Developing a Local Positioning Algorithm Based on the Identification of Objects in a Wi-Fi Network of the Mall

Olexander Belej
Department of Computer-Aided Design
Lviv Polytechnic National University
Lviv, Ukraine
Oleksandr.I.Belei@lpnu.ua

Natalia Nestor
Department of Computer-Aided Design
Lviv Polytechnic National University
Lviv, Ukraine
natalia.nestor@gmail.com

Orest Polotai
Department of Information Security Management
Lviv State University of Life Safety
Lviv, Ukraine
orest.polotaj@gmail.com

***Abstract*—The proposed algorithm for local positioning in the mall is based on the Wi-Fi standard, in which the signal strength received by the mobile device from Wi-Fi access points is the only source of information about the location of objects. The study formalizes the problem of local identification of the object in the mall using Wi-Fi technology; The requirements for a local positioning system that identifies an object using Wi-Fi technology are formulated. The developed prototype can be used to determine the location and construction of a route of a moving object in the mall.**

Keywords—algorithm, local positioning, mobile device, signal, map, identification, mall.

I. INTRODUCTION

Currently, there are many technical solutions to the problem of determining the location of a physical object in space, which is united under a single term, is the local positioning system. All positioning systems can be divided into two classes: global positioning systems and local operate on a limited territory.

However, the main problem of GPS and cellular systems resides in the indoor environment and in scenarios with deep shadowing effects where the satellite or cellular signals are broken. In this paper, we survey different technologies and methodologies for indoor and outdoor localization with an emphasis on indoor methodologies and concepts [1]. The positioning system is used by an indoor navigation software developed for smartphones and complemented by a database of annotated entities (persons, devices, areas, and points of interest) to allow the inference of location-dependent, context-sensitive information through an API provided for upper layer applications [2].

Wi-Fi and Bluetooth based positioning methods considered in this survey are fingerprint approaches that determine a user's position using a database of radio signal strength measurements that were collected earlier at known locations [3].

Authors in research [4] proposed a system, which automatically recognizes a location from image sequences taken of indoor environments, and it realizes augmented reality by seamlessly overlaying the user's view with location information.

Data transmission is carried out using radio signals, the frequency of which depends on the standard wireless network. Each signal carries positional dependent information that can be used to estimate the location of an object [5].

Location-based services are the hottest applications on mobile devices nowadays and the growth is continuing. Indoor wireless positioning is the key technology to enable location-based services to work well indoors, where GPS normally could not work. Bluetooth has been widely used in mobile devices like phone, PAD, therefore Bluetooth based indoor positioning has great market potential [6].

This article [7] first identifies two main challenging issues, fingerprint annotation, and device diversity, and then reviews the state of the art of fingerprint crowdsourcing-based indoor localization systems, comparing their approaches to cope with the two challenges. A propose a new indoor subarea localization scheme via fingerprint crowdsourcing, clustering, and matching, which first constructs subarea fingerprints from crowdsourced RSS measurements and relates them to indoor layouts.

In paper [8], the authors proposed the radio map construction from crowd-sourced sample scheme to handle these challenges. They propose a device calibration algorithm to fuse samples from different devices to obtain grid fingerprints.

The publication [9] considers the possibility of local positioning in wireless networks based on the power received by the object of the signal, provides a mathematical description of the procedure for transferring the power of the signal to the distance between the source and the signal receiver, but not ready method of positioning the object, and Also, there are no results of experiments that could empirically confirm its ability.

In [10], the author proposes a new hotspot ranking-based indoor mapping and mobility analysis approach based on the sporadically collected crowdsourced Wi-Fi received signal strength data. This approach aims to construct the indoor mapping, as well as achieve the mobility analysis of the users following their daily motion patterns in the target environment.

The fuzzy control was used to assign the different weight to PSO and BP algorithm during different periods. PSO algorithm plays a main role in the previous evolution period, and the BP algorithm plays a vital role in the later period. The model can overcome the slow convergence and easily getting into the local extremum of basic BP algorithm, and can also improve the learning ability and generalization ability with a higher precision [11].

The paper [12] presents the proliferation of the Internet of Things (IoT) has fostered growing attention to real-time locating systems using radio frequency identification for asset management, which can automatically identify and track physical objects within indoor or confined environments. Various RFID indoor locating systems have been proposed. However, most of them are inappropriate for large-scale IoT applications owing to severe radio multipath, diffraction, and reflection. In this paper, we propose a newly fashioned RTLS using active RFID for the IoT.

Most of the studies examined did not address the point that an access point could operate in one of two modes: either to intercept packets transmitted over a wireless network or to receive and transmit packets for organizing the exchange of information over the Internet over the Internet. The combination of functional positioning and the provision of packet exchange with external networks will expand the field of wireless positioning without increasing the cost of acquiring additional equipment.

The purpose of the work is to develop the structure and algorithm of the system of local positioning of objects in the mall using Wi-Fi technology in real time. The following problems are defined for the achievement of the set goal: formalization of the problem of local identification using Wi-Fi technology and formation of requirements for the system of the mall, which carries out the local positioning using; development of the algorithm for the functioning of the automated system of local identification in the mall.

II. Construction of the Map of the Local Positioning of Objects and Their Identification in the Mall

The main problem for which an automated positioning system for a shopping center is being developed can be formalized as follows. There is an object of positioning *O* - a mobile device provided with a WI-FI adapter, and to the *O* the only requirement is required - the WI-FI adapter should be active (not necessarily connected to the network). Within a certain predefined zone Z (local coordinate system on a plane), the WI-FI infrastructure, which is a set of access points *APi, i: 1.n*, where n is the number of access points, at which at any point *Z* the value of the signal/noise" ratio for each *APi, i: 1..n* is greater than unity. The parameters of the positioning object *O* (device model, manufacturer, MAC address, specifications) are not known in advance, as well as the time and trajectory of occurrence and motion on the plane Z. *APi (x, y)* - coordinates of the *i*th access point in the local coordinate system are unchanged and known in advance. The main problem of the automated positioning system is to give in real time with a specified interval of time *t* coordinates *O* in the coordinate system *Z*.

The universality of an automated system that can solve the above problem is laid out in the absence of restrictions on the mobile object of identification - this is the principle justified by the current trend of the development of wireless networks and the market of mobile devices, and only with such a statement of the problem such a system can represent not only scientific but an applied interest.

For the experiments, an identification area was selected, in the role of which was a closed room with the size of the parties 18 meters and 12 meters. In the three corners of the room, WI-FI routers operating in the listening mode of the ether were installed in the predefined coordinators.

As a result of the calibration of the selected premises, a positioning map was obtained, depicted in Fig. 1. At each calibration point in decibels, the average signal strengths from the respective routers are indicated - Router1, Router2, and Router3.

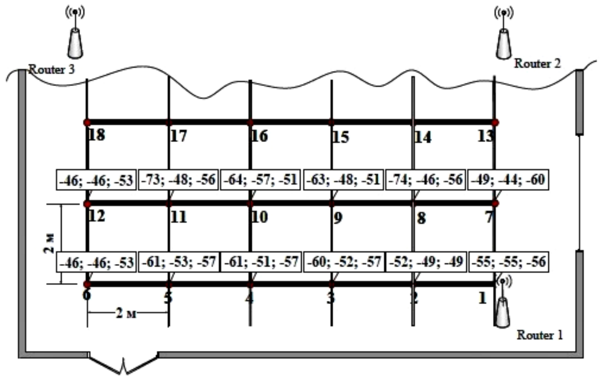

Fig. 1. Part of the map positioning of Wi-Fi routers in the mall.

A series of experiments were carried out with the help of the received map of the local positioning at the mall, each of which will be presented further.

To determine the signal strength of various mobile devices, five devices with WLAN interfaces were selected as experimental models: a laptop, a netbook, two smartphones, and a tablet. For the selected devices, measurements of the power of the signal received from them were carried out at the same points of the map of the local positioning. Dependence of received signal strength from distance for Samsung Galaxy S2 and Lenovo IS2500 smartphones is presented in Fig. 2 (the number of devices displayed on the graph is reduced to two to ensure readability and ease of perception). Trend lines for different devices are different, which can have a significant effect on positioning errors and location information on the map.

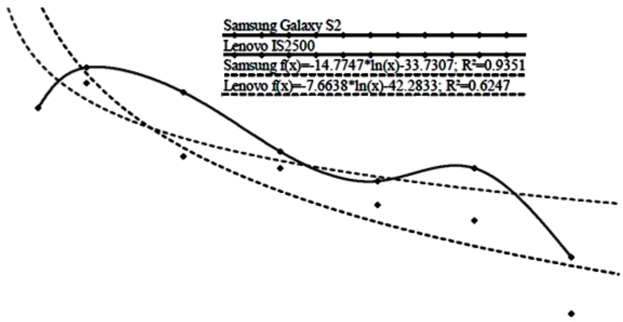

Fig. 2. RSSI (r) dependence for two different mobile devices in the mall.

Due to the fact that it is possible to programmatically change the power of the radiation of a WI-FI signal only at the level of the developer of a mobile device, this option is not available to the average user. In rice 5 depicted trend lines for two devices form a "range", which "stacks up" the value of the signal strength of all other devices that participated in the experiment. The conducted experiment confirmed the impact of the wireless adapter model on at least one positional dependent signal characteristic - power. In this regard, it is advisable to conditionally set a certain signal power range that will be universal for all mobile devices in the given positioning solution situations when creating an automated positioning system.

To deploy a positioning system is not enough to use one access point, so there is a problem of synchronous measurement of signal strength from several access points. An experiment was conducted to measure the power of the WI-FI signal of one and the same mobile device with two access points of the same model. Results of measurements are presented in Fig. 3. The constructed lines of trends allow us to conclude that it is possible to neglect the difference in the sensitivity of identical access points when carrying out measurements.

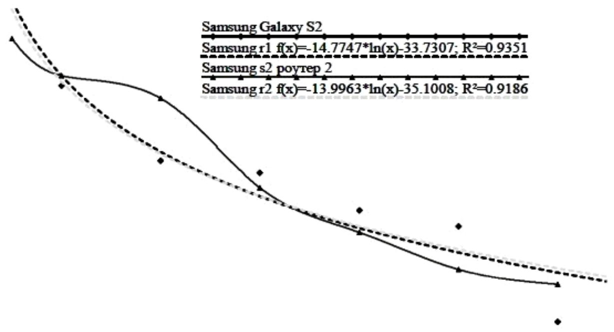

Fig. 3. Signal strength for two access points in the mall.

At the calibration stage, the mean deviation of the mean values of the signal strength in the interval from the reference model of the dependence of the signal strength on the distance was calculated for determining the optimal time interval required to measure the exact signal strength.

TABLE I. THE AVERAGE DEVIATION OF SIGNAL POWER ON THE INTERVAL MAPPING OF THE POSITION RELATIVE TO THE NORMATIVE VALUES

The distance between the receiver and the transmitter of the signal (m), x	**F(x)**	**Average signal strength per gap (dBi), s**			
		20	***40***	***60***	***90***
4	-54	-56	-55	-55	-55
5	-57,7	-55	-54	-56	-55
6	-60	-67	-61	-61	-60
7	-62,5	-64	-63	-63	-62
8	-64,5	-60	-61	-63	-63
9	-66	-64	-59	-64	-65
10	-67,5	-68	-65	-68	-68
11	-69	-67	-70	-70	-70
12	-70,5	-68	-72	-73	-73
Average deviation		2,7	2,4	1,3	1,2

Based on the average deviation obtained, the optimal calibration time, during which it is possible to obtain an acceptable level of signal strength, is equal to 60 seconds. All subsequent measurements of the signal strength were carried out over a specified time interval.

III. Structure and Model of the System of Local Positioning in the Mall

To automate the positioning process and ensure the ability to download a plan of premises, calibration data processing, collect information about the power of the received signal and construct the route of the object in the mall, an appropriate local positioning system is proposed.

The grid initialization model involves determining $RSSI_0$ using the basic algorithm, which, in turn, is used to create a list of the nearest access points from the database. Implementing this stage, you need to enter parameters from the basic algorithms: $RSSI_{\max}$, $RSSI_{\min}$, which are defined relative to $RSSI_0$. Next, the cell length (*CL*) and the number of rows of cells (*M*) in the grid are calculated:

$$CL = \frac{2D_{\min}}{N_{\min}}, \quad (1)$$

where $D_{\min}$ - distance from the access point with $RSSI_{\max}$, $N_{\min}$ - a number of access points in the territory, limited by square length $D_{\min}$ and the center at the point A_0 with $RSSI_0$.

$$M = 2roundup(\frac{D_{msx}}{CL}), \quad (2)$$

where D_{msx} - distance from the access point with $RSSI_{\min}$.

The grid overlay center is the point A_0 with $RSSI_0$. The final stage in the formation of a grid is the placement of access points in the corresponding cells (Fig. 4). This model is stored in the database to further compare the position of the agent with the point A_0.

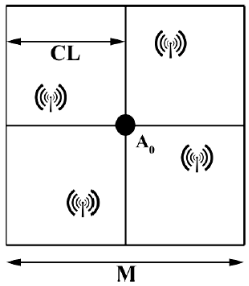

Fig. 4. Model initialization the object in the map local positioning of the mall.

The location monitoring model involves a new scan of the Wi-Fi signal to determine the direction of the object in the mall and to transfer its location calculations to one of the nodes on the local position map. The execution process of the model is presented in Fig. 5.

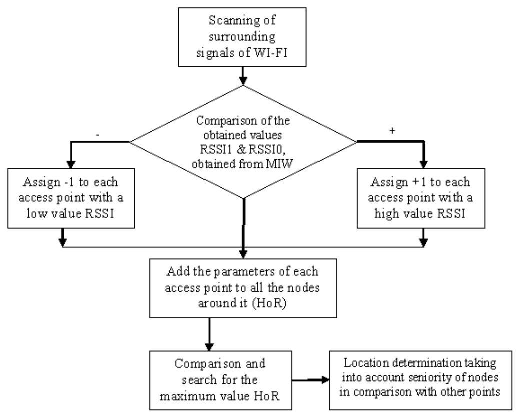

Fig. 5. Model of tracking the location of the object in the system of local

positioning of the mall.

After applying the model, all received data is superimposed on a regular local positioning map. As a result, the formation of the map can be divided into 2 stages.

At the first stage, the HoR value is calculated for each grid point. Next, a node is selected with the maximum HoR value. The selection of cells for calculating the location of the agent occurs at the last stage.

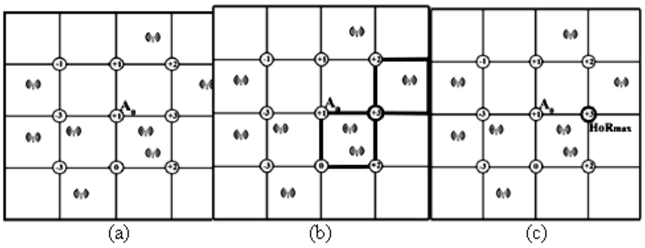

Fig. 6. The appearance of the regular grid when calculating the HoR value for each grid point (a); when selecting a node with the maximum value of HoR (b); with selected cells that will be used to calculate the location of the agent (c).

This algorithm creates a mesh initialization model and checks it for the density of the access points. To check each block of the dynamic grid, the density difference between the access points is determined. If *N* is the number of access points in the nested block, then the density of any zone will be declared depending on the rule: *N>4* - high density, *N<2* - low density, other values *N* - normal density. After checking the blocks, new cells and nodes are created. After checking the cell blocks, they can be divided or folded. If a cell contains 3 or more access points, it is divided into four equal cells, creating one node in the middle.

The map extension model is called after tracking the agent, only if a new agent location is created. In this model, the maps are recalculated without repeating all the steps performed in the MIW. In this version of the algorithm, the map is centered on the new location of the agent, after verification, similar to the one used in the initialization model. For addition and division repeated only check the card.

In Fig. 7 shows the context diagram of the system of the local object positioning on the map of the mall. In this scheme, as the source information on which the positioning system is based, the map and MAC address of the identified mobile devices are determined in the mall.

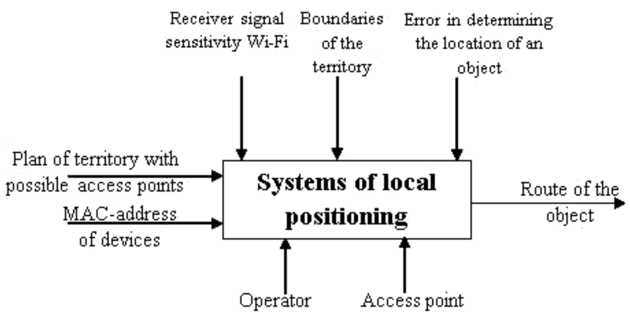

Fig. 7. Context diagram "Systems of local positioning in the mall".

The result of the system's operation is to determine the route of the object. After construction, the context diagram is detailed using a first-level decomposition diagram. When constructing a DF-diagram, the original decomposition circuit is divided into four components. The DF diagram for this problem is shown in Fig. 8.

The priority of the implementation of the steps for solving this problem is as follows: mapping of access points; get RSS values from access points; analysis of the received values of RSS and values of points of calibration; mapping of object points on a plan.

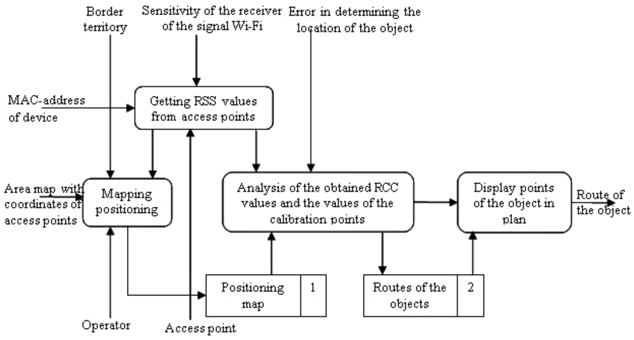

Fig. 8. DF-diagram of the route of the object in the mall.

As a result of the “Mapping positioning” block, we receive a set of calibration points placed on the specified plan and contain the signal strength of the positioning object in the mall received by the routers.

The result of the block “Getting RSS values from access points” is a set of values of the signal strength of the specified object of the mall.

The block “Analysis of the received values of RSS and values of points of calibration” is intended for reception of coordinates of movement of the object, which in real time are displayed on the plan of malls` territory and are saved with the database for further analysis.

The result of the block “Display points of the object in the plan” is the route of the object, which is laid on the map of the mall in real time, and for the operator interested in the interval of time.

IV. DISCUSSION

Using the proposed system of local positioning, which included software and three identical access points, local ranking maps were compiled and experiments were conducted to determine the route of the objects. As a mobile device, the Samsung Galaxy S2 mobile phone was used in the access point mode, capable of constantly sending broadcasts using the WI-FI signal in the mall.

In Fig. 8 large dashed lines indicate the actual route of the object in the mall. Measurement of the signal strength of the mobile device was carried out within 5 seconds, which is sufficient to determine the signal strength of the object, taking into account the signal normalization at the calibration points 4, 10, 16, 22, 28, 34, 40, 46, 52. The obtained values for calculating the coordinates of the object in the mall used two approaches: deterministic and probabilistic. The small dotted line indicates the route in the mall, obtained using the deterministic approach, the solid line is probabilistic.

Absolute deviations from the actual route are presented in Table. 2.

TABLE II. DEVIATION FROM THE ACTUAL ROUTE IN THE MALL AT THE SELECTED POINTS OF CALIBRATION, M

Number of the calibration point	**4**	**10**	**16**	**22**	**28**	**34**	**40**	**46**	**52**	**Mean deviation**
Euclidean distance	1,8	2,2	2,4	2,5	2,3	2,4	2,1	2,2	3,8	2,4
Distance on probabilistic distribution of Bayes	0	1,2	2,2	0,4	1,6	1,8	0,3	1,9	1,4	1,04

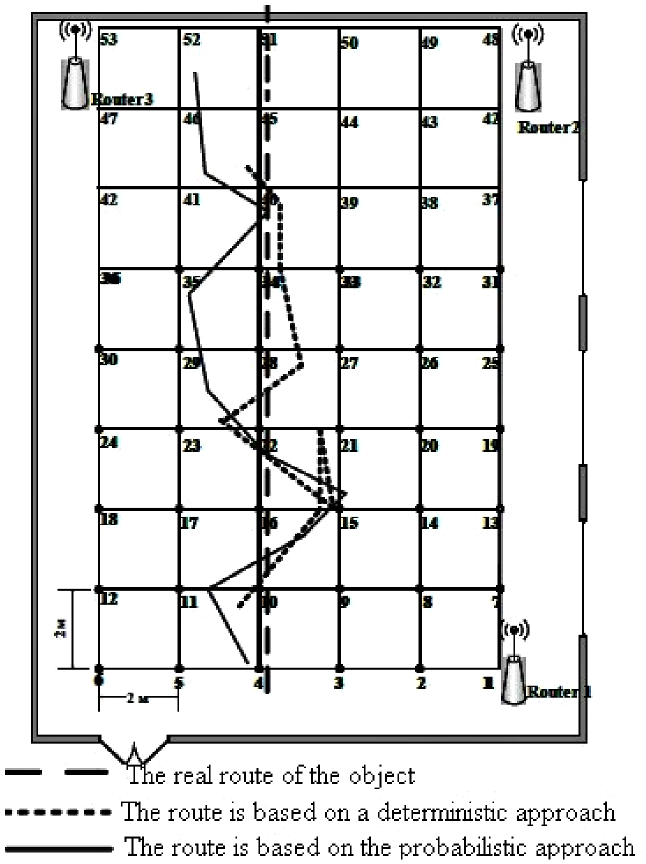

Fig. 9. Determination of the object's route on the map positioning of the mall.

Based on the results obtained, one can conclude that it is possible to apply both approaches to solving a local problem of positioning the object. The accuracy of the positioning object on the plane with the help of a map of local positioning does not exceed 2,5 meters, which corresponds to real functioning the positioning systems.

V. CONCLUSION

The problem of the local identification on the WI-FI technology is formalized, taking into account real requirements that can be presented in the case of commercial use.

As a result of familiarization with the most significant works of domestic and foreign scientists on the problem of local positioning, the main advantages and disadvantages of each of the proposed positioning methods were identified and the conclusion about the optimality of the method of determining the location of a mobile object by the level of the received signal from it based on the map of local positioning in the mall during the design of the system of local positioning of the object was limited the range of possible signal strength of the mobile device was selected at the mall. Obviously, this issue needs further study to obtain more precise coordinates when tracking any manufacturer's mobile device (in the experiment under review, only one manufacturer's mobile devices are used).

The proposed formalization of the problem of local identification WI-FI causes a number of scientific and technical problems that require the following solutions: the integration of the functionality of the WI-FI access point for the simultaneous location of the object and the provision of exchange of packets with external networks; a combination of different authentication methods to improve accuracy without artificially increasing the cost of wireless infrastructure; Choosing the best option to hide access points and secure data transfer over the network. These issues will be addressed in future studies.

The authors formalized the problem of local identification using Wi-Fi technology, formulated the requirements of systems that carry out local positioning using Wi-Fi technology. The proposed system after its testing and adaptation can be used to locate and construct a route of a moving object in enclosed spaces.

REFERENCES

[1] A. Yassin, Y. Nasser, M. Awad, A. Al-Dubai, R. Liu, C. Yuen, R. Raulefs, E. Aboutanios, "Recent Advances in Indoor Localization: A Survey on Theoretical Approaches and Applications", IEEE Commun., Surv. Tutor, 2017, vol. 19, pp. 1327–1346.

[2] R. Schultz, G. Varga, L. Tóth, "Indoor location services and context-sensitive applications in wireless networks. In Indoor Positioning and Indoor Navigation", 2010 International Conference, IEEE, 2010, pp. 1-10.

[3] P. Davidson, R. Piché "A Survey of Selected Indoor Positioning Methods for Smartphones", IEEE Commun., Surv. Tutor, 2017, vol. 19, pp.1347–1370.

[4] J. Kim, H. Jun, "Vision-based location positioning using augmented reality for indoor navigation", IEEE Trans. Consum. Electron, 2008, vol. 54, pp. 954–962.

[5] J. Qi, G.P. Liu, "A Robust High-Accuracy Ultrasound Indoor Positioning System Based on a Wireless Sensor Network", Sensors, 2017, vol. 17, pp. 25-54.

[6] Y. Wang, X. Yang, Y. Zhao, Y. Liu, L. Cuthbert, "Bluetooth positioning using RSSI and triangulation methods", Las Vegas, NV, USA, 2013, pp. 837–842.

[7] B. Wang, Q. Chen, L.T. Yang, H.C. Chao, "Indoor smartphone localization via fingerprint crowdsourcing: Challenges and Approaches", IEEE Wireless Commun., 2016, vol. 23, pp. 82–89.

[8] Y. Ye, B. Wang, "RMapCS: Radio Map Construction From Crowdsourced Samples for Indoor Localization", IEEE Access, 2018, vol. 6, pp. 24224–24238.

[9] J. Röbesaat, P. Zhang, M. Abdelaal, O. Theel, "An Improved BLE Indoor Localization with Kalman-Based Fusion", An Experimental Study, Sensors, 2017, vol.17, p. 951.

[10] M. Zhou, Q. Zhang, Y. Wang, Z. Tian, "Hotspot Ranking Based Indoor Mapping and Mobility Analysis Using Crowdsourced Wi-Fi Signal", IEEE Access, 2017, vol. 5, pp.3594–3602.

[11] J. Ren, S. Yang, "An Improved PSO-BP Network Model", Shanghai, China, 2010, pp. 426–429.