Adaptive Signal Processing for a Magnetic Indoor Positioning System

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***Abstract*— In this contribution a DC magnetic signal based positioning system is presented which shows no special multipath effects and has excellent characteristics for penetrating various obstacles. The proposed system allows high ranging resolution in indoor environments by using adaptive signal processing algorithms.**

***Keywords*—Indoor Positioning; Localization; Magnetic Indoor Local Positioning System, Adaptive Filtering**

I. INTRODUCTION

MILPS (Magnetic Indoor Local Positioning System) designates a current research project at the Geodetic Institute at the Technische Universität of Darmstadt and its prototype of an accurate indoor positioning system [1]. The principle of MILPS is based on direct current (DC) artificial magnetic fields, which are generated by electrical coils. By measuring the magnetic field components of multiple coils fields, the unknown position of a mobile station can be estimated. In contrast to many existing infrastructure based systems (typically utilizing optical waves, radio waves or ultrasound), magnetic fields are able to penetrate commonly used building materials without attenuation, fading, multipath or signal delay. Thus, the position estimation is not negatively influenced by these interferences, which lead – amongst other – to a higher accuracy in position estimation. Furthermore, the use of magnetic fields simplifies the access to the system. Neither special communication protocols nor a complicated user management is needed.

One of the key implementation issues of MILPS is the signal processing, because of its fundamental meaning for the operation of the system. After a brief introduction of the system architecture and components an overview of the current signal processing strategy is given.

II. RELATED WORKS

The use of artificially generated magnetic fields for tracking purposes has been investigated by a number of authors over the last decades [1-10]. Some commercial systems already exist [2] [3]. In contrast to MILPS the majority of magnetic fields based tracking systems are designed for motion tracking and virtual reality, in a number of artistic, industrial and biomedical applications. Magnetic field generation is typically based on the use of concentric coils or permanent magnets, giving small radius coverage areas only (typically < 1.5m).

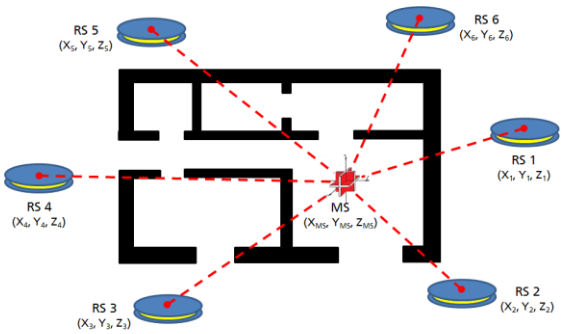

Figure 1: System architecture of MILPS with multiple reference stations and a mobile station

In general, magnetic fields based positioning systems fall in two categories using AC fields or DC/pulsed DC fields. For example systems that use sinusoidal magnetic fields are described in [4] and [5]. For distance determination, the magnetic fields have to be first filtered by frequency. Systems using pulsed DC fields are described in [6] and [7]. Here, the fields are generated sequentially. In [8] a system for indoor positioning is presented, which utilizes distributed coils instead of concentric coils to provide building-wide coverage. To detect the signals from the different coils a code division multiple access (CDMA) approach was used. Ref. [9] presents a magnetic localization and orientation system for medical diagnoses and treatments to wirelessly track an object that moves through the human gastro tract. Ref. [10] explores the usage of triaxial magnetometers and a vessel with known magnetic dipole to localize the sensors in underwater environments.

III. MILPS – MAGNETIC INDOOR LOCAL POSITIONING SYSTEM

The objective of MILPS is the provision of an accurate indoor positioning system based on artificial generated magnetic fields covering a whole building with a minimum of infrastructure and complexity. In order to enable position estimation, similar to other infrastructure based systems reference stations (RSi) consist of electrical coils placed inside the building are used (Fig. 1). For the position determination a mobile station (MS) is equipped with a magnetic field sensor (magnetometer). By measuring the field components of multiple (at least three)

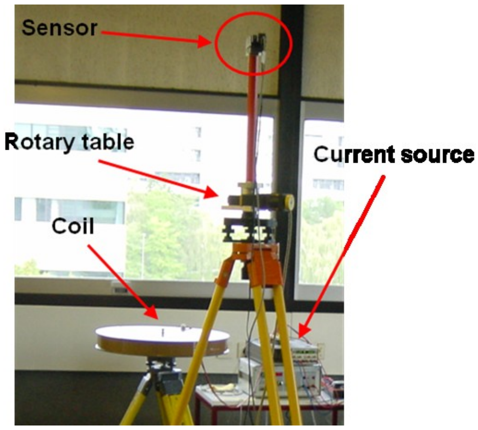

Figure 2: Experimental system of MILPS

coils the distances between the RSi and the MS are determinable. The coils are activated sequentially using real time clock in order to distinguish between their magnetic fields (time division multiplexing, TDM).

Based on the coordinates (X_i, Y_i, Z_i) of the RSi in the building reference system the unknown 3D coordinates of MS (X_{MS}, Y_{MS}, Z_{MS}) can be estimated by use of the lateration principle. A description of MILPS's 3D position estimation method as well as the positioning accuracy assessment are not to be part of this contribution and will be discussed later in detail. However, applicable methods using overdetermined sphere intersection algorithms have been described in [11] and [12] already.

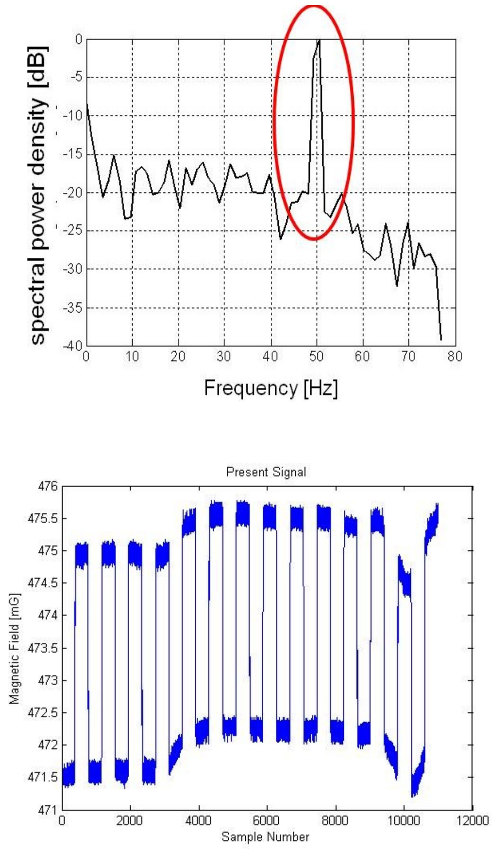

Figure 3: Fourier analysis of an example measurement inside a building (above); Differential measuring principle of MILPS in order to eliminate interference fields (below)

IV. EXPERIMENTAL SYSTEM AND MEASUREMENTS

On the basis of prior software simulations an experimental system was built (Fig. 2). It consists of a coil of 140 turns of wire wrapped on 50 cm diameter core. The current running through the coil is 15 A. Magnetic field sensing is accomplished using three Honeywell magnetoresistive transducers aligned in orthogonal directions allowing the capturing of the three vector magnetic field components.

First of all, some measurements with the experimental system inside buildings had been carried out. The evaluation of these measurements showed that besides the earth magnetic field further magnetic fields (e.g. caused by the electricity in buildings) interference with the coils' field (Fig. 3, above). Thus, a differential measuring principle for eliminating the interference fields was applied [1]. Therefore the coil's current direction is periodically switched. By differencing the resulting alternating magnetic signals all interference fields with a frequency lower than the switching frequency can be eliminated (Fig. 3, below).

V. SIGNAL PROCESSING AND FILTERING

For determining the distance between the coil center and the measuring sensor based on the measuring principle above, methods of digital signal processing are used. Besides the filtering it is also important to separate the signal in different clusters while one cluster consists of the measurement data during one switching interval. For the following evaluation the median of all values in one cluster in conjunction with the median deviation (as measure of precision) are used.

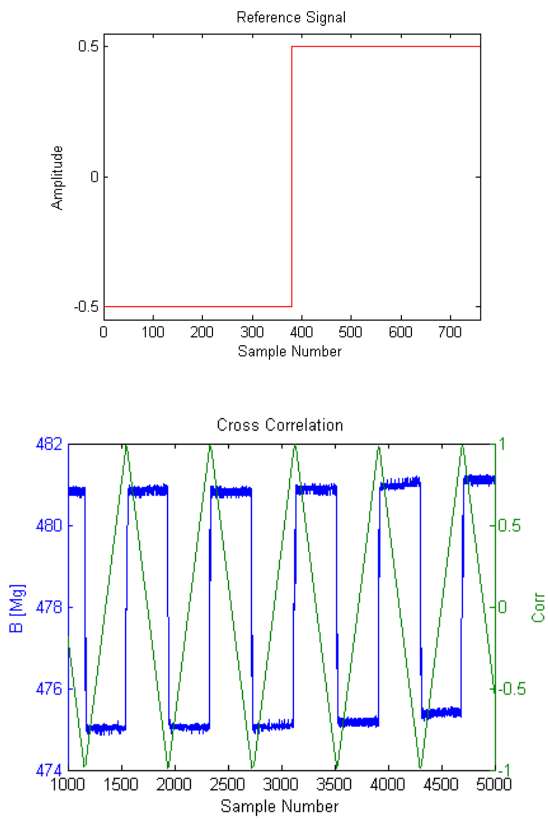

Figure 4: Cross-correlation between magnetic signal and reference signal

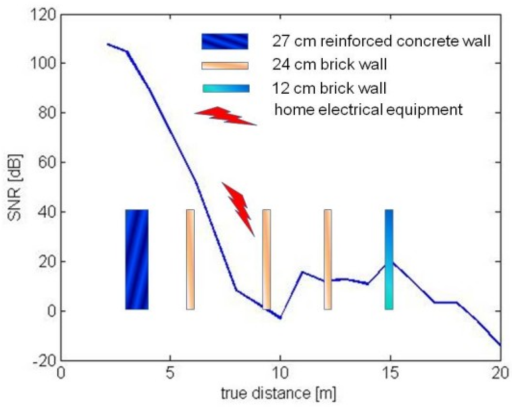

Figure 5: measured signal to noise ratio (SNR)

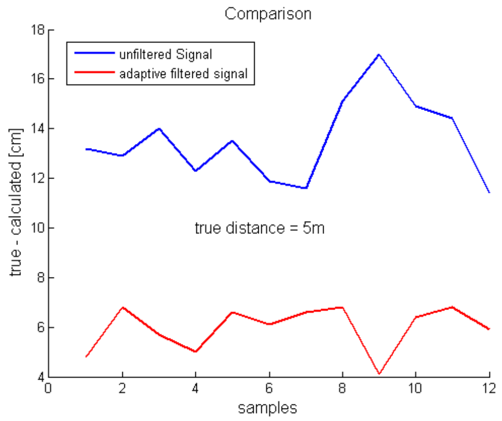

Figure 6: Comparison between unfiltered and adf-filtered signals

To separate the signal in different clusters a commonly used method is the cross-correlation. In this particular case the correlation between the captured signal and a reference signal (Fig. 4, above), depending on the switching frequency and the measuring time, is computed and examined in respect to its extreme values. Obviously, a new cluster starts on each of these values (Fig. 4, below).

Based on the differences of the cluster medians the coil's magnetic field B can be estimated. The distance between coil and magnetometer is than calculated by the following equation:

$$r = \sqrt[3]{\frac{\mu_0 NIF \sqrt{1+\sin^2 \varphi}}{4\pi B}} \qquad (1)$$

Where r is the distance between sensor and coil center, N is the number of turns of wire, I is the current running through the coil, F is the area of the coil, B is the magnetic field and φ the elevation angle between coil and sensor (angle between the horizontal and the line of sight). To determine the elevation angle φ either magnetic field observations to at least three coils are needed (cf. [8]) or additional sensors, such as inclinometer, have to be used what is to be discussed at a later stage/point in time. In the present stage of development only one coil is used. Moreover, the sensor and the coil are located on the same horizontal plane that the elevation angle $\varphi = 0$.

The performance of the current prototype can be shown by plotting the signal-to-noise (SNR) ratio of the magnetic signal relative to the distance between coil and sensor. Figure 5 depicts the determined SNR in a test scenario whereby miscellaneous obstacles exists in the measurement line. In this scenario, at a distance between 3 m and 4 m the coil and sensor are separated by a 27 cm reinforced concrete wall. At distances between 6 m and 9 m the sensor is in the vicinity of the home electrical equipments and furthermore the coil and the sensor are separated by an additional 24 cm brick wall. This example shows – as expected – that the SNR decreases very rapidly as a function of range and degrades considerably in the proximity of electrical noise source. However, the presence of obstacles such as walls and/or metallic objects causes essentially no loss in SNR efficiency.

Other important signals processing algorithms are digital filters to eliminate both further interferences and noise. By using digital filters, special frequencies the present signal consisting of can be eliminated. The drawback though of normal FIR filter (Finite Impulse Response) is that they are invariant in respect to the absolute time (nonstationarity). So it is impossible to be responsive to changing frequency abilities. To prevent this circumstance at nonstationary signals, adaptive filters are used [13]. By using the information of a reference sensor, these filters are able to adapt to the momentary frequency and statistic abilities. Figure 6 shows the difference between the computed distance from an unfiltered signal and a signal processed with an adaptive filter (adf).

As can be seen, the results of the adaptive filtered signals show less deviations compared to the true distance of 5 m compared to the unfiltered signals.

VI. CONCLUSION AND OUTLOOK

The results of the measurements performed with the prototype confirm the feasibility of detecting the magnetic field of a 50 cm diameter electric coil at distances up to about 16 m. Further analyses of the raw data reveal that the measured magnetic fields at short distances ($r < 6$m) as well as at a longer distance ($6\text{ m} < r < 16\text{ m}$) show a sufficiently good signal-to-noise ratio. By using adaptive filter techniques the accuracy of the estimated distances between coil and magnetometer could be improved significantly (see Fig. 6): for short distances (< 6 m) accuracies of 4 - 7 cm could be attained. Thereby during the measurements the reference sensor was placed close to the measurement sensor ($r <= 5$ m). At larger distances ($r > 16$ m), the SNR degrades considerably, because the generated magnetic field decreases rapidly with increasing distance (see Fig. 6). Thus, the following experiments will be focused on the use of adaptive filters at larger distances (> 10 m) and the investigation of the impact of the baseline length between mobile and reference sensor. Furthermore improvements of the adaptive filtering algorithms will be done to enable real-time processing.

Further works are the refinement of the results by using collected calibration data. Moreover the prototype is improved by increasing the coil diameter and/or the current running through it in order to enhance the maximal range and accuracy of the system.

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