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Optimized indoor positioning using graph-theory-based map matching

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Abstract

The accurate and precise localization in all environments enables development of countless services and applications, from navigation and tracking to other location-based services (LBS). While outdoor LBS, considering the decade when it was introduced, is reasonably highly developed, the indoor LBS or indoor positioning services (IPS) are currently one with the most attention in the industry and academia. This paper provides an overview of indoor positioning services, technology on which it relies, and highlights future challenges to overcome. The initial experiments were conducted after implementation of our IPS solution in the closed environment and, considering the use of only raw fingerprint method as one of the positioning methods, initial results indicated the necessity for further correctional measures. Based on the conclusions, our experimental graph-theory-based map matching approach is proposed which is expected to introduce a corrective measure to the fingerprint method optimizing the localization accuracy and the localization process in general.
Keywords: indoor positioning, fingerprint, map-matching, graph theory

Optimizirano pozicioniranje u zatvorenim prostorima temeljeno na mapiranju putanje pomoću teorije grafova

Sažetak

Točno i precizno lociranje u svim okruženjima omogućuje razvoj beskrajnog broja usluga i aplikacija, od usluga navigacije i praćenja do drugih lokacijski ovisnih usluga (engl. *location-based services* (LBS)). Dok je vanjska LBS tehnologija, s obzirom na desetljeće kad je razvijena, razumno visoko razvijena, LBS tehnologija s primjenom u zatvorenim prostorima trenutno je jedna od onih s najvećom pozornošću i industrije i akademske zajednice.

Ovaj rad prezentira pregled IPS tehnologije, tehnologija na kojima se temelji te naglašava izazove koje mora svladati. Inicijalna testiranja našeg rješenja su provedena unutar eksperimentalnog okruženja i korištenjem osnovne fingerprint metode, početni su rezultati upozorili na nužnost korektivnih mjera. Na osnovi zaključaka predložen je, naš pristup temeljen na mapiranju putanje koristeći teoriju grafova kojim se očekuje optimiziranje fingerprint metode te poboljšavanje cjelokupnog procesa lokalizacije.
Ključne riječi: pozicioniranje u zatvorenim prostorima, fingerprint, mapiranje putanje, teorija grafova

1. Introduction

The accurate and precise location of an individual, in all environments, opens an interminable area of application and usage. The outdoor LBS technology is being developed since the 1960s and it completely changed the localization, navigation and tracking services [1]. The indoor positioning services (IPS) or indoor location-based services (ILBS), has the ultimate goal to correctly, precisely and unambiguously locate, navigate and track an individual in closed environments using fewer resources possible considering time, energy, etc. Today's IPS technology, with respect to accuracy and resource requirements, rely either on infrastructure or infrastructure-free solutions [1]. Infrastructure solutions require implemented infrastructure in the form of tags or other devices, which are dedicated for localization purposes. Infrastructure-free solutions do not require any form of dedicated infrastructure but rely solely on the Signals-of-Opportunity (SOOP), or, use of any signals within the environment which are not normally intended for localization [2]. Such signals are TV, radio broadcast signals, cellular network signals and, one of the most used, Wi-Fi signals with optional further fusions to other available signals such as from Inertial Measurement Unit (IMU) and other. The random nature of SOOP and its weak and uncertain correlation with person's position/location requires the use of mathematical and algorithmic techniques to filter, to fuse with other signals, and ultimately, to stabilize and raise the correlation between measurement and estimated location [1].
The intention of this paper is to provide an overview of our IPS experiment currently being conducted within an experimental environment. Also, the intention is to present current results, conclusions and, most importantly, to provide an overview of our new approach - graph-theory-based map matching which is being developed with the aim to improve current results and IPS in general.

2. Related work

Frattasi and Della Rosa in [1] provide a highly comprehensive overview of a mobile positioning and tracking technology and related issues presenting very thorough fundamentals, basics, methods, techniques in all relevant technologies such as used for positioning, navigating and tracking applications.
He and Chan in a highly cited article [3] provide an overview of recent advances in two of major areas of Wi-Fi fingerprint-based indoor localization: advanced localization techniques and efficient system deployment presenting the issues how to make use of temporal or spatial signal patterns, user collaboration, etc. Also, a study and comparisons are provided with future projections and expectations.
Lin, Chen, Deng, Hassan and Fortino in [4] propose a novel localization method (LNM) approach that utilizes the neighbor relative received signal strength to build the fingerprint database and adopts a Markov-chain prediction model to assist positioning. Very thorough experiments were conducted on a heterogeneous set of different mobile devices to express very promising results comparing to other localization algorithms.

Della Rosa, Nurmi, Pelosi, Laoudias, and Terrezza in [5] present the negative impact of different mobile device hand-grip and human body presence and orientation to received signal strength (RSS) measurements when indoor localization is conducted. The results confirmed that such factors cannot be neglected and must be considered as highly influential.

Gilliéron, Spassov, and Merminod in [6] present an enhanced indoor navigation approach incorporating map-matching techniques and using their own Personal Navigation Module (PNM) consisting of GPS receiver and, most importantly, IMU, which provides the information of person's movement from accelerometer, gyroscope and magnetometer. Dead Reckoning localization is utilized incorporating the map-matching techniques.

Wilk and Karciarz in [7], except providing an overview of map-matching techniques, presents an approach fusing a Wi-Fi positioning technique, Dead Reckoning (IMU-based) technique, and map-matching techniques. The results of the experiment provided smoother and natural user transitions within closed space but further areas of improvements were noticed.

Magiera in [8] presented an approach using IMU-sensors and Dead Reckoning and using a map-matching algorithm with a function to map (place) a user's trajectory to a map (floorplan) by detecting the collisions between trajectory and the walls finding the best fit of the trajectory. The results showed a successful matching but with a highlighted time consumption.

3. Model and methodology

The intensive research in the area of IPS provided several empirical approaches for indoor positioning/localization. A plethora of IPS methods were adopted and tested for WLAN infrastructure and mobile station (MS) localization [1] [3]. Whether the MS is sending probe requests to the surrounding Access Points (APs) or only receiving beacon frames periodically sent from the APs, further steps of positioning rely on the specific information extracted from those [1]. For the purpose of this work, the method using beacon frame reception is used and the Received Signal Strengths (RSS) reported in decibel-milliwatts (dBm) is measured from all the surrounding APs which is used for distance estimation [1] [3]. The fingerprint method consists of two phases. The training phase (also called offline or calibration phase) where multiple samples of RSS of all surrounding APs are recorded and averaged on the grid of known locations within the closed space and stored to a Fingerprint Database (FD). The second phase is the test phase (also called the online phase or localization phase) where the samples of RSS on the unknown location are recorded and compared with those in the FD. Estimated position is then calculated using one of the nearest neighbor (NN), k-nearest neighbors (kNN), weighted kNN or Support Vector Machine (SVM) methods.

The experimental environment (closed space) which configuration is shown in Figure 1, is consisted of four rooms (Green, Red, Blue, and Yellow room). The Green room dimensions are approximately 37 m x 25 m, the Red room is 5 m x 14 m, Blue room 13.1 m x 14.3 m and the Yellow rooms is 5.9 m x 25 m.

The APs which are used for this method are D-Link DIR510L AC750 placed in the Green room on the marked positions in Figure 1 and do not use any global synchronization but only its own distributed synchronization where beacon frame configuration and the broadcast period is according to the default settings.

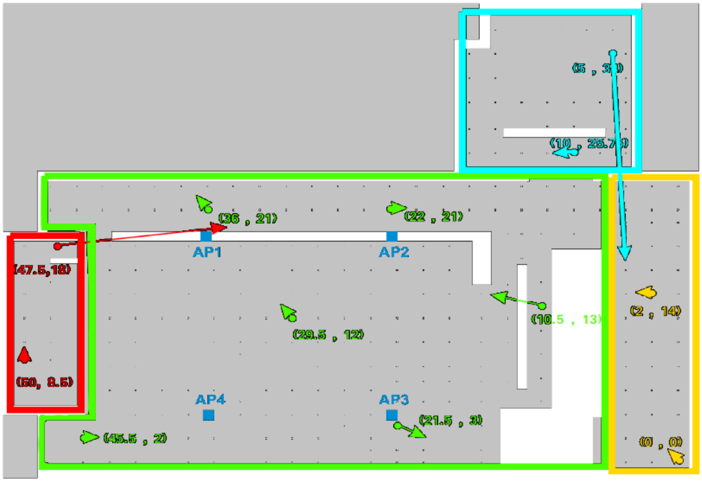

Figure 1. The experimental space (IPS area) with expected and raw estimated positions

The highly random nature of Wi-Fi wave propagation, the heterogeneity of network interfaces (NICs) in the MSs, different interpretations of the RSS by different NICs, the configuration and the period of periodical beacon frames are some of the factors which directly affects to the localization accuracy and precision [1] [3] [4].

Experimental testing using only raw fingerprint localization was conducted. The known testing positions coinciding with the start of the arrow are placed on Figure 1. The tips of the arrows showed also in Figure 1, are showing the estimated raw positions. The length of the arrows is presenting the localization error. The conclusion of this experiment is that the results of using only of raw fingerprint method are relatively inaccurate, unpredictable, varying and highly depended not only on the mentioned factors, but also on the space configuration, the APs placement, the surrounding materials, the line-of-sight (LOS) to the APs, indicating that correctional filtering, fusing and other mathematical and algorithmic methods have to be applied. With the reasonable necessity to improve the localization accuracy, the experimental graph-theory-based map-matching concept was introduced which is currently being under development. The intention with the proposed approach is to apply an additional correction measures to a raw estimated positions and movement trajectory, and to examine if such trajectory can be fitted to a floorplan or a specific sequence of rooms that individual has visited and to evaluate if the next positions or, at least, rooms, can be predicted therefore optimizing further localization process. Such a concept requires the introduction of graph theory, map-matching techniques and other steps to satisfy the intended requirements.

Map-matching is the technique very well known in outdoor localization and navigation technology and it consists of methods with which estimated positions and movement trajectories are fitted to or attached-to a more logical and structured model, mostly used, graph grid allowing additional mathematical and other operations [6] [7] [8] [9].

The first step in the approach is to apply a high-definition, but flexible considering the resolution or the number of nodes, to an IPS area of the experimental environment and place it within the Euclidian plane where all nodes of the graph have its own coordinates. Except for the node coordinates, each node has an additional attribute in the form of a number which indicates possible directions towards neighboring nodes. Most of the nodes have the link to other eight neighboring nodes but those close to walls and corners have a smaller number of possible links limiting possible hops in certain directions. After geometric graph is applied to the IPS area, fingerprint grid, as a set of known locations with averaged RSSs, also must be placed within a Euclidian plane, scaled and overlapped with the graph grid plane coinciding the plane origins. The overlapping procedure has to be conducted only once, except in the case if the number of graph nodes is changed. The process is shown in Figure 2.

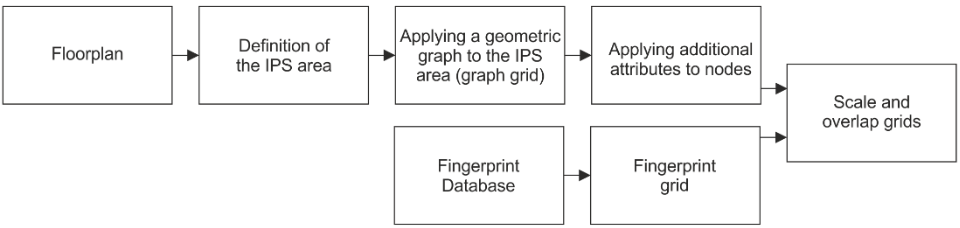

Figure 2. Block diagram of graph and fingerprint grid overlapping procedure

The second step in the concept is the process which is conducted simultaneously with the fingerprint localization procedure, and it consists of several steps (Figure 3).

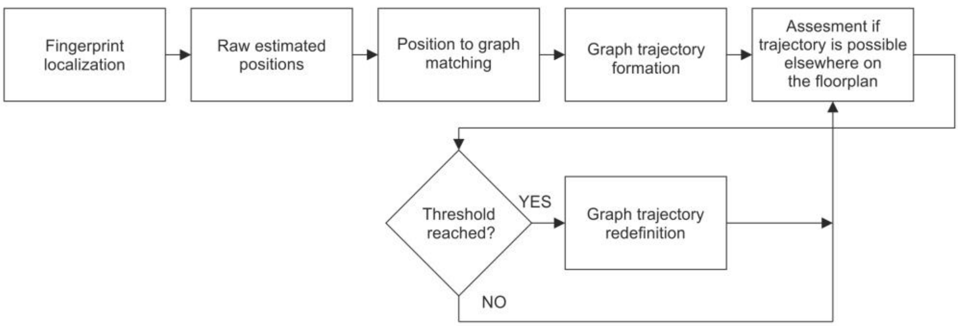

Figure 3. Block diagram of simultaneous map-matching

Raw estimated positions are mapped to a geometric graph by either one of the most known methods: Point-to-point (P2P) or Point-to-Curve(Link) (P2C) [6]. The P2P method is based on a calculation of Euclidian distances from neighboring nodes and selection of the closest one. The P2C method is based on the calculation of the distance to a closest neighboring link. Next step within the process is to connect all the mapped nodes on the graph using

Shortest-path-problem forming a trajectory (path) seen as a specific sequence of neighboring graph nodes [10]. After the graph trajectory formation, assessment if such trajectory is possible elsewhere on the floorplan is conducted by finding all other exact sequences on the graph.

For very simple sequences, it is expected to have a high number of matchings elsewhere on the floorplan. In the other hand, if the sequence is longer and with a specific geometric feature, it could be fitted, if not only in one, then, in few other places narrowing the possible area for further localization from entire map to a specific area where the user is expected to be. Also, the current trajectory is redefined by leaving only last few nodes closest to the last one in the sequence, and "forgetting" the ones closest to the beginning. By this, it is taken into consideration that the user could visit previously already visited positions and allowing the algorithm to work with a simplified sequence.

4. Conclusion

After implementation of our solution inside an experimental environment, the results showed the necessity for further correctional procedures which could improve the fingerprint localization. By introduction of an experimental graph-theory-based map-matching concept, the complex problem of localization is presented within a very familiar area of mathematics - graph theory, allowing the use of broad sets of methods and techniques. Considering the expected benefits, the most highlighted one is that this approach will allow localization in a narrowed area of possible locations excluding the unexpected (impossible) ones. Also, the efficiency of the approach is expected to be higher in more complex floorplans than in the less complex ones.

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References

[1] Frattasi, S., Della Rosa, F.: Mobile Positioning and Tracking, Second edition, IEEE Press, Wiley, 2017.

[2] Yang, C.: Signals of Opportunity for Positioning, ION Southern California Section, 2011

[3] He, S., Chan, S.-H. G.: Wi-Fi Fingerprint-based Indoor Positioning: Recent Advances and Comparisons, IEEE Communications Surveys & Tutorials, 2015, DOI: 10.1109/COMST.2015.2464084

[4] Lin, K., Chen, M., Deng,J.: Mohammad Mehedi Hassan, and Giancarlo Fortino: Enhanced Fingerprinting and Trajectory Prediction for IoT Localization in Smart Buildings, IEEE TRANSACTIONS ON AUTOMATION SCIENCE AND ENGINEERING, 2016.

[5] Della Rosa, F., Xu, L.,Nurmi, J., Pelosi, M., Laoudias, C., Terrezza, A .: Hand-Grip and Body Loss Impact on RSS Measurements for Localization of Mass Market Devices, IEEE, 2011, 978-1-61284-4577-0188-7/11/$26.00

[6] Gilliéron, P.-Y., Spassov, I., Merminod, B.: Indoor navigation enhanced by map-matching, European Journal of Navigation, Volume 3, 2005.

[7] Wilk, P., Karciarz, J.: Optimization of map matching algorithms for indoor navigation in shopping malls, International Conference on Indoor Positioning and Indoor Navigation, October 2014, 978-1-4673-8054-6/14/$31.00 ©2014 IEEE

[8] Magiera, J.: MATCHING TRAJECTORY OF A PERSON TO A MAP IN INERTIAL NAVIGATION SYSTEM, SCIENTIFIC JOURNAL OF POLI SH NAVAL ACADEMY, 2015, DOI: 10.5604/0860889X.1187600

[9] Wikipedia: Map-matching, https://en.wikipedia.org/wiki/Map_matching, edited: 27.5.2018

[10] Sedgewick, R.: Algorithms, Princeton University, Addison-Wesley Publishing company, 1992.