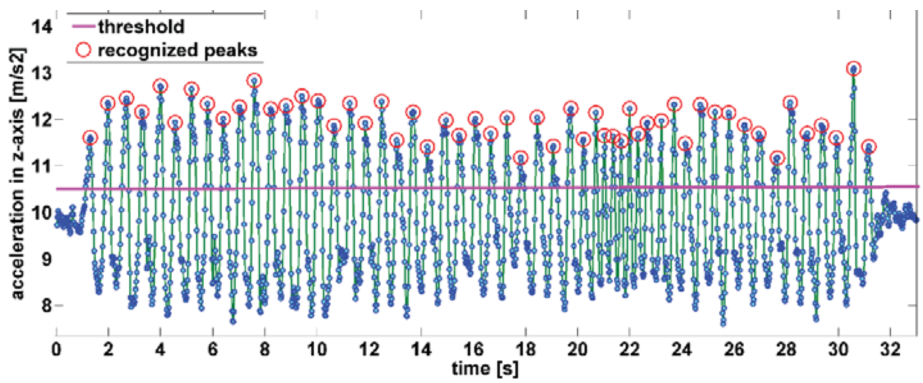

Figure 3. Accelerometer data from z-axis and detected steps.

For the inertial navigation algorithm, the step detection algorithm was combined with orientation data of the smart phones at the step time as can be seen in Figure 4 as example.

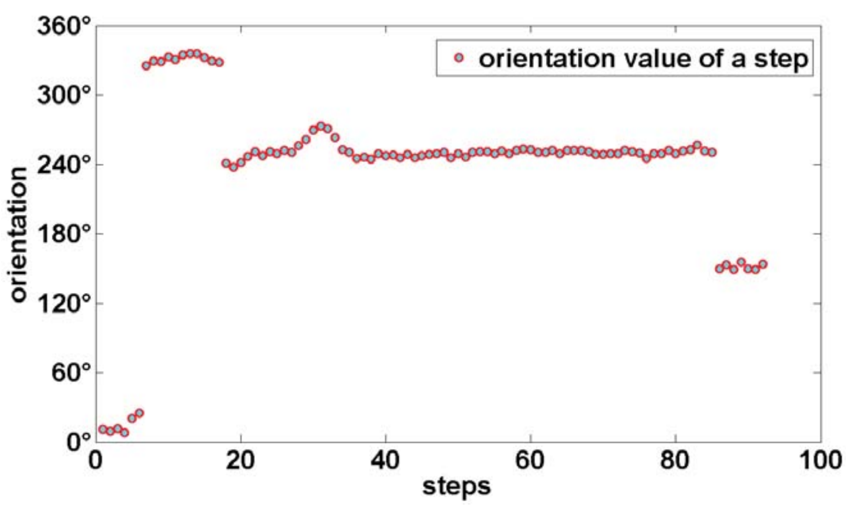

Figure 4. Example of orientation values at step from android orientation sensor.

The disadvantage of inertial navigation, however, is that the starting position must be known and there is always a drift of the calculated position to the real position, which increases with every new calculation when moving along.

4. Recognition of the iCPs

For more tests 17 iCPs positions were chosen form the 49 analyzed positions as discussed in chapter 2. This iCPs are divided up in 4 sections, which must be passed in logic sequence. For example, the first section is the entrance section. The aim was to detect the used entrance with a Wi-Fi fingerprinting strategy. By considering this logic sequence and give some APs a higher weighting it was possible to recognize the 17 iCPs with a rate of 92,9 percent. This results are illustrated in Figure 5.

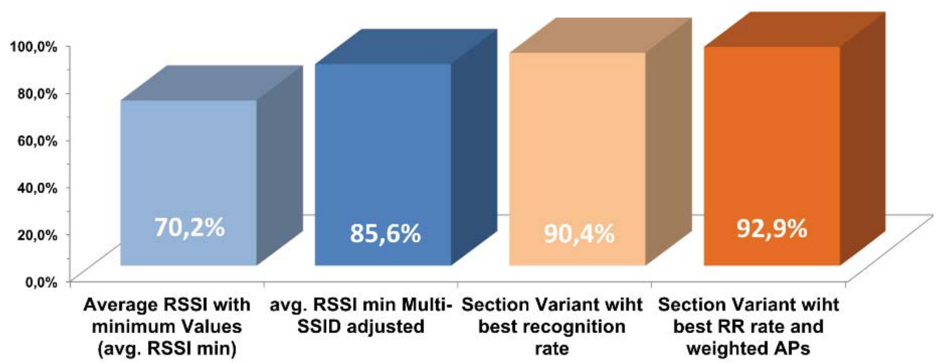

Figure 5. Average recognition rate of Wi-Fi Fingerprinting by dividing in sections.

For recognition of the iCPs while moving, the number of possible iCPs is reduced by using a logical sequence how they can be passed. So always only a limited number of iCPs is observed. If a minimum Euclidean distance between the measured RSS values and the RSS values in the database is found, then the iCP is recognized as can be seen in Figure 6.

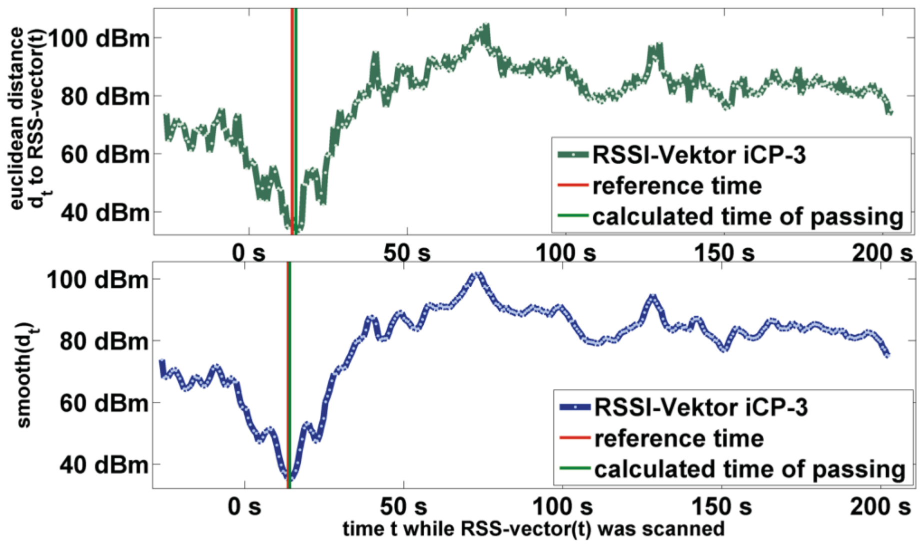

Figure 6. Euclidean distances of a certain iCP calculated from continuous RSS scans while walking along a trajectory.

In the test runs the iCPs were recognized in movement with an accuracy of 2.5 m on average. For further work more RSS values should be considered instead of using one minimum value.

5. Inertial Navigation with iCPs

To combine the inertial navigation and the iCPs the current position is corrected at the position of recognized iCP. Also information of the possible passing direction and step size (stairs) was considered. Figure 7 and Figure 8 show the joined trajectories TR-Ei5 and TR-E8 and compares GPS, inertial navigation and iCP supported inertial navigation.

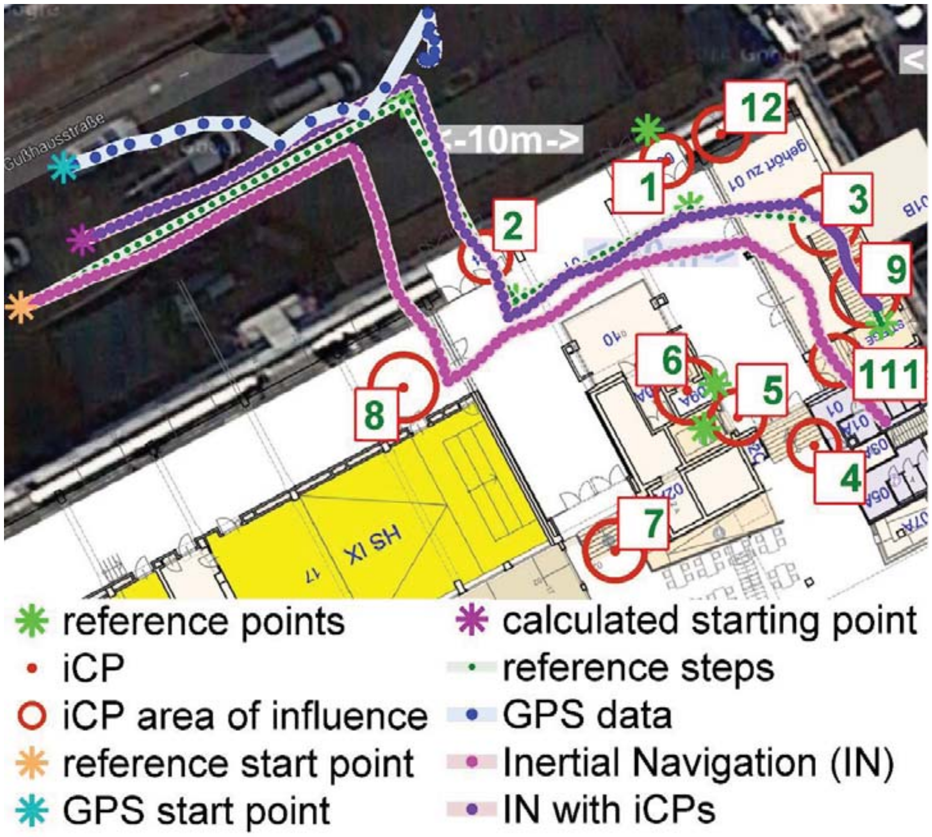

Figure 7. Test run TR-EI5.

With the described combination of sensors and wireless module higher accuracies then with using the GPS receiver only could be achieved. If sensors and modules are combined current test results showed an achievable positioning accuracy of 1.9 m on average. In contrast, the accuracy achieved with inertial navigation was 4,3 m and with GPS was 16.7 m on average, if GPS was available at all. Details of the results are shown in Table 1.

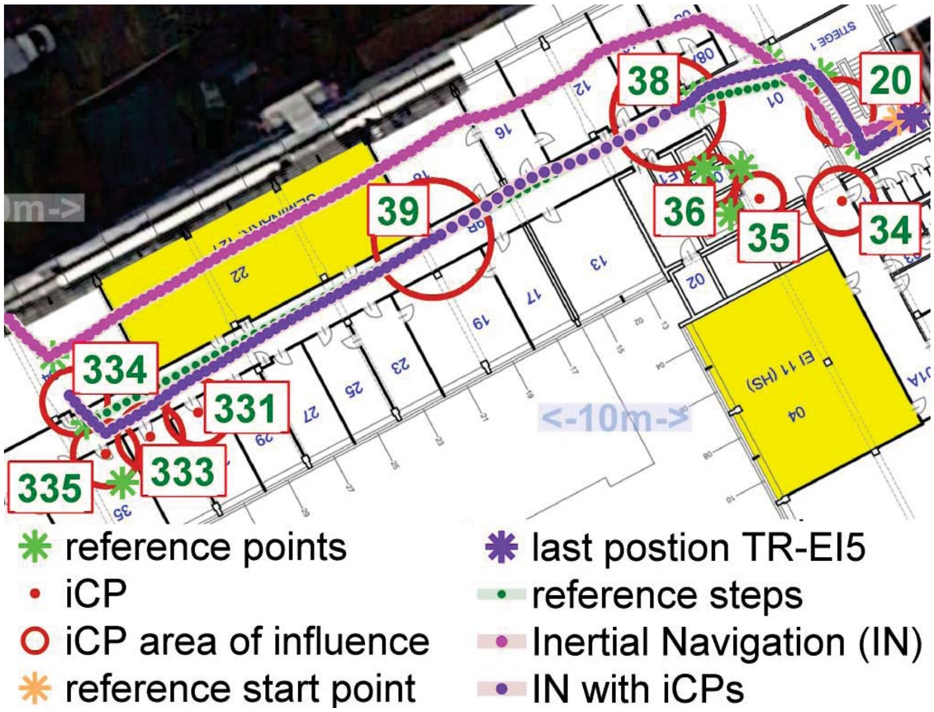

Figure 8. Test run TR-EI8.

Test runs	average			end position			maximal			start pos.	
	GPS	IN	iCP-IN	GPS	IN	iCP-IN	GPS	IN.	iCP-IN	GPS	iCP-IN
TR-EI1	34,5	2,9	2,3	36,6	3,5	2,2	45,7	4,3	4,5	45,5	3,0
TR- EI2	20,7	6,0	4,0	25,8	4,0	2,0	37,4	10,0	11,3	37,4	11,3
TR- EI3	16,4	3,2	1,9	31,3	3,5	0,0	31,3	6,4	4,8	1,4	2,0
TR- EI4	12,8	4,3	1,5	22,6	8,5	1,0	22,6	8,5	4,7	20,4	1,5
TR- EI5	14,7	4,2	1,9	32,2	5,9	1,1	32,2	6,4	5,5	8,9	5,5
mean	***19,8***	***4,1***	***2,3***	***29,7***	***5,1***	***1,3***	***33,8***	***7,1***	***6,2***	***22,7***	***4,7***
TR- EI6		4,8	1,5		8,7	2,1		9,2	2,7	***N.A.***	
TR- EI7		3,8	1,1		4,6	3,1		6,9	3,7		
TR- EI8		5,5	1,3		6,5	0,5		8,0	3,4		
mean		***4,7***	***1,3***		***6,6***	***1,9***		***8,0***	***3,3***		
All values are in meter.											

Table 1. Results - Comparison of GPS, inertial navigation and iCP supported inertial navigation.

6. Conclusions

With the presented iCP supported inertial navigation it was possible to solve the disadvantages of this navigations type. The drift of the calculated position can be corrected with the recognition of iCPs. By using the iCP algorithms it is not necessary to know the start position anymore perform inertial navigation. A needed start position for the inertial navigation can be calculated when an iCP is passed.

Another advantage of the iCP approach compared to common fingerprinting is the reduction of needed reference points. Commonly a raster of reference points where the RSS values are measured are defined. With the iCP approach only RSS values on way points have to be measured for the calibration of the system.

For a further development of the iCP approach some more improvements could be investigated. For Example, the recognition of an iCP with one minimum value can be expanded by using a threshold or using a pattern recognition approach for sensor and RSS data. Also it might be meaningful to research on stochastic methods for iCP recognition.

Contacts

Hannes Hofer and Guenther Retscher

Department of Geodesy and Geoinformation, Research Group Engineering Geodesy, TU Wien, Gusshausstrasse 27-29 E120/5, 1040 Vienna, Austria
E-Mail: h.hannes@gmx.at
or guenther.retscher@tuwien.ac.at