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Outdoor and Indoor Positioning using Smartphones

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Introduction

Location-Based Services (LBS) join the components information, communication and navigation. Nowadays, modern smartphones can connect themselves to the Internet nearly everywhere. Therefore, smartphones with their possibilities to communicate, their access to information and with their array of sensors which enable navigation, represent an outstanding example of an LBS. Whereas current commercial navigation systems can only be used outdoors, most of these smartphone sensors can be applied for positioning and navigation outdoor as well as indoor. In order to gain an optimal position solution, the data has to be combined within a navigation filter. Within this filter, all of the available sensor data are integrated according to their individual measurement accuracies.

Navigation with Smartphones

Motivation

Nowadays, about three quarters of the people in middle europe own mobile phones, of which more than 50 % are smartphones. Predictions are, that the sale of mobile phones will rise and in three to four years nearly every sold phone will be, by definition, a smartphone. This leads to the assumption, that in 2017 more than two thirds of the people will have a smartphone.

Positioning Sensors

Modern smartphones contain an array of sensors for positioning, see Table 1. While low-cost smartphones only include accelerometers and Wifi, more advanced smartphones might include GNSS chips, cameras, magnetic sensors, proximity sensors, gyroscopes and barometers. Basically, all of these sensors can be used for navigation purposes in some way, however they differ highly in availability and accuracy. Where Cell ID positioning (as well as GSM positioning) is working outdoors as well as indoors, its accuracy of 100 to 200 meters is too bad to even identify a building. GNSS on the other hand is more accurate (~10 m), but only available outdoors with a good visibility to the corresponding satellites. In regions where GNSS fail, methods like Wifi positioning step in. Wifi positioning is, compared to other localization methods, quite accurate with an accuracy of 3 to 5 meters, works indoors but does depend on the creation of an according database based on signal measurements done in advance. Relative positioning is possible with the inertial sensors (accelerometers combined with gyroscopes) of modern smartphones. However, solutions calculated out of low cost inertial sensors are not very reliable and drift over time. Additionally, the position and orientation from the smartphone to the person who carries it should be known.

Sensor	Type of Navigation	Infrastructure	Outdoor	Indoor
GNSS	absolute position	GNSS satellites		
Wifi	absolute position	radio map database		
Camera	information from QR tag	- / QR tags		
Accelerometer	step detection (distance)	-		
Gyroscope	relative orientation	-		
Magnetic sensor	absolute orientation	-		
Barometer	relative height	-		
Building plan	map matching, map aiding	plan development		

Table 1: Smartphone sensor comparison

Additional to the mentioned sensors, building plans may be used within smartphone navigation (Figure 1). They can be used in two ways; on the one hand, in the sense of being a supplemental sensor which is called map aiding, and on the other hand, the estimated postion can be projected onto paths of a map which is defined as map matching. These positioning possibilities are the reason why the building plan is listed as an additional sensor in Table 1. Table 1 specifies the needed infrastructure for the positioning with the corresponding sensor, the type of navigation and the indoor and outdoor capability of every individual sensor. In Figure 2, two short applications for the sensor readout of the inertial sensors as well as the Wifi signals are shown.

Figure 1: The map as additional sensor

Figure 2: Readout of the smartphone sensors

Navigation Filters

With the use of navigation filters, the measurement data of different sensors can be combined to estimate the position of the smartphone. These measurements are integrated within the filter by applying a motion as well as an observation model. Additionally, the measurement noise of every individual sensor is introduced to weight the different measurements according to their accuracy. Regardless which kind of sensors the smartphone has, the filter can handle every type of measurement (absolute/relative position, motion parameters like velocity or acceleration, absolute/relative orientation, etc.) by modifying the observation model accordingly. By using a motion model, the filter works also in case of absent sensor measurements, since this model transfers the state vector from one epoch to the next by applying the dynamic parameters of the last epochs.

The Kalman Filter, the Grid-based Estimation as well as the Particle Filter (Figure 4) are based on the concept of a motion as well as an observation model. The Kalman Filter estimates the mean and the covariance of the position, while for the Grid-based Estimation and the Particle Filter samples within the state space have to be generated and evaluated with a probability according to the motion of the smartphone and the measurements. Figure 3 shows the results of a Kalman filtered and a Particle filtered Wifi trajectory within a building.

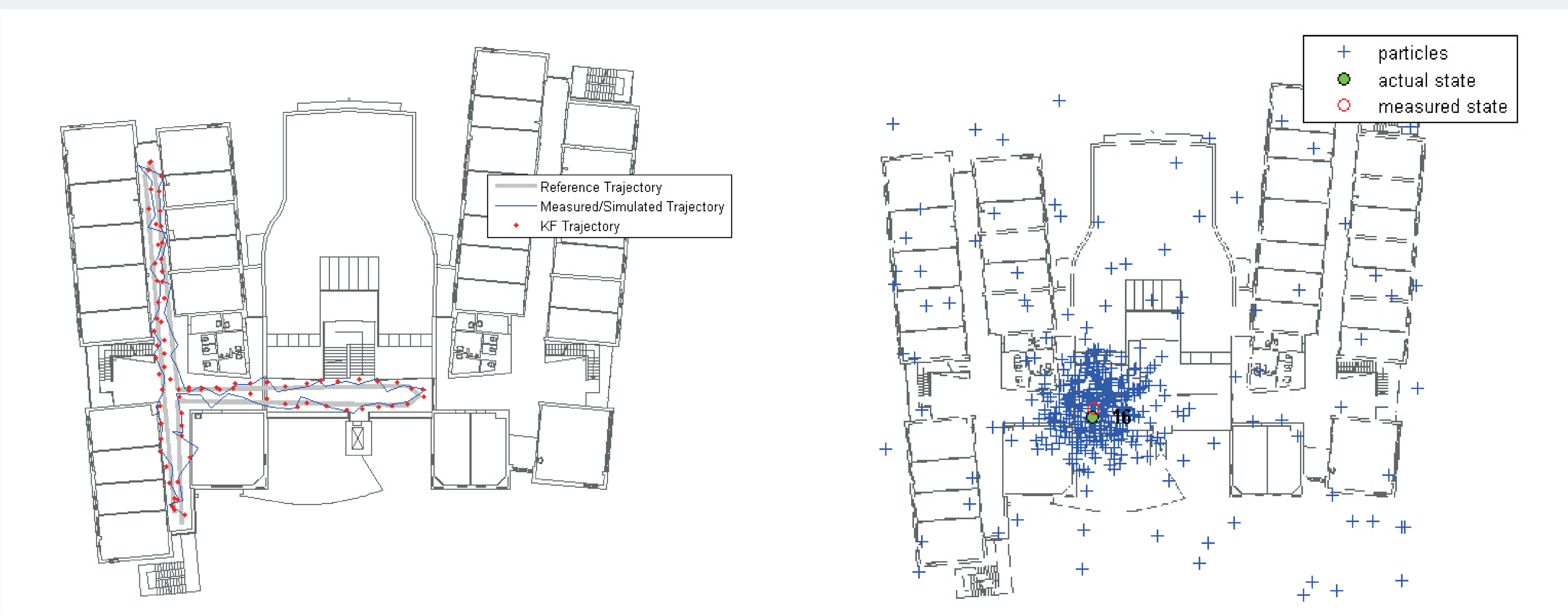

Figure 3: Kalman Filter (left graph) compared to the Particle Filter (right graph)

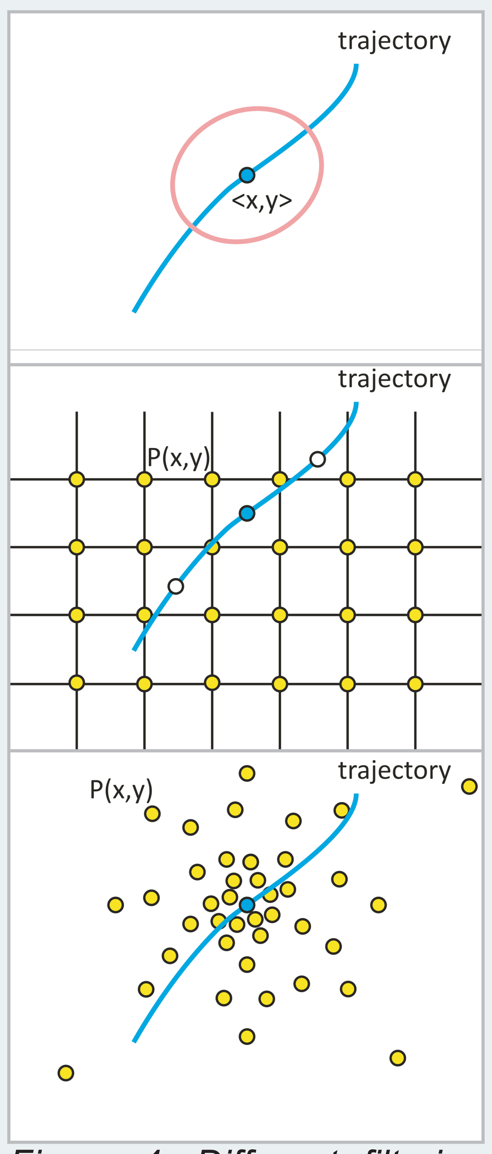

Figure 4: Different filtering methods in the field of navigation (Kalman Filter, Grid-based Estimation, Particle Filter)

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