Resonant Magnetic Coupling Indoor Localization System

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UbiComp'13 Adjunct, September 8–12, 2013, Zurich, Switzerland.
ACM 978-1-4503-2215-7/13/09.

http://dx.doi.org/10.1145/2494091.2494108

Abstract
Building on previous work [4] that introduced a novel indoor positioning concept based on magnetic resonant coupling we describe an improved system to be shown during the UBICOMP 2013 demo session. We improved the magnetic field model, implemented a particle filter for position estimation and a software suite for configuration and calibration of the system.

Introduction
Despite much research indoor localization, especially in dynamic environments, has still not fully been solved (see e.g. for a recent review of existing techniques [6],[2]). The problem is particularly difficult when it comes to a combination of low cost, simple installation, high degree of robustness with respect to changes in the environment and accuracy in the sub meter range. In [4] we have proposed a novel indoor location system that leverage the specific physical properties of oscillating magnetic fields to fulfill the above requirements. Thus we use beacons that generate a magnetic field that periodically expands and contracts. Unlike in RF or ultrasonic systems, which both generate propagating waves, the magnetic field in our system does not separate from the transmitter and propagate. Instead the vast majority of energy is "pulled back" into the transmitter oscillating circuit as the field contracts. Energy is only transmitted if, within the area of

field expansion, there is an oscillator tuned the precisely the right resonant frequency (resonant coupling to the receiver Figure 1). As described in [4] the key advantage of the system is that since there are no propagating waves disturbances like multi path propagation and diffraction do not occur. Magnetic fields are also difficult to block and even massive ferromagnetic objects only cause local disruptions and have no influence on the positioning accuracy in other areas.

Related Work

The basic physical principle is well known and has previously been used for example for wireless power transmission [1] and user interaction [3]. However, our work has been the first one to adapt it to robust, low cost indoor positioning.

Compared to the system we had described in [4] the demo system features an improved magnetic field model, on board inertial sensors supporting particle filter based location estimate stabilization, more robust synchronisation, mature wireless data transmission, and a software suite for system setup, evaluation and visualisation.

Note that our system fundamentally differs from the magnetic positioning system presented in [5],which does not use the resonant coupling principle.

System Description

As described in our previous work [4] the system consists of two components: stationary magnetic field transmitters and wearable receiver units which measure the magnetic field strengths at their positions. These measurements are used to determine the position and orientation of the receiver in relation to the set of transmitters

Magnetic Field Transmitters The field emitters use 3 perpendicular transmitter coils (200 turns) to sequentially generate oscillating magnetic fields. This coil setup allows to limit the position of the receiver at a low number of relative positions at the intersections of the magnetic field lines of the perpendicular and sequentially generated magnetic fields of a transmitter. On the hardware side oscillating circuits tuned to 20kHz maximize the power output of the 16V peak to peak 0.176A input signal of the coils.

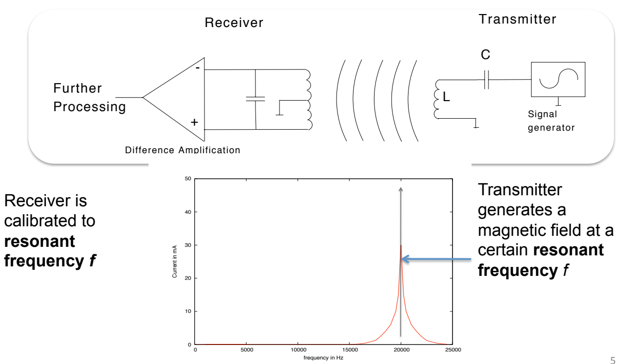

Figure 1: Oscillating circuits included in the transmitter and receiver coils filter out influences of other electro magnetic sources and maximize the power output of the transmitter coils. The lower signal plot depicts the sensitivity of the receiver coil linked to the frequency of the magnetic field.

Wearable Receiver Unit The receiver unit estimates the magnetic field strength at its current position using a 3 axis receiver coil. To filter out electromagnetic noise, the board is also equipped with an oscillating circuit tuned to the same resonant frequency as the transmitter. Integrated adjustable amplifiers accurately allow to sample the dynamic input signal (1.5 V at 10 cm and 0.004 V at

4 m) even at large distances. Onboard acceleration and gyroscope sensors provide magnetic field independent information for gesture recognition tasks and stabilize the position and orientation estimation of the receiver. The gathered movement information can be either stored on the onboard SD card or can be transmitted using a Zigbee based RF Connection or a serial connection to the PC. The LiPo battery supplies enough power to run the receiver for 8 hours.

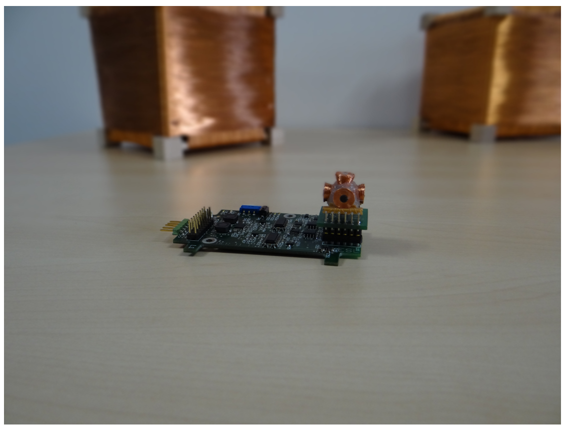

Figure 2: The transmitter coils (in the background) and the receiver circuit (in the foreground).

After collecting all measurements at the receiver's positions, the processing program converts the raw magnetic field measurements to distance and position information, the underlying field model uses the law of Biot Savart $\frac{1}{d^3}$ dependency to linearise the magnetic field information. Also the inhomogeneity of the magnetic field is taken into account. The distances, acceleration and gyroscope information are then used in a particle filter to estimate the position, heading and orientation of the receiver.

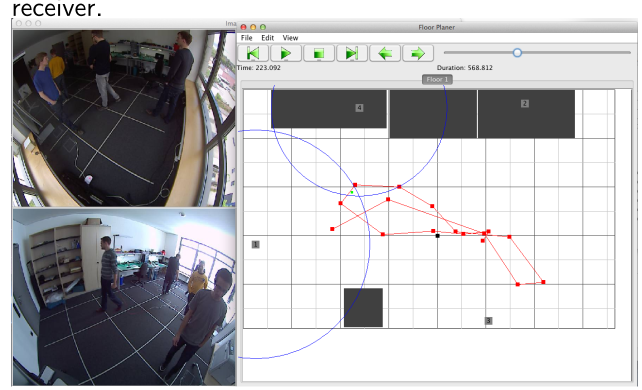

Figure 3: A screenshot of the MagSys software suite.

Interface Software

We implemented a Java based application MagSys which can be used to retrieve the information transmitted in the lower level position estimation program presented in the previous subsection. The main functions are (1) calibration and setup of the localization system, (2) definition of region of interests, (3) on- / off line illustration of the sensor data (current position, meta information like receiver is in a region of interest, on-line annotation of activites and positions, sensor data), (4) integration of network cameras for ground truth information (online dewarping of fisheye webcam pictures), (5) off-line annotation and replay functionality of recorded data sets for post process- ing and (6) simple integration of new sensor modalities (especially spatial sensor). A screenshot of the system is shown in Figure 4

System Performance

In our previous work, we have shown that this system is robust enough to distinguish between more than 20 different locations in apartments, houses, bureaus or cellars. The current prototype system with handmade prototype coils currently provides Cartesian coordinates with an accuracy of $62.3cm$ with a standard deviation of 34.6. This is more than enough to provide meta information about user position required by most applications (e.g. *The person is near the fridge.*). Note that when attaching a sensor to the body, the body already covers an area of approximately $0.5m^2$ so that accuracies below 50 cm are often pointless. In terms of usefulness for typical applications it is important to note that our system can also provide the approximate orientation of the receiver (in the coordinate system of the magnetic transmitter).

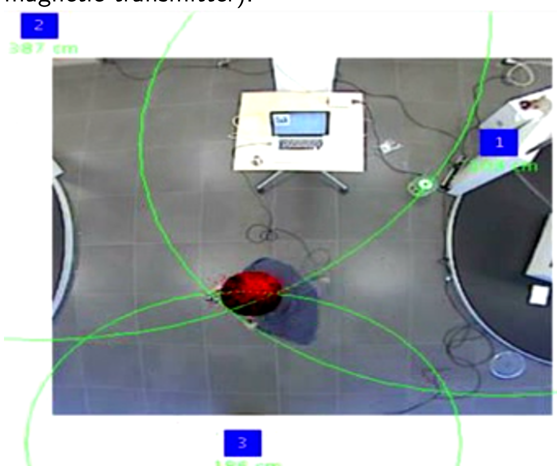

Figure 4: Example of the localization output of our system. The blue squares are the transmitter coils. The green circles the location estimates from the individual coils, the red cloud the particle filter based combined location estimate.

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