Feasibility Study: Magnetic-Based Passenger Localization in Train Stations

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Abstract

Train stations are a key element of any transport network because they concentrate a large amount of passenger traffic on a daily basis. Passenger localization in train stations is though limited nowadays by the lack of satellite reception indoors and underground. A possible solution could be to use magnetometers, since they are embedded in today's smartphones and are available in all urban environments. One of the most extended algorithms to perform magnetic localization is magnetic fingerprinting, however magnetic fingerprinting has not yet been proved viable in train stations. The aim of this article is to present a feasibility study of the possibility to apply magnetic fingerprinting in train stations to locate passengers. We have measured and analyzed the magnetic maps of different train stations in Munich, Germany. Our results show that, the functioning of the trains and the electric topology of the stations hinder the passenger localization using magnetic fingerprinting.

Keywords

magnetic localization, urban multimodal localization, magnetic fingerprinting, magnetic map

1. Introduction

Passenger localization in train stations is limited nowadays by the lack of satellite reception in indoor or underground environments, see Figure 1. Train stations are a core aspect of any transport network since they concentrate a large amount of passenger traffic on a daily basis.

An accurate localization in train stations would enable many location-based services, such as finding specific shops in the station or guidance for visually impaired passengers. Travel planning applications could indicate personalized commuting options depending on the physical condition of each passenger or the multimodal chain chosen for each trip.

The ubiquity of smartphones has enabled the development of localization systems for indoor environments based, e.g. on inertial sensors [1], signal intensity levels, or most commonly a combination of both [2, 3, 4].

Nonetheless, smartphones are also equipped with magnetometers and train stations have the potential of presenting a characteristic magnetic field signature. The biggest advantage of magnetometers is that they can be used in all scenarios, such as outdoors, indoors or undergrounds, to provide a seamless navigation during urban trips. Therefore, we envision the possibility of using the magnetic field to locate passenger in train platforms.

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Figure 1: Platform of the S-Bahn station Marienplatz in Munich, Germany

Passenger localization based on magnetic fingerprinting has two main steps. A first step to construct a map or database of magnetic field values at different positions of a specific area; e.g. a train platform. The second step is the matching or inference of the measured magnetic field to a specific position in the map or an entry in the database.

Until now, there has been works that demonstrated the possibility of using the magnetic field intensity and inertial measurements to track a pedestrian's position in controlled environments by means of a particle filter [5, 6, 7].

These works have a common structure: the particle filter implements a movement model based on dead-reckoning, which is based on inertial measurements. Then, the particles are updated based on matching, i.e. comparing, the magnetic field intensity of each particle to the one measured by the magnetometer. Those particles whose magnetic field is most similar to the measured one are those which survive. The authors in [8] implement magnetic field map matching based on a particle-filter as well. However, they use simultaneously three magnetic maps, namely horizontal, vertical and direction maps, to position a robot.

Magnetic field-based positioning can also be implemented without particle filters. For instance, the authors in [9] use magnetic map matching to reduce the drift in an inertial localization system based on smartphones. Other works go beyond the combination of magnetic field and inertial measurements, and integrate signal intensity levels as well [10]. The authors in [11] in contrast implement a hidden Markov Model to match the measured magnetic field intensity to a magnetic map.

To the best of our knowledge, the magnetic fingerprinting technique has not yet been applied in train stations to locate passengers. Thus, the goal of this article is to present a feasibility study of the possibility to apply magnetic fingerprinting in train stations to locate passengers.

There is some infrastructure in train stations that may generate characteristic magnetic signatures, e.g. metallic objects, such as pillars, bins or benches; or electrified structures, such as mechanical stairs, lifts or ticket machines. However, the power line of the trains may destabilize the magnetic map of the station.

In order for the magnetic map of the train station to be suitable for localization purposes, it has to fulfill the following characteristics:

- High spatial variation
- Low temporal variation

The high spatial variation facilitates the mapping, because a low spacial variation implies that many entries of the stored map have similar values. The temporal variation on the contrary needs to be low in order for the stored map to be stable over time.

Section 1 is dedicated to the introduction. Section 2 is commited to describe our measurement setup. Section 3 analyzes the different urban trains present in Munich. Section 4 is devoted to the generation of the magnetic maps of the different train stations. Finally, Section explains 5 sums up the conclusions of this work.

2. Measurement Setup

The measurements of the magnetic field have been performed with a rigid wooden structure, which has four magnetometers fixed at 1.7 m, 1.4 m, 1.1 m und 0.8 m height, see Figure 2. The chosen heights represent the height of the four most common smartphone positions, respectively phoning, reading, pocket and hanging.

Figure 2: Rigid wooden structure containing four magnetometers at 1.7 m, 1.4 m, 1.1 m and 0.8 m. The magnetometers have been highlighted in the figure with blue circles.

The three-axis magnetometers have been calibrated. The calibration of the magnetometer is of crucial importance in order to correct instrumentation errors and magnetic deviations, i.e. soft and hard iron effects due to the host platform [12]. In order to calibrate the magnetometers, the cardboard structure has been manually moved describing random paths covering all directions. The recorded raw magnetic field measurements form a shifted ellipsoid if the magnetometers are not calibrated. A least-squares algorithm is used to find the rotation, translation and scaling factor to bring the ellipsoid to a sphere with radius equal to 1 centered in the origin. The center of the sphere represents the biases of the three-axis magnetometer. The radius of the sphere is used to normalize the uncalibrated magnetic measurements to the local magnetic field intensity. The calibration process took take place in a disturbances-free environment, i.e. under a homogeneous magnetic field.

3. Analysis of Different Urban Trains of the City of Munich

For this work we consider different types of train networks of the city of Munich. There are two types of urban trains in Munich: the subway (U-Bahn) that runs mostly underground in the city area, and the suburban train (S-Bahn) that covers a wide area and often run aboveground. In Table 1 we present the electric characteristics of these two train networks.

	Suburban Train	**Subway**
Current	Alternate	Direct
Electrification	Catenary	Rails
Voltage	15 000 V	750 V
Intensity	16.7 A	$>$1000 A

Table 1
Electric characteristics of the suburban train and the subway of the city of Munich

The suburban train network of the city of Munich is based on overhead contact wire, that means, the current is transportated over the catenaries. The suburban train runs on alternate current at 15 000 V. The subway network of the city of Munich is based on a rail contact wire, that means, the current is transportated at the rail level. The suburban train runs on direct current and drows more than 1000 A to accelerate and brake.

In order to cover a representative subset of train stations, we have chosen three suburban train stations: one in the suburbs, which is outdoors, and two underground stations, one in the city center and one that is shared with subway lines crossing at a different level. We have measured in two different subway stations (all underground): one belonging to a single line and one station shared by two subway lines at the same level.

4. Generation of Magnetic Maps

4.1. Static Measurements of Subway Stations

In order to examine if the magnetic map of the platforms is sufficiently invariant over time, we have performed static measurements over 15 min. We have chosen this timespan to allow measuring at least one train entering and leaving the station during these static measurements.

The chosen point to perform the static measurements is not located in the proximity of electrified constructions that might add magnetic field perturbations, such as mechanical stairs or lifts.

The static measurements at the Holzapfelkreuth subway station show that the magnetic field temporal variation is so high that the map obtained is no longer meaningful within a few seconds. This is shown in Figure 3, where the blue line shows the norm of the three axis of the magnetometer positioned at 1.1 m height. The shadowed blue areas represent the timespan where the trains circulating on the adjacent track enter, stay and leave the station. The shadowed orange area represents the timespan where the train circulating on the main track enters, stays and leaves the station.

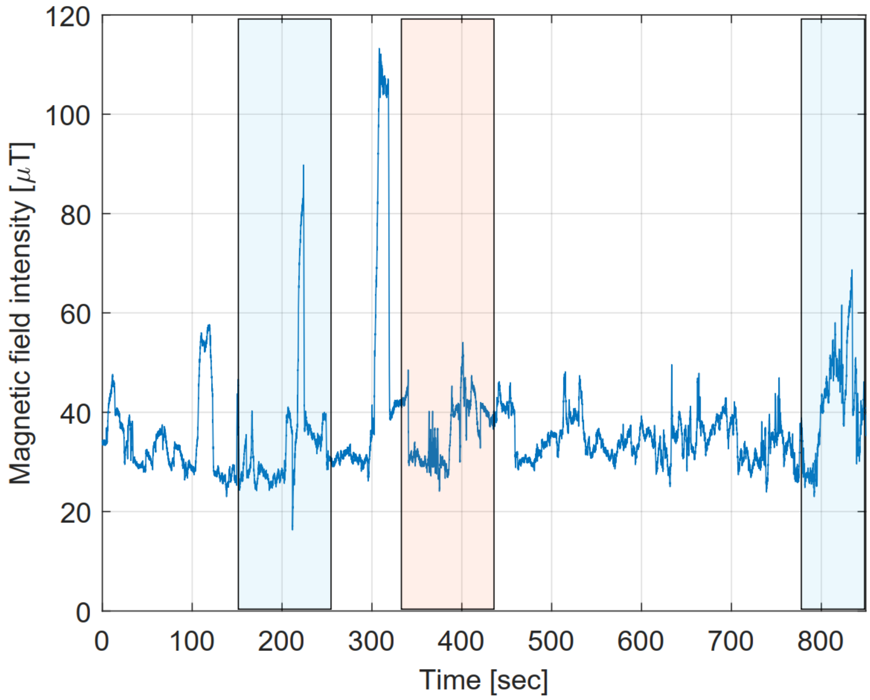

Figure 3: Norm of the three-axis magnetometer during static measurements at the platform of the Holzapfelkreuth subway station. The trains entering, staying and leaving the station have been marked with shadowed-areas: orange for the trains circulating on the main track and blue for the trains circulating on the adjacent track.

Figure 3 shows with a blue line the norm of the three-axis magnetometer positioned at 1.1 m height. As the figure shows, high-amplitude temporal variations of the magnetic field of the subway station are constantly measured. These temporal variations are due to trains accelerating and braking in the station under observation and in nearby stations. The subway stations are connected in Munich in groups of 10, therefore magnetic field generated by trains moving in nearby stations can be as well measured. This is due to the very high current intensity the subway needs to accelerate and brake, see Table1.

This very high current intensity causes a strong magnetic field that can be measured not only at the platform level, but also in another levels. These results have been observed as well at the platform and at the shops level of the subway station Muenchner Freiheit. The high-amplitude temporal variations of the magnetic field of subway stations makes it unfeasible to generate a stable magnetic map, needed for the localization of passengers based on magnetic fingerprinting.

4.2. Static Measurements of Suburban Train Stations

We have performed static measurements of 15 min duration in one point of the centric underground suburban train station Marienplatz depicted in Figure 1.

Figure 4 shows the blue line that represents the norm of the three axis of the magnetometer positioned at 1.1 m height. The blue line for the suburban train stations seems to be thicker for

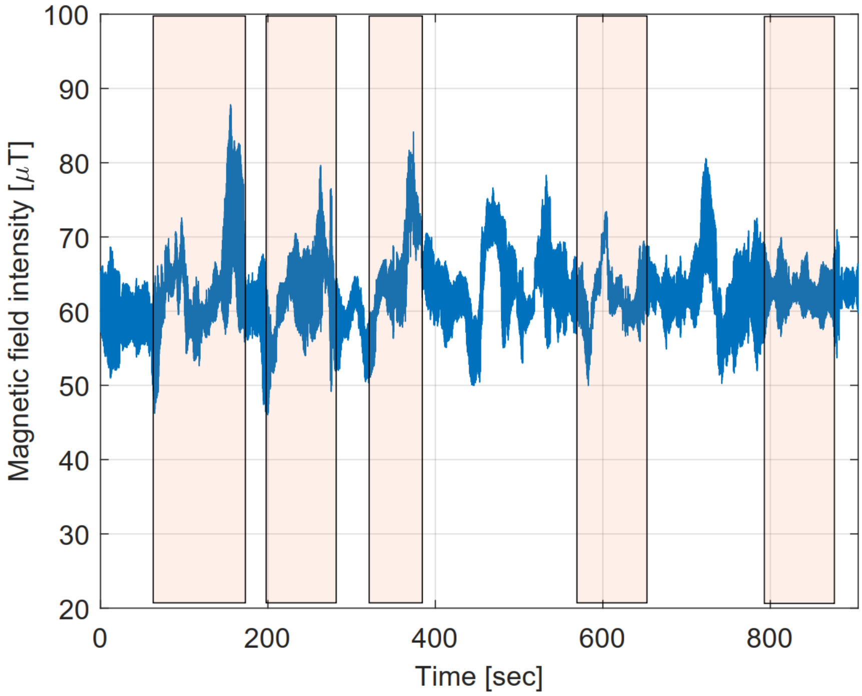

Figure 4: Norm of the three-axis magnetometer during static measurements at the platform of the Marienplatz suburban train station. The orange-shadowed areas indicate the train entering, staying and leaving the station.

suburban trains than for the subway, however, this effect is due to the sinusoid created by the alternate current. The shadowed orange areas represent the timespan where the train enters, stays and leaves the station. In this platform there is only one track in one direction, therefore only main track. As Figure 4 shows, medium-amplitude temporal variations of magnetic field are constantly measured.

We have performed static measurements at the platform of the Rosenheimer Platz suburban train station, located in the city center and at the Gauting suburban train station, located in the suburbs of Munich, obtaining similar results.

Figure 5 shows with a blue line the norm of the three-axis magnetometer positioned at $1.1\,\mathrm{m}$ height. The trains entering, staying and leaving the station have been marked with shadowed-areas: orange for the trains circulating on the main track and blue for the trains circulating on the adjacent track.

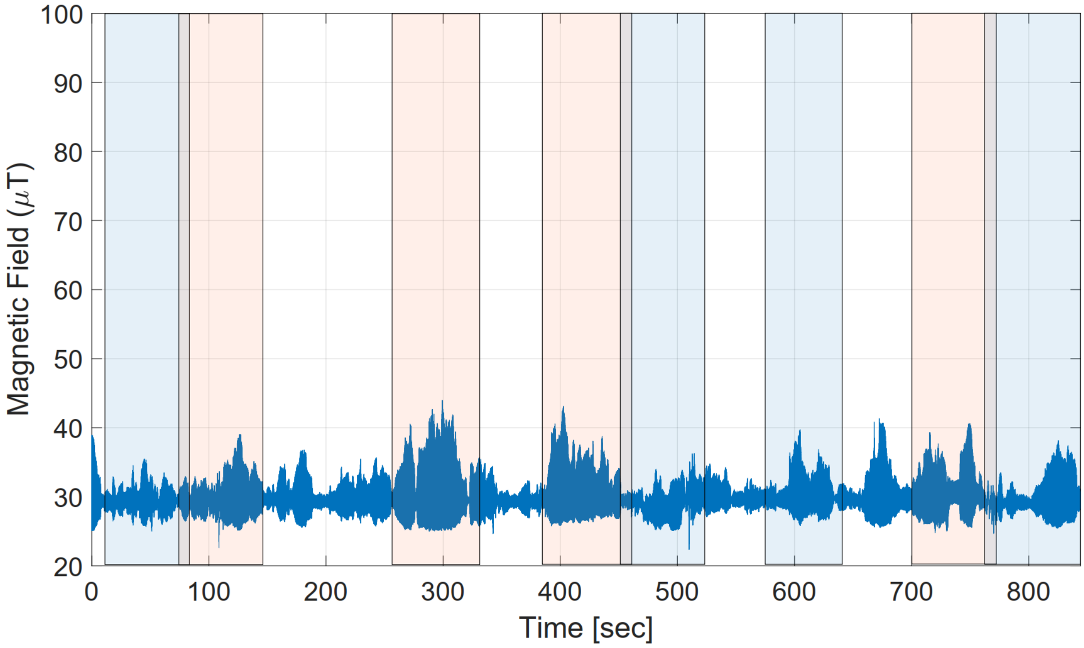

Figure 5: Norm of the three-axis magnetometer during static measurements at the platform of the Rosenheimer Platz suburban train station. The trains entering, staying and leaving the station have been marked with shadowed-areas: orange for the trains circulating on the main track and blue for the trains circulating on the adjacent track.

The low-amplitude temporal variations of the magnetic field of the suburban train station shown in Figure 5 are constantly measured. These temporal variations are due to trains accelerating and braking in the station under observation and in nearby stations. Comparing this figure with the results obtained for the train station Marienplatz, see Figure 4, one can see that the temporal variations of the latter are of greater amplitude.

The train station Marienplatz is placed in the urban area of the city and shares station with the subway. Despite of the fact of the suburban train platform not being at the same floor as the subway platform, the strong magnetic field of the subway line can be measured as well at the suburban train platform. Therefore, for shared stations, the resulting magnetic map of the suburban train platform includes medium-amplitude temporal variations of the magnetic field due to the proximity of the subway platform.

All in all for the non-shared suburban train stations, the amplitude of the temporal variations caused by trains accelerating and braking in the station under observation and in nearby stations is in average $8\,\mu\mathrm{T}$. That means that the spatial variations of the magnetic map of the station should be greater than this value in order for the map to be useful for passenger localization.

The next step is to create a map of a suburban train station to analyze the spatial variation of the magnetic field. In view of the obtained results, we have decided to continue our study with the Gauting suburban train station, since the Rosenheimer Platz suburban train station in Munich city center is much more transited by trains and passengers.

4.3. Magnetic Map of Suburban Train Stations

In order to analyze a representative part of a train station, we have decided to generate the longitudinal map of the train platform with the aim of analyzing its spatial variation. We have chosen a grid of $0.5\,\mathrm{m}$ spacing, producing a map of 110 points. We have chosen this grid spacing because it is the minimum meaningful accuracy for passenger localization taking into account the human body dimensions.

Each grid point represented in Figure 6 is computed as the average of the values measured during $5\,\mathrm{s}$ in static. In addition, each longitudinal map has been measured eight times and the eight realizations have been averaged in order to reduce the influence of the trains.

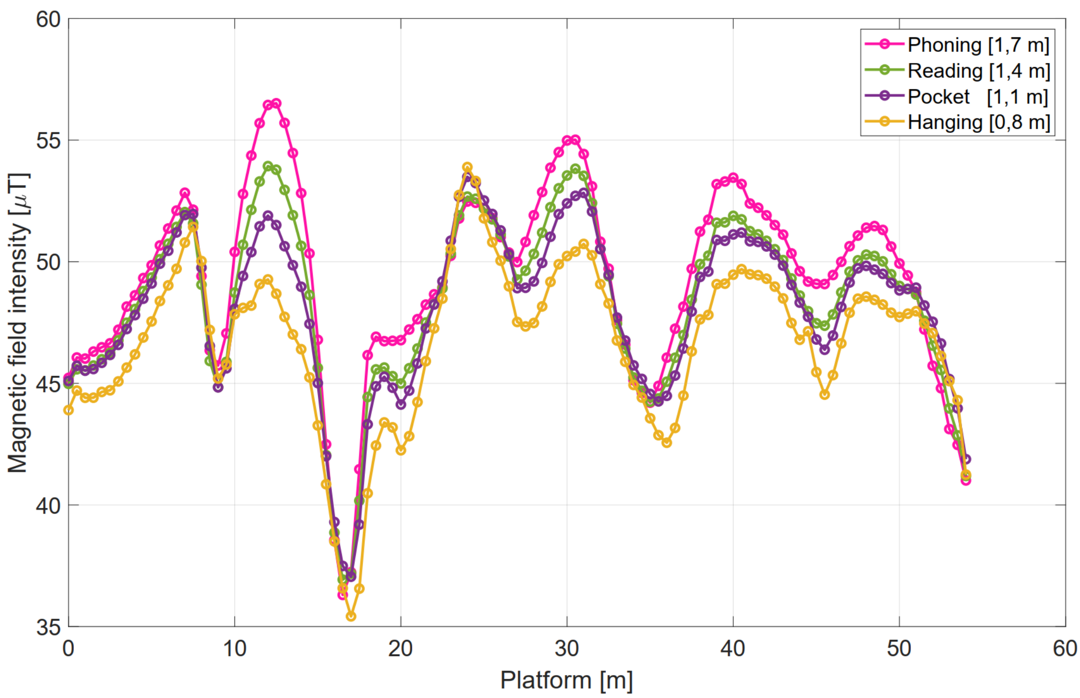

Figure 6: Magnetic intensity map of the norm of the three-axis magnetometer for the four magnetometers attached to the wooden structure shown in Figure 2, measured at the platform of the Gauting suburban train station with a $0.5\,\mathrm{m}$ spacing grid.

Figure 6 shows the recorded magnetic map at different heights, namely $1.7\,\mathrm{m}$, $1.4\,\mathrm{m}$, $1.1\,\mathrm{m}$ und $0.8\,\mathrm{m}$, that correspond with the smartphone positions phoning, reading, pocket and hanging, respectively. This magnetic map has been created with the wooden structure shown in Figure 2.

In order to analyze the temporal variation of the resulting map over a longer timespan, we have carried out four more measurements during two months. No significant changes have been observed in the resulting magnetic maps obtained during that period, being the mean standard deviation for all measured grid points is $0.39\,\mu T$.

Even if the resulting magnetic map of the non-shared suburban train platforms has proven to be static over time, its spatial variations are mainly in the range of $8\,\mu T$ for all measured magnetometer heights, as shown in Figure 6. Taking into account that the average amplitude of the temporal variations of the magnetic field caused by trains is as well in the range of $8\,\mu T$, see Figure 5, the use of magnetic fingerprinting for passenger localization in suburban train platforms is hindered.

5. Conclusion

In this work we present a feasibility study of the possibility to generate magnetic maps of train stations to locate passengers using magetic fingerprinting. We have analyzed different types of urban trains of the city of Munich.

On the one hand, we have observed that high-amplitude temporal variations of the magnetic field of the subway are measured. These temporal variations are always present and are due to trains accelerating and braking in the station under observation and in nearby stations. Thus, it is not possible to generate a stable magnetic map of subway stations.

On the other hand, low-amplitude temporal variations caused by trains accelerating and braking in the station under observation and in nearby stations are constantly measured in suburban train stations. Even if the magnetic map of non-shared suburban train stations is proven to be stable over time, the magnitude of the temporal variations produced by trains is very similar to the magnitude of the spatial variation of the magnetic map, hindering this way the passenger localization in suburban train stations using magnetic fingerprinting.

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