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Ubiquitous smartphone based localization with door crossing detection

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ABSTRACT

The positioning of users using their smartphones represents interesting service for various areas. Position of users can represent valuable information for various service providers. In industry 4.0 smart devices such as smartphone or tablet can help users to react faster in case of emergency. It can help to reduce reaction times for service workers and improve users' orientation in the environment, or delegate work to the nearest available employee. In previous work we have described modular positioning system that is able to automatically select optimal positioning module based on available radio signals. In this paper we will focus on estimation of crossing between environments e.g. indoor and outdoor. The proposed algorithm is crucial for implementation of seamless positioning. Since both environments have specific demands not only on positioning solutions but also on maps and navigation algorithms. The proposed algorithm does not require deployment of new infrastructure and can be used on widely available smartphones. The algorithm was tested in real conditions by different users and using various smartphone devices to prove its performance under various conditions.

1. Introduction

Currently positioning of mobile devices represent important topic not only for researchers, and service providers, but also for industry (Rojko, 2017). Nowadays every employee has a smart device that could help him to improve his work performance by introducing new location based services (LBS). In industry 4.0 there is a possibility to utilize LBS in order to reduce time required to fix broken equipment, delegate work to the nearest employee, improve orientation of (new) employees in the environment, or in case of emergency situations. Such services will, however, require robust positioning system that will be able to work seamlessly in both indoor outdoor environments.

Currently there is a large number of specialized systems developed for indoor environment (Xiao et al., 2016; Yassin et al., 2017). These are based mainly on signals from available wireless networks (Cipov et al., 2012; Kriz et al., 2016) and data from inertial measurement units (IMUs) (Yassin et al., 2017; Bojja et al., 2016), although other types of data like visible light (Qiu et al., 2016), ultrasound (De Angelis et al., 2015) or camera images (Jiao et al., 2017) can be utilized to estimate position of mobile users and devices.

On the other hand, in the outdoor environment we have well established satellite positioning systems, commonly called Global Navigation Satellite Systems (GNSS). GNSS are in theory able estimate position of user anywhere in the world. They perform reasonably well, when signals from satellites are not blocked by obstacles or affected by multipath propagation phenomenon. Unfortunately, these conditions are hard to achieve in urban areas or industrial parks, therefore, in some cases alternative positioning systems have to be used also in the outdoor environment (Kriz et al., 2016).

In the previous work we have proposed modular positioning system (Brida et al., 2014), which can be used in both indoor and outdoor environments with a good positioning accuracy. The idea of the modular positioning system is to estimate positions of users by automatically selected positioning solution based on available radio signals and data from available sensors. Currently the system allows positioning using Wi-Fi, cellular networks and GNSS (Brida et al., 2014). Moreover, IMUs integrated in the modern smart devices can be utilized to improve positioning accuracy for dynamic users.

In this paper we will focus on problem of detection of crossing between environments, e.g. users moving from indoor to outdoor environment and vice versa. The algorithm for door detection will be proposed and tested for this purpose. The proposed solution does not require any additional infrastructure and is based on sensors commonly implemented in smartphones. The algorithm will allow not only automatic switching between maps for indoor and outdoor environments but could also lead to further improvements of modular positioning system from the accuracy point of view, as more information about environment and movement of user will be available.

The rest of the paper is organized as follows; related work is presented in Section 2. The Section 3 describes the proposed algorithm

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for door detection. Experiments and achieved results will be presented in Section 4 and Section 5 will conclude the paper.

2. Related work

2.1. Modular positioning system

The modular positioning system is currently under development at the Department of Multimedia and Information-Communication Technologies (Brida et al., 2014). The main idea is to develop single localization system that will be able to provide position estimates seamlessly in heterogeneous environments e.g. indoor and outdoor. It is based on the assumption that in various environments various approaches to position estimation have to be used. The system is able to provide user with position estimates in both indoor and outdoor environments, using GPS, Wi-Fi or GSM signals, as can be seen from Fig. 1. The system is able to automatically select optimal positioning solution based on measured signals taking into account number of signals and their quality. Moreover, IMU can be used to estimate path of the user. The modules were chosen based on the fact that these signals are available at all devices. Since the modular system is an open platform other modules can be implemented in the future, based on available technologies, e.g Bluetooth, Zig-Bee, UWB, etc.

Positioning modules that use signals from Wi-Fi and GSM networks are based on fingerprinting approach. The fingerprinting framework is based on assumption that available signals and their parameters depend on the position of user. The framework requires so called calibration phase (or off-line phase). During the calibration phase the measurements of Received Signal Strength (RSS) are collected and stored in the radio map database. The radio map database consists of reference points with known position linked to RSS samples measured at the given reference point.

During the positioning phase (or on-line phase) the position of mobile user is estimated based on comparison between on-line measurements with the data stored in radio map database. Euclidean distance is most widely used for comparison of RSS samples (Machaj and Brida, 2011) and position estimator can be defined as:

$$\hat{x} = \frac{\sum_{i=1}^{M} \omega_i \cdot c_i}{\sum_{i=1}^{M} \omega_i}, \tag{1}$$

where c_i represent position of ith reference point M is number of reference points and ω_i is a non-negative weighting factor. Traditionally the weights are computed as inverted value of distance between RSS vectors. The estimator of the formula (1), which keeps the K highest weights and sets the others to zero is called the WKNN (Weighted K-Nearest Neighbours) method (Bahl and Padmanabhan, 2000). WKNN with all weights $\omega_i = 1$ is called the KNN (K-Nearest Neighbours) method and the simplest method, where $K = 1$, is called the NN (Nearest Neighbour) method (Tsung-Nan and Po-Chiang, 2005). In Honkavirta et al. (2009) it was found that WKNN and KNN methods commonly outperform the NN method, especially in cases when K is set to 3 or 4.

2.2. Door detection algorithms

Algorithms for door detection are becoming important part of positioning and navigation systems in indoor environment, since their use can further improve accuracy of existing systems. In this subsection a short overview of door detection algorithms will be presented.

The door detection algorithms can be in principle divided into three main categories, the first one are vision based solutions. These are mainly based on image from camera (Adar and Bayindir, 2015; Shalaby et al., 2014; Kim et al., 2011) and developed for application in robotics, since robots are commonly equipped with at least one camera. More recently approaches based on laser scanning (Quintana, 2016) and depth measurements using a Kinect camera (Dai et al., 2013) have also emerged. Camera based door detection is mostly based on approaches that utilize corner and shape detection algorithms in combination with image classification. These approaches can provide good results, however, are not optimal for use with smartphone camera due to the fact that most users hold the smartphone in a way that its back and front cameras are facing down and up, respectively. Therefore, captured images lack data required for door detection.

The second category of door detection algorithms are infrastructure based solutions, these algorithms utilize data from new infrastructure that has to be deployed on site. This means that implementation cost might rise significantly and, on top of that, widely used smart devices might not be equipped by sensors or receivers that are required for system to operate. Such solutions are most widely based on RFID tags (Xie et al., 2015) or UWB transmitters (García et al., 2015). As these technologies might provide high positioning accuracy.

The third category of algorithms is represented by infrastructure free approaches. Algorithms from this category mainly use data that are provided by sensors integrated in smart devices and therefore does not require further investments into new infrastructure or new devices. Most of the proposed solutions presented in available literature was based on magnetometer readings.

Door detection algorithm available on smartphone devices was presented in Zhao et al. (2015), authors used raw magnetometer readings to estimate crossing of the doors. The main advantage of the approach is that the algorithm does not need any information about floor plan or any calibration measurements. The approach can provide detection of the doors with success rates around 60% and depends highly on door material.

MagicFinger (Carrillo et al., 2015) is a representative solution of magnetic based positioning system. The approach is based on 3D magnetic fingerprinting and can provide reasonable positioning accuracy. However, using magnetic fingerprinting for door detection requires database of magnetic fingerprints of all doors measured in different directions as magnetic field depends on orientation (Torres-Sospedra et al., 2015). Moreover, comparison of magnetometer output data with the database is not trivial since magnetic signatures are not measured on static points but should be measured during movement, therefore difference of movement speeds between data in magnetic map and data measured during positioning has to be considered.

3. Proposed algorithm

The proposed algorithm is based on Pedestrian Dead Reckoning (PDR) which utilizes smartphone IMU sensors to estimate path of the user. The proposed algorithm for door crossing detection is using tracking information together with data from IMU sensor to estimate if user crossed door or not. In the paper we focus primarily on non-automatic door.

3.1. Pedestrian Dead Reckoning

In the proposed algorithm we are using approach where heading angle is calculated from gyroscope data, and step detection is done by using output data from accelerometer. Particle filter (PF) has been used in the indoor environment as a correction method. More details on calculation process can be found in our previous work (Racko et al., 2016). As described in our previous work, we have used fixed step length of 0.75 m as this value was proven to provide reasonable results with combination of PF. Incorrectly chosen step length may lead to increased positioning error. Use of PF is feasible in the indoor environment, because there were many obstacles which helps to eliminate some particles used for position estimation, and thus improve position estimation accuracy.

On the other hand use of magnetometer for corrections could lead to higher errors in path estimation because of metal parts in building, such as railings, or doorframes. On the contrary, in the outdoor environment use of magnetometer data for estimated path correction seems to be a better option. PF will not be able to provide good correction since there