Use of magnetic fields in combination with Wi-Fi and RFID for indoor positioning

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Introduction

Positioning and navigation of pedestrians outdoors is nowadays possible with an accuracy of only a few meters by using GNSS and inertial sensors. Similar accuracies are achievable by using smartphones. If GNSS is used for positioning, a direct line of sight is necessary. Hence, other positioning techniques are required to navigate pedestrians through buildings. There are several indoor positioning approaches. Here fingerprinting is used as positioning technique. Fingerprinting needs transmitters which transmit specific signals, for example Wi-Fi, RFID, UWB etc. Thus, certain infrastructure is required in buildings to do fingerprinting. The advantage of the geomagnetic field is that no transmitter infrastructure is necessary for measuring magnetic flux density. Therefore its use in fingerprinting seems promising. The idea is to refine an approximate solution for the position of the user by the use of magnetic field fingerprinting. To derive this approximate solution another signal source should be used for fingerprinting. Because Wi-Fi infrastructure already exists in many buildings, it seems to be convenient to use Wi-Fi fingerprinting.

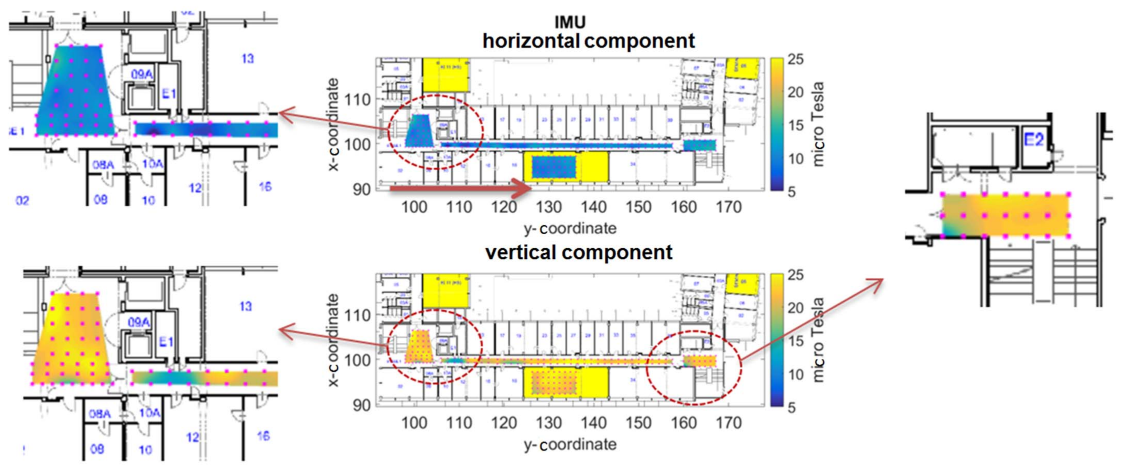

Figure 1: Radio maps of the IMU (red arrow marks the orientation of the user)

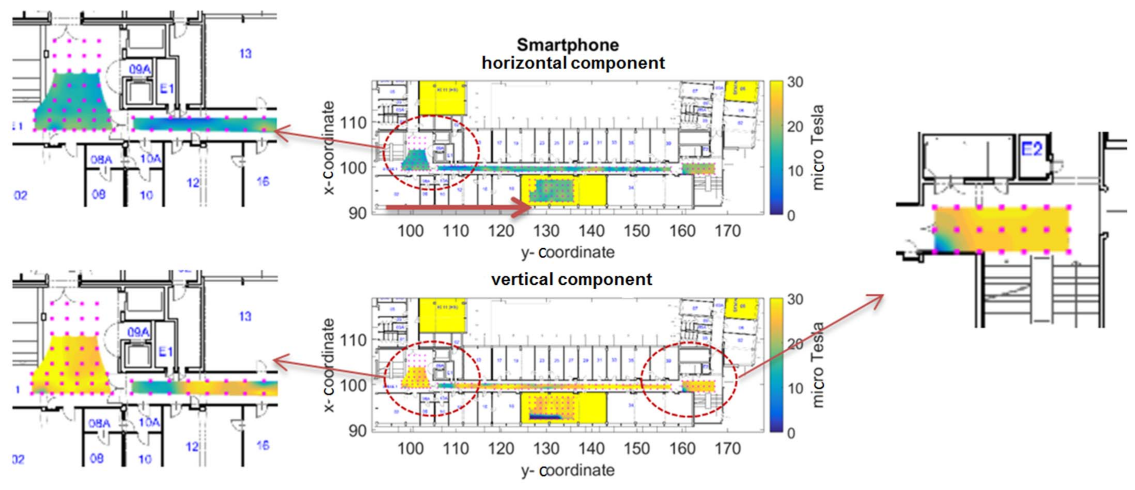

Figure 2: Radio maps of the Smartphone (red arrow marks the orientation of the user)

Fingerprinting

A Radio maps

Fingerprinting mainly consists of two parts, the offline and the online phase. In the offline phase the signal strengths of one or more signals of opportunity are observed at certain points with known coordinates. Afterwards these signals strengths are stored in the so called radio map. In the online phase, the signal strengths are observed at an unknown point. By comparing the observed signal strengths with those from the radio map, the unknown position can be determined. The radio maps are the basis for deriving positions in fingerprinting. To reduce the influence of the user's body, on every radio map point the magnetic field is measured in four orientations. Figure 1 and 2 show the radio maps of both sensors. By comparing the radio maps according to the used sensor, an offset in the flux density is visible. This is due to calibration of the IMU. The structure of the radio maps however seems to be independent from the used sensor. Especially the maxima and minima of the vertical component of both sensor coincide. The variations of the magnetic field are bigger in the radio maps of the smartphone.

Table 1: Average positioning error of the ten test points in [m]

	IMU		Smartphone	
	Euclidean	Mahalanobis	Euclidean	Mahalanobis
Magnetic field	22.92	17.78	17.87	15.11
Wi-Fi	-	-	2.31	2.75
RFID	-	-	2.52	2.09
Mag + Wi-Fi (Var. 1)	3.67	3.28	3.38	3.07
Mag + Wi-Fi (Var. 2)	2.93	2.89	2.66	2.55
Mag + Wi-Fi + RFID	2.35	2.98	2.25	2.04

B Static positioning

To derive the achievable accuracies, the coordinates of ten test points are calculated by using different fingerprinting variants. The first three variants are to use pure magnetic field, pure Wi-Fi and pure RFID fingerprinting. The first combination variant is to get an approximate solution by using Wi-Fi fingerprinting and afterwards only radio map points which lie within a square of eight meters side length are used for magnetic field fingerprinting. The final position is the one derived from this magnetic field fingerprinting. In the second combination approach, the approximate solution from Wi-Fi fingerprinting and the solution from the magnetic field fingerprinting with fewer radio map points are averaged. The last variant is the combination of magnetic field, Wi-Fi and RFID fingerprinting. Additionally, two distance criteria are used, the Euclidean distance and the Mahalanobis distance. The number of nearest neighbors used to calculate the position stays constant during all calculations and is five. Table 1 shows the achievable accuracies according to the used distance criteria and the fingerprinting variant.

C Kinematic positioning

For evaluating the kinematic test measurements a Kalman filter is used. The state vector, which will be estimated, consists of the x- and y- coordinates and the velocity of the user. First a motion model has to be chosen to predict the state. The motion model used here relies on polar coordinates (Equation 1). Therefore the estimated coordinates from time k-1, the travelled distance and the actual heading are necessary. The travelled distance is calculated by multiplying the estimated velocity from time k-1 with the time interval of the Kalman filter. This time Interval is chosen to 0.5s. The heading is the control input and is derived from the magnetometer of the sensor. The observations for the coordinates in the Kalman filter are derived from magnetic field and Wi-Fi fingerprinting. Figure 3 shows the result for one trajectory.

$$
\begin{aligned}
\bar{y}_k &= \hat{y}_{k-1} + \Delta t \cdot \hat{v}_{k-1} \cdot \sin(\psi_k) \\
\bar{x}_k &= \hat{x}_{k-1} + \Delta t \cdot \hat{v}_{k-1} \cdot \cos(\psi_k) \\
\bar{v}_k &= \hat{v}_{k-1}
\end{aligned}
\qquad (1)
$$

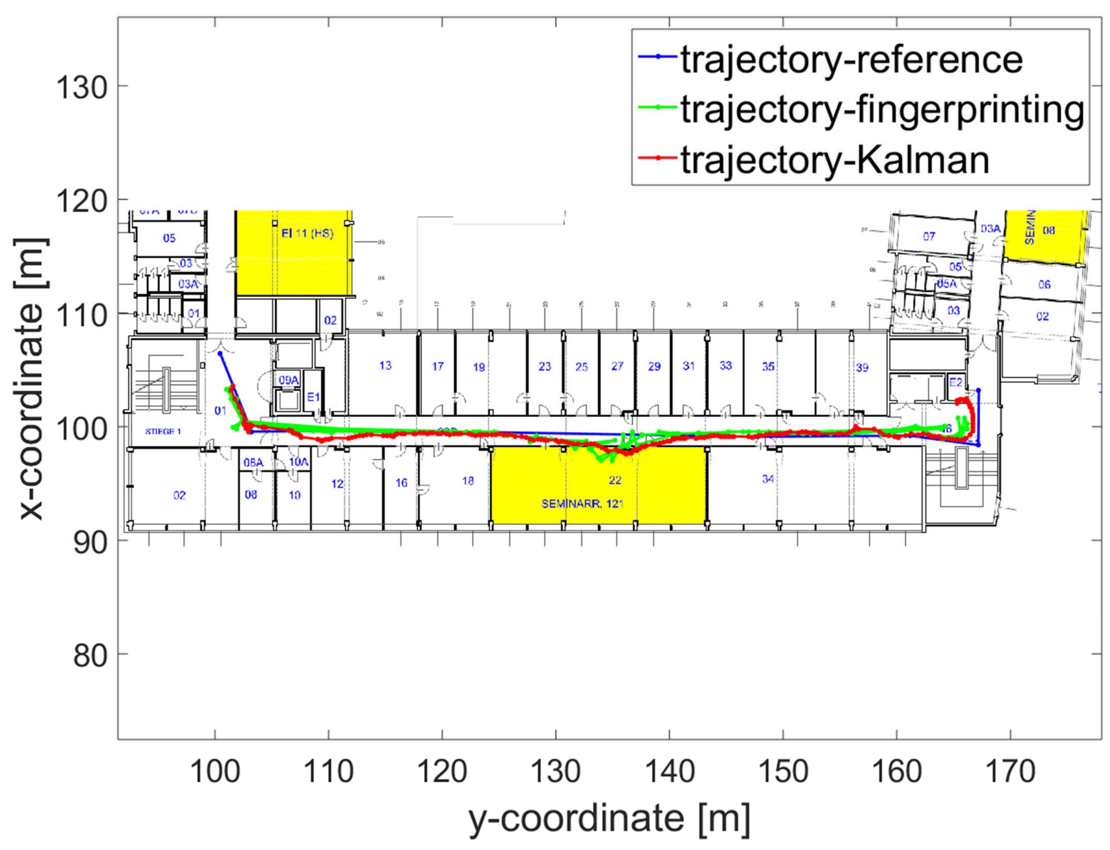

Figure 3: Estimated trajectory and corresponding observations from fingerprinting

Temporal variations

For fingerprinting it is necessary that the radio maps are valid over a longer period of time. If the magnetic flux density varies over time, the fingerprinting process is affected in a negative way. To analyze the temporal variations epoch wise measurements were done over more than two months with the smartphone on several test points. Figure 5 shows the result of these measurements on one of the test points. The horizontal component stays constant over time but the vertical component decreases after one and a half months from approximately 35µT to 30µT. Because of the changes which are bigger than the measurement noise of the sensors, it is important to keep the radio maps up to date.

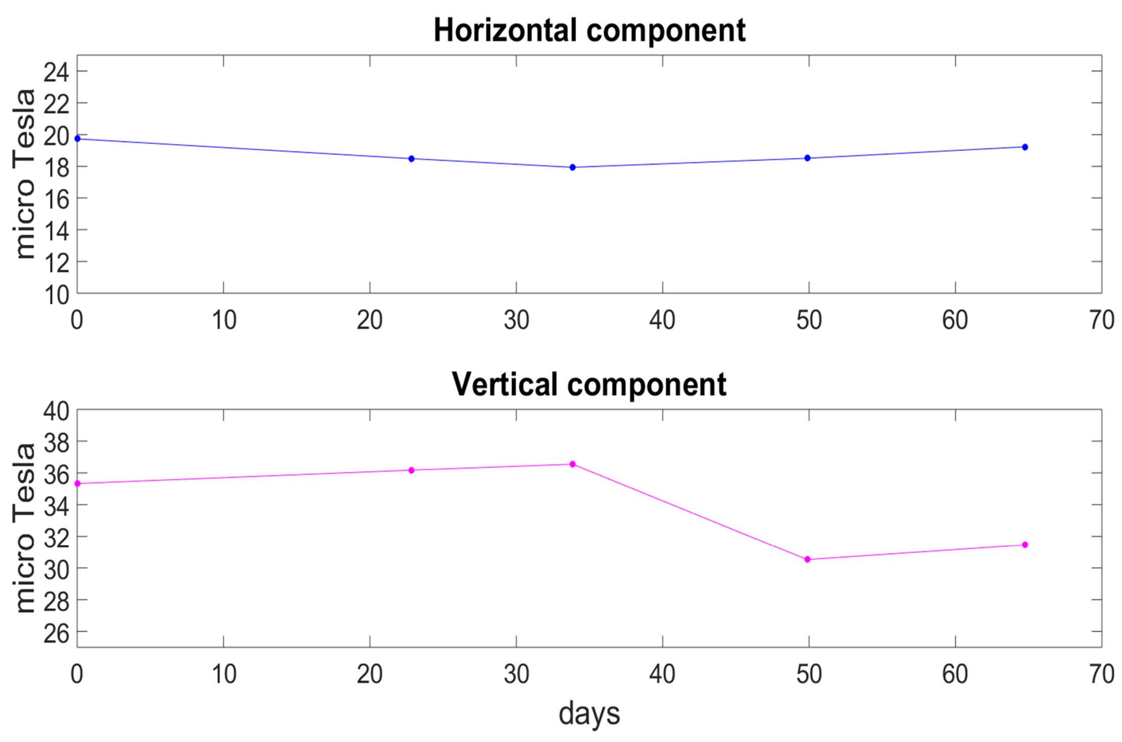

Figure 4: epoch wise measurements on a test point

Conclusions

The achievable accuracy by using magnetic fields, Wi-Fi and RFID in fingerprinting is approximately two meters. But as shown above, the temporal variations of the magnetic field are considerably higher than the measurement noise. Hence, in an extension of this positioning system a radio map update algorithm has to be included. Additionally, also the inertial sensors should be used to support the positioning phase. With the accelerometer steps and the corresponding step length could be estimated though. The gyro could be used to increase and stabilize the heading accuracy. Kinematic fingerprinting is another part of this positioning system where more investigations have to be carried out.