A NOVEL MAGNETIC INDOOR POSITIONING SYSTEM FOR INDOOR LOCATION SERVICES

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Abstract. In this contribution an accurate Magnetic Indoor Positioning System (MILPS) currently under development is introduced. MILPS utilizes artificial magnetic fields generated by coils for ranging between multiple coils and a magnetic sensor. The proposed DC magnetic signals have excellent characteristics for penetrating various obstacles in indoor environments and show neither special multipath effects nor further wave propagation errors, especially at none line of sight conditions. By determining the distances to at least three reference coils placed inside the building, the 3D position of a mobile station equipped with the magnetic sensor can be estimated using the lateration principle. In the following the basic function principle of the positioning system as well as a first prototype are presented. Furthermore the results of test measurements done with industrial magnetic sensors and embedded low cost sensors – the latter immediately applicable for indoor location services – are presented.

Keywords. Magnetic Indoor Positioning System, Accurate Local Positioning System, Indoor Location Services

1. Introduction

Following the idea of location based services for outdoor, this type of applications promise also new value-added mobile applications inside of buildings. One basic task for providing such "Indoor Location Services" is the existence of indoor positioning systems since global satellite based solutions (Global Navigation Satellite Systems, GNSS) could not be used due to the shading of satellite signals inside buildings.

For that reason, many efforts have been undertaken in the past years for the development of indoor localization systems. A lot of these systems require a positioning infrastructure consisting of reference stations – similar to the satellites in GNSS – placed inside the building. By exchanging signals between the reference and one (or more) mobile station(s) geometrical (e.g. distances, angles) and/or topological information (e.g. signal fingerprints) concerning the relative position of transmitters and receiver(s) can be derived. Therefore signals based on wireless technologies like ultrasound, electromagnetic or optical waves are utilized. Based on the geometrical and/or topological information position estimation for the mobile station(s) can be done.

However, often the availability of such systems cannot be guaranteed due to walls, furniture, plants etc. since the signals are not able to penetrate such obstacles (shading) or are distorted (attenuation, fading or signal delay) while passing the building material. Furthermore, these systems suffer from multipath as refractions, especially at none line of sight (NLoS) conditions between the reference and mobile stations. In result, the systems are unreliable and due to the propagation errors it is not possible to achieve accuracies better than several meters. Furthermore, depending on the position estimation technique, some systems only allow the determination of 2D position.

This text introduces an accurate Magnetic Indoor Local Positioning System (MILPS) under development, which overcomes the disadvantages of existing infrastructure based systems. It is suggested to utilize alternating magnetic signals which show no NLoS errors or multipath effects in indoor environments as described above. In the following the architecture of MILPS, the current prototype and the result of test measurements are outlined. Furthermore, test measurements were also done with modern smartphones (e.g. Apple iPhone) in order to evaluate the ability of MILPS for mass-market applications.

2. Basic Principle and Architecture of MILPS

Similar to other infrastructure based systems, reference stations (RS) consisting of electrical coils, which generate periodically static magnetic fields, are utilized. For the position determination a mobile station (MS) equipped with a triaxial magnetic field sensor (magnetometer) is used. By capturing the generated coil's magnetic field in the unknown point (Fig. 1), ranging between coil and sensors can be carried out. The relation between the magnetic field vector B and the distance r to the coil's center can be given by the following equation:

(1)

N is the number of turns of wire, r_0 the coil radius, θ the elevation angle, F is the coil's area and μ_0 being the magnetic permeability of space.

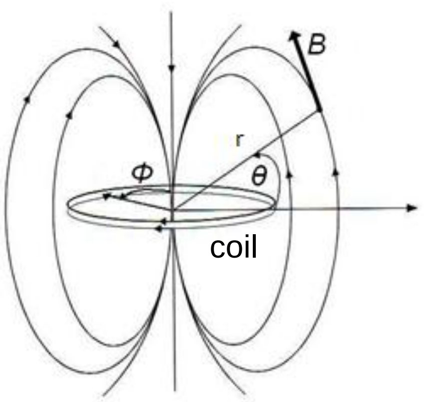

Figure 1. Coil's magnetic field

Determining the distances to multiple – at least three – coils placed inside the building, the 3D position of the mobile station can be estimated using the lateration principle (Fig. 2).

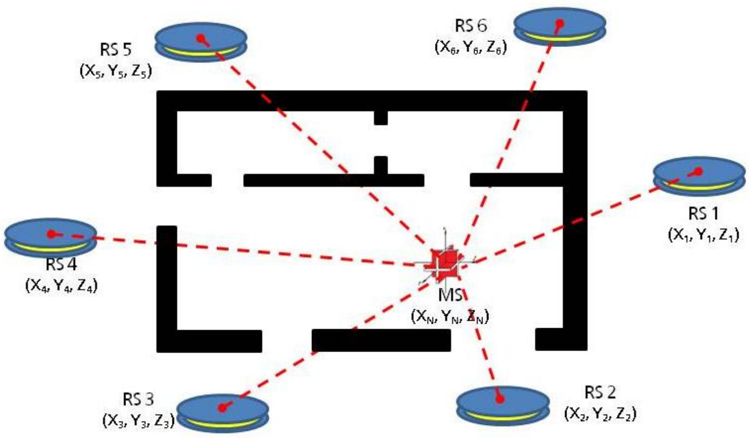

Figure 2. System architecture of MILPS with multiple reference and a mobile station

Details concerning the derivation of distance determination using magnetic fields are given in Prigge (2005) and Blankenbach & Norrdine (2010). A description of an applicable algorithm for 3D position estimation by the use of trilateration can be found in Blankenbach & Willert (2009) and Norrdine (2008).

Besides the static positioning, in future the system is also intended for location estimation of persons and objects in kinematic applications. By integrating additional passive sensors all six degrees of freedom (6 DoF) of the mobile station can be estimated. Since these stations do not interact with the reference stations, there is no restriction in the number of users. In addition the system radiates electromagnetic waves with very low frequencies (Hz range) and causes no interferences with commercial devices. Essentially the system can operate in every type of environment. Thus, it can be deployed wherever other positioning systems fail, e.g. in mines, tunnels, inside of buildings.

3. Prototype and Signal Processing

On the basis of previously applied simulations especially concerning the maximum reachable range of the system, an experimental system was built (Fig. 3).

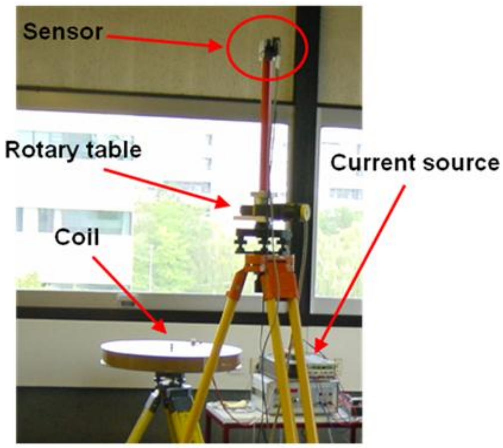

Figure 3. Experimental system of MILPS

The prototype consists at this time only of one coil with 140 turns wire wrapped on 50 cm diameter core and a commercial magnetoresistive magnetometer as mobile station. The coil is plugged to a current source which is controlled by a software application running on PC or laptop.

Initially several range measurements were executed with this prototype. Thereby the basic task was to eliminate other interference fields like the earth magnetic field or perturbations caused by electrical components installed inside the building.

3.1. Measurement Principle

For the elimination of interference fields in the captured signals, a differential measurement principle in conjunction with digital signal processing algorithms was developed. Differential means that the generated magnetic field is switched in polarity in order to filter perturbations from the environment by difference. In result a kind of square wave signal is created shown in Figure 4 for an observed magnetic field at a distance of 12 m between coil and sensor. The captured signal consists of different clusters while one cluster includes the measurement data during one switching interval.

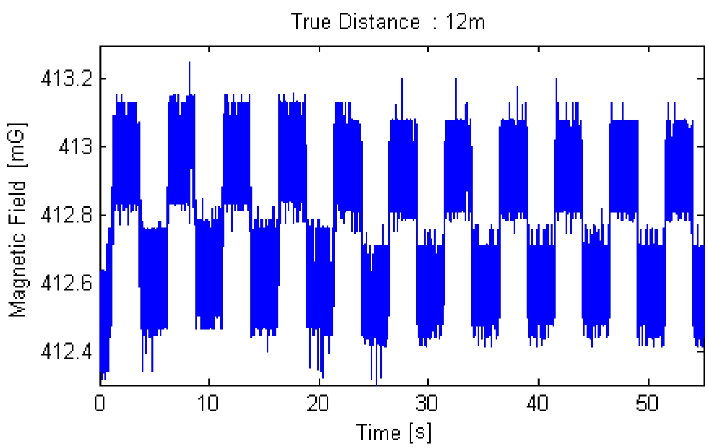

Figure 4. Captured magnetic field at a distance of 12 m

Based on the difference between the medians of two successive clusters the coil's magnetic field can be determined and hence the distance between the coil's center and the magnetometer can be calculated. In the absence of synchronization between sensor and coil, the used approach to separate the signal in different clusters is the cross-correlation of the signal and a rectangle template signal. Figure 5 shows the result of the cross-correlation applied on a captured signal. The cross-correlation gives the extreme values indicating the begin of each new cluster.

The use of a differential measurement principle would filter out every long periodic interference field like earth magnetic field. However, digital filters like notch filter, high pass and others can be designed to eliminate further interference such as the 50 Hz power and high frequency fields.

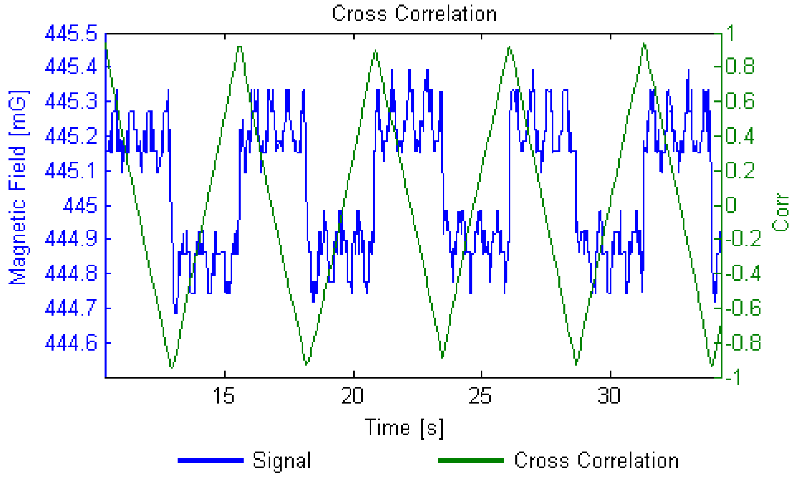

Figure 5. Cross-correlation between captured and template signal

3.2. Adaptive Filters

Since the predesigned filter is not able to be responsive to changing noise frequencies, in addition an adaptive filter (cf. Hofbauer & Moschytz 2000) is implemented. Adaptive filters (adf) are used for finding the optimal coefficients of a variable filter to extract an estimate of a desired signal, which is in the present case an uncorrupted magnetic field at a reference sensor located at a known position.

Figure 6 depicts an example of deviations between the calculated distance from an unfiltered signal and a signal processed with an adaptive filter. For practical reasons coil and sensor were placed in the same horizontal plane. In result, equation 1 is simplified because the elevation angel θ is reduced to zero.
As it can be seen, the results of the adaptive filtered signals show considerably smaller deviations compared to the true distance of 5 m than the unfiltered signals. By the use of this measurement and analysis strategy, the existing prototype allows currently the determination of ranges up to distances of 16 m between coil and magnetometer. In the example shown below, the accuracy of the range estimations can be given with 10-20 cm for short ranges (<8 m) and maximum 40 cm for long ranges (8-16 m) disregarding any systematic errors[1] still assumed in the data. One reason for the decreasing accuracy is the deteriorated signal-to-noise ratio (SNR) caused by the cubically decreasing magnetic field strength with distance.

[1] Since system calibration has still to be done.

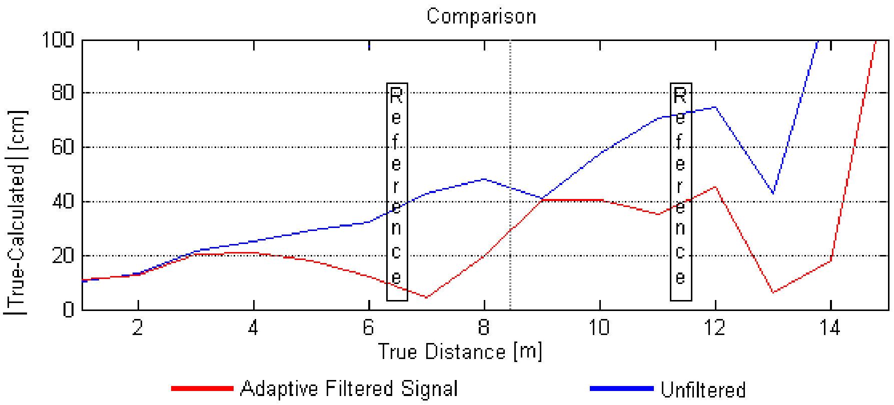

Figure 6. Comparison between unfiltered and adf-filtered signals

4. Mass-Market Indoor Location Services based on MILPS

The popularity and mass distribution of smart phones like iPhone or Android phones provides them also to be promising platforms for mobile location services inside of buildings. Comprising multiple sensors enables such units to collect different kinds of data, amongst other magnetic fields. However, the localization remains a challenge in indoor environments especially by the use of the embedded low quality sensors.

Thus, an evaluation for using the integrated sensors for the positioning determination using MILPS was done. Therefore the Apple iPhone 3GS and iPhone 4, containing ultra low power digital three-axis electronic compasses, were tested as platform. Hence, again test measurements for determining 2D distances were done by using a customized iOS-App “Teslameter” (Fig. 7, left). Teslameter (2010) measures the "deviation[s] from the magnetic field lines being tracked by the device" (CLHeading 2010) for its three space axes. The values are measured in the range -128 to +128 microtesla. It displays the values and their progression for the three axes and computes the strength of the magnetic field. The app has been extended by logging and archiving capabilities. Measured data is logged to files, where it can be later accessed and evaluated.

The analysis of the raw data shows, that it is possible to detect the coil’s magnetic signal up to a distance of five meters with both phones. The ranging accuracy as comparison between the measured and true distances depends on the distance between coil and sensor. The deviations to the true distances vary from 1-2 cm for very short distances (1-2 m) and 10-15 cm for distances between 2 and 5 m (Fig. 8).

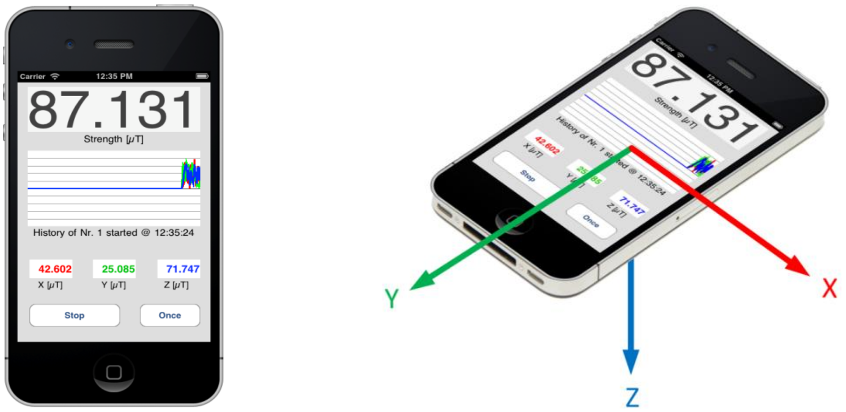

Figure 7. Customized iOS-App "Teslameter" for MILPS measurements (left); Orientation of the iPhone magnetometer axes (right).

For iPhone 3GS it has to be mentioned, that this accuracy is only reachable if the z-axis (Fig. 7, right) of the sensor points towards the coil's centre.

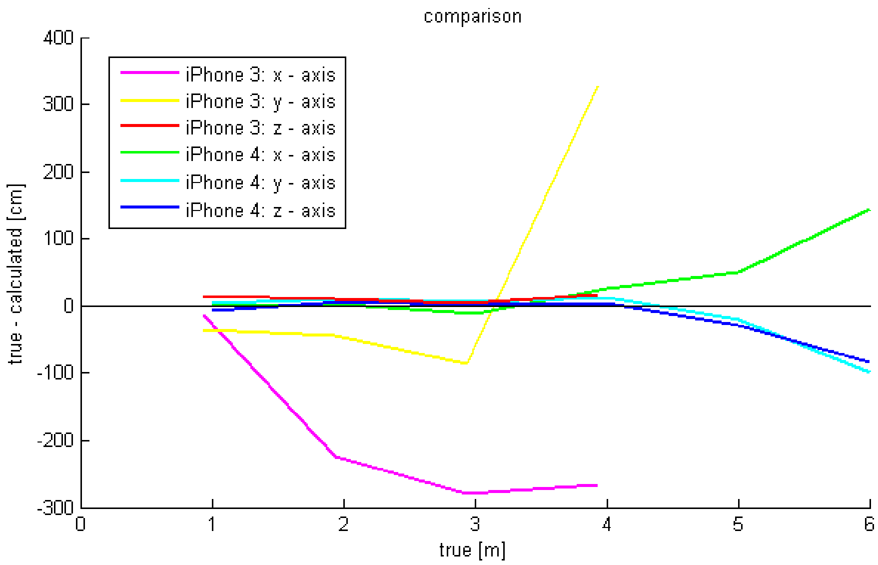

Figure 8. Results of test measurements with iPhone 3GS and iPhone 4

It appears that inside iPhone 4 the magnetic sensor is replaced by a more sensitive sensor. This could also be verified by the estimation of the measuring rate and resolution out of the raw data of both phones.

4.1. Evaluation of Localization Accuracy

As already outlined in section 2, based on determined distances the position can be calculated by lateration principle. In the present case at first “only” 2D distances are determined. So the position can be calculated by the intersection of two circles with its center at the coils’ positions and the radius given by the measured distances (Fig. 9).

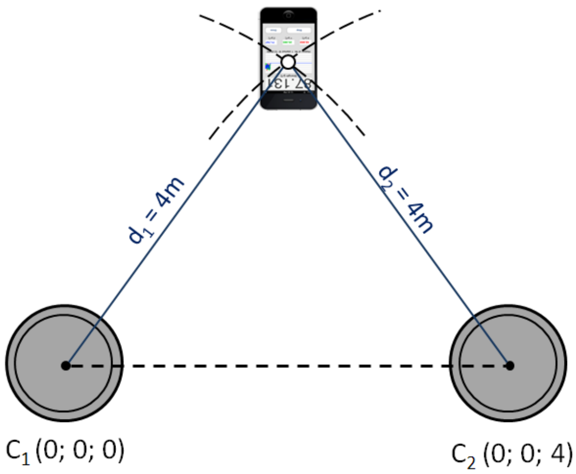

Figure 9. Simple 2D positioning example for accuracy evaluation

The resulting positioning accuracy can then be estimated by the law of error propagation (disregarding existing systematic errors and the geometric configuration in first approach). Based on the ranging results achieved with iPhone 4, for the simple example outlined in Figure 9 it is supposed, that the measured distances (d1, d2) are 4 m with a standard deviation of 0.15 m[2]. If the baseline between the two coils has a length of 4 m, the 2D position accuracy can then be estimated approximately to 0.25 m.

5. Conclusion and Outlook

A prototype of a magnetic positioning system was introduced allowing accurate indoor localization. For the position determination several coils are placed inside the building, generating magnetic fields, which can be detected by mobile stations equipped with a magnetic sensor (Fig. 2). Even low quality sensors – currently only for short distances – integrated in

[2] Corresponds to the maximum error from the comparison to the true distances.

modern smartphones (e.g. iPhone) can be used. The results achieved at test measurements with iPhone motivate further investigations using MILPS for mass-market indoor location services. In this context additional devices are to be investigated as well as the combined use of magnetic sensors with other built-in sensors.

The future work is focused on the improvement and further development of the entire system. Therefore the coverage area of MILPS is going to be enlarged by the use of larger coils and higher currents. In addition, the measurement strategy (e.g. adapted measurement frequency) is currently improved as well as the data analysis (e.g. adaptive filtering). Further work is the calibration of coils and sensors to minimize systematic errors and to enhance the accuracy in position estimation. Finally robust positioning algorithms have to be implemented in order to enable 3D localization.

Acknowledgment

The authors would like to thank the Deutsche Forschungsgemeinschaft (German Research Foundation) for funding this project (Grant no. BL 1092/1-1; Website: http://www.ilps.tu-darmstadt.de/projekte_5/milps_ilps/milps_ilps.de.jsp).

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