Low cost high precision indoor localization system fusing inertial- and magnetic field sensor data with radio beacons

[Demonstration Abstract]

Konstantin Klipp
Fraunhofer FOKUS
Kaiserin-Augusta-Allee 31
10589 Berlin, Germany
konstantin.klipp@fokus.fraunhofer.de

Jonas Willaredt
Fraunhofer FOKUS
Kaiserin-Augusta-Allee 31
10589 Berlin, Germany
jonas.willaredt@fokus.fraunhofer.de

Helge Rosé
Fraunhofer FOKUS
Kaiserin-Augusta-Allee 31
10589 Berlin, Germany
helge.rose@fokus.fraunhofer.de

Ilja Radusch
Fraunhofer FOKUS
Kaiserin-Augusta-Allee 31
10589 Berlin, Germany
ilja.radusch@fokus.fraunhofer.de

ABSTRACT

This short document describes the basic principle of the indoor localization system we would like to demonstrate in the contest. In the following a short overview of the system and some details of its components are explained. As deployment requirements the system relies on very few Bluetooth beacons installed at the area and a magnetic map which has to be measured in advance.

Categories and Subject Descriptors

C.3 [**Special-Purpose And Application-Based Systems**]: Microprocessor/microcomputer applications

Keywords

Indoor Localization, Navigation, Position, Bluetooth Beacon, Foot Sensor

1. SYSTEM OVERVIEW

The system uses a smartphone, a wireless low cost foot sensor and Bluetooth beacons as hardware. The Bluetooth beacons have to be mounted at least at the entry points to the localization area which can be the main door for example. Receiving signals of these beacons initializes the indoor localization system on the smartphone of a user. The smartphone is used as a sensor system of accelerometer, gyroscope and magnetometer to estimate orientations and as a receiver of the Beacons. For this reason the smartphone has to be hold in walking direction which is intuitive for the user when watching a map on the screen while being navigated. A beacon map and a map storing magnetic field features are used to estimate the position and orientation of the user. Another sensor system is used in this approach to detect steps and measure step sizes. The foot sensor is able to calculate a highly accurate distance vector which describes the traveled distance of the user in three dimensions. Its result is reported to the smart phone via Bluetooth Low Energy. The smartphone then serves as a data fusion device that calculates the final position of the user. If there are fixed walking paths in the localization area (e.g. in hallways) they can be saved in the magnetic field map, too. If there are fixed walking paths the system can use this information in the fusion module to increase the accuracy.

2. FOOT SENSOR

The foot sensor consists of a three axis accelerometer, a three axis gyroscope, Bluetooth module and a battery. It can be tightened with the shoe strings for example like it is shown in Figure 1 and Figure 2. The Bluetooth module of the foot sensor is used to report step data to the smart phone and it is also able to process the sensor data. Bluetooth Low Energy (BLE) is used for the data transmission to maintain a long battery life and low cost MEMS sensors are taken to ensure a small size. The accelerometer and gyroscope data is fused on the sensor to compute a quaternion which represents the current orientation of the sensor. The rotated acceleration vector is integrated twice to get the distance vector. The gyroscope signal is analyzed and knowledge about the human walking dynamics is used in a similar way like it is described in [1] to correct accelerometer errors. The resulting distance vector is then sent to the smartphone after each step.

3. RADIO BEACONS

Radio beacons are used to set the initial position for the user wearing the positioning device. As they set the initial position, they are best placed at doors that mark the entrance/exit of a building. As radio technology Bluetooth 4 Low Energy was chosen, because it consumes little energy and its signal only spreads within a radius of a few meters

Figure 1: Top view of the foot sensor. Size is approximately 4x4x1cm

Figure 2: Side view of the foot sensor attached to the strings of a shoe.

which needed for a roughly accurate estimate of the position. The beacons emit advertisement packets that contain their unique ids which are being received by the localization device of the user. After receiving an advertisement packet the Beacon module looks up the affiliated beacon position in a database that contains the mappings Beacon_ID to position. It then sets its position to the beacon's position with an accuracy error of the signal reach of the beacon (a few meters). The power of the received signal(s) are then analyzed by the module in order to obtain a more accurate estimate of the user's position. Having a precise position the beacon module reports that position to the fusion module.
Depending on the environment it might sometimes be necessary to install special radio beacons that are switched on via an infrared module that activates the beacon when a user is in close distance. This further optimizes the accuracy of the user's position.

4. FUSION MODULE

The smart phone compares the measured magnetic fields and the magnetic field map data and fuses this information with a 6d orientation algorithm which uses accelerometer and gyroscope data to estimate rotations. The 6d orientation can be calculated using Sebastian Madgwick's algorithm [2]. A deterministic and, depending on the information in the map, a probabilistic fusion framework which includes walking directions, step information from the foot sensor, magnetic field features and walking path information is applied to get an accurate position information. All fusion algorithms are real-time capable and will work on modern middle class smartphones.

5. DEPLOYMENT REQUIREMENTS

The localization area has to be set up with at least one radio beacon. In practise signal strengths in the near field of the beacons are used to initialize the system after a user walked from outside into a building. In the contest this could be achieved by a radio beacon close to the start point or with several beacons at all entry points of the evaluation area. The amount of beacons that are needed depends on the size and walking path structure of the localization area. After the installation the beacon near field signal strengths are measured with a smart phone and the values are stored with their positions in the beacon map. The second step is to build a magnetic field map. Therefore cells in the localization area have to be defined and the magnetic field components will be measured in the cells. A smart phone application allows to measure multiple cells with its magnetometer while walking though the cells. The app also allows to set up possible walking paths. The positions and measured magnetic field features of the cells are stored in the magnetic field map.

6. EXAMPLE EVALUATION RESULTS

As the system fuses different single components the overall accuracy depends strongly on how the single components perform. The foot sensor for example will has an average error of 0,5% to 2% of the walking distance, also depending on the user. The overall accuracy of the system also depends on the size of the area that is not covered by close beacon signals. In our typical office building with about 2000 square meters we only needed two beacons except for the ones at the entrance to achieve a position accuracy of about one meter.

7. REFERENCES

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