A Survey of Indoor Positioning Systems and Algorithms

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***Abstract*—Positioning objects has been an important topic since it is needed to locate people, guide them to a certain place, and assist companies and organizations with their assets management. Several systems and algorithms were proposed to solve the positioning problem and to enhance existing systems. In this paper, we survey various indoor positioning systems to explore the related challenges that exist in this area and evaluate some proposed solutions. We provide a categorization and classification of the current indoor positioning systems and identify some possible areas of enhancements**

***Index Terms*—Indoor Positioning, Sensor Networks, Positioning Algorithms, Wireless Positioning Technologies, Object Tracking.**

I. INTRODUCTION

Tracking people and objects became a very interesting field of research in the last ten years. The theory of positioning has been used in various application areas. For example, a company could acquire the necessity to position its equipment to track down its assets. Additionally, indoor positioning is very useful for positioning people within buildings such as hospitals and nursing homes (e.g., positioning the first responders of a rescue team in a building, given the absent of a positioning system). These applications require positioning, either to track down people or to guide them to a certain place within a building in order to save their lives.

In an outdoor environment, the Global Positioning System (GPS) works efficiently in positioning and targeting different types of entities. It has been used in many outdoor applications for localizing people, cars, as well as other objects. However, GPS lacks the same level of efficiency when used within indoor environments. This problem is due to the existence of obstacles that can weaken the signal of the GPS (e.g., building architecture, walls) where the existence of different equipment can cause a noise in the GPS transmitted signal.

Pedersen [1] proposed a micro positioning strategy that should be implemented within the indoor environment in order to position and track objects. He stated that this strategy would work as a replacement for the GPS positioning system. In addition, Fhelelboom [2] found that a wireless local area network (WLAN) can be used within any indoor environment to position objects.

In this paper, we review the different positioning environments, the different systems applied for each environment and the algorithms used within each system. We specify two scenarios for positioning people and objects within an indoor environment. Each of these scenarios has its own challenges, which researchers tried in the past to mitigate by proposing several solutions over the last ten years.

We have organized the paper as follows. In the next section, section II, we point out some preliminary technical information regarding indoor positioning. In section III we discuss the problems and challenges that are associated with indoor positioning systems. Next, in section IV we discuss the existing approaches for localizing object within an indoor environment. This is followed by a comparison of the different positioning approaches and solutions in section V. Then, we propose some solutions that can help improve positioning in indoor environment in section VI. Finally, in section VII we render our conclusion.

II. PRELIMINARIES

Here we present some preliminary information that researchers must be aware of indoor positioning systems and environments.

A. Type of Positioning

In this section, we focus on two types of positioning. The first type is positioning objects when there is an installed positioning system within the building and users are carrying tools such as RFID or any other equipment based on the wireless sensor network used in the system. We identify this type as a Fixed Indoor Positioning System. The second type is positioning users who have the equipment such as RFID when the building does not have the system installed within that giving environment. It is referenced as pedestrians positioning.

B. Positioning Principle

There are mainly four principles used in building positioning systems. These principles are Trilateration, Triangulation, Scene Analysis and Proximity [3]. The principle used can provide a faster calculation of the position. It can also provide a better accuracy depending on the system architecture too.

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In Trilateration [4], we find the "x" and "y" coordinates of a point using the distance between this point and three other points with known coordinates. First, the three radiuses are computed. Then, using Equation (1) we subtract the radiuses to get the distance between each point and we simplify the equation in 2 to get the values of "x" and "y" of the required point.

$$(r_a)^2 - (r_b)^2$$
$$(r_a)^2 - (r_c)^2 \qquad (1)$$

The Triangulation principle [5] is similar to Trilateration, however, we use angles is order to get the distance d.

Scene Analysis is another principle of positioning in which fingerprinting is used. A fingerprint is the signature that differentiates the scene from other ones. In other words, a fingerprint is the unique characteristic or collection of characteristics of the scene. It works by collecting some information from the scene and compare the collected information with the existing database match for each scene.

The proximity principle [6] is mainly used in Radio Frequency based systems. In this principle, we use a grid of antennas with fixed locations within the building. When a person carrying the mobile station is detected, the closest antenna is the one considered when calculating the object's location. If the mobile is detected by more than one antenna, the antenna that receives the strongest signal is then considered when calculating the object's location.

C. Positioning Principle

There are different attributes used to measure the location of an object. These attributes are either sent by the sensor or measured by the Base Station when the signal arrives. The attributes used are Received Signal Strength (RSS), Angle Of Arrival (AOA) and Time Of Arrival (TOA) [7]. All of the mentioned attributes are used by the Base Station to calculate the coordinates of the target object's position. Moreover, selecting the attribute used within an indoor positioning system results in a different calculation of the position. These attributes have an effect on the resulting position calculation along with the type of wireless technology and the algorithm used within the system.

TOA is the time taken by the signal to travel from the source sensor node to the Base Station. It is calculated by subtracting the time the signal left the source sensor node from the time the signal arrived at the Base Station.

TDOA is Time Difference of Arrival. It is calculated by sending two types of signals. The difference between the Time of Arrival of the two signals is the TDOA.

RSS is the Strength of the received signal. It is measured at the Base Station and used to calculate the coordinates. RSS can be affected by many factors such as obstacles.

D. Type of location provided

There are three types of locations that can be provided by a positioning system. These types are (i) physical location, (ii) symbolic location, (iii) absolute location and (iv) relative location [9, 10, 11].

III. PROBLEMS AND CHALLENGES

In this section, we discuss the existing problems and challenges that are encountered when implementing indoor positioning systems and algorithms.

A. Accuracy

Accuracy of a positioning system is the closest calculated position that can be achieved to a target object. Different systems provide different accuracies. For example, RADAR systems provide an accuracy of 2-3 meters [12]. Where, a cricket system which uses ultrasonic signals has an accuracy of 2 cm [13]. However, the accuracy is still a very challenging area of research for many researchers in this field.

B. Range of Coverage

Each positioning system works in a different range. The most effective systems are the ones that cover the widest range. Ranges of existing systems go from 5 meters to 50 meters. Providing a system that has coverage of more than 60 meters is a challenge by itself.

C. Security

The security aspect of indoor positioning systems has not been a major concern in most of the undertaken research in this area. However, it is an important factor in positioning within Personal Network (PN) [14] which users use to position objects and people in their home. An example of a secure wireless indoor positioning system is the Beep system [15].

IV. LITERATURE REVIEW

Researchers and companies have made substantial contributions to the topic of Indoor Positioning systems and environments. Indoor Positioning area is full of useful contributions. In this section we discuss the different indoor environments and the state of the art of indoor positioning systems.

A. Fixed Indoor Positioning

Common architecture of Fixed IPS systems is having fixed number of Base Stations (BS) which is the main computer that receives all the signals from the different nodes and calculates the coordinates of the target object using the parameters sent from the sensor nodes. All BS are required to be installed in fixed locations within the building. In addition, a Wireless Sensor network including the sensor nodes is needed. In this structure, the sensor nodes are responsible for propagating the signal received from a mobile station to the base station as well as doing simple calculation of the destination or time of transmissions. This behavior depends on the design of the system. The third main component of the fixed indoor positioning architecture is the mobile devices or tags carried by people or attached to target objects. These tags provide a unique identification for each object or person. Therefore, errors will be limited. Next, we list each wireless technology with the systems, which are developed based on this technology. Functions of IPS are discussed in [8].

a. Infrared Positioning Systems

These systems use infrared signals in order to transmit signals from sensor nodes to the BS. One of the most well-known infrared positioning systems is the active badges developed by AT&T Cambridge [16]. In this system, users carry an ID card equipped with infrared LED. The infrared LED sends a unique code every fifteen seconds. Furthermore, there are infrared sensors installed on a ceiling and if the IR badge is within six meters, the sensor is able to read the code. The BS receives the data from the IR sensors periodically. Finally, the BS is able to build a map of each badge location using the information retrieved from the sensors. Active Badges have mainly four commands, WITH, LOOK, NOTIFY, and HISTORY, each of which provides a different function. For example, WITH shows the badges that exists in the sensor area, LOOK is used to look for a badge by a sensor, NOTIFY is used to notify the BS when the badge is found and HISTORY shows the badges positions over a certain period of time.

b. Ultrasonic Positioning Systems

Ultrasonic beacons are used more often than infrared technology. Ultrasonic systems provide more accurate positions for objects. Ultrasonic based systems are more accurate than Radio Frequency based systems as we will see in the discussion section. However, Ultrasonic systems need to have a fixed structure of the system [17].

Examples of the systems developed based on Ultrasonic technology are the Active Bats [18] developed by AT&T Cambridge too. This system has a similar structure to the active badges.

The Crickets system [13] developed by the Massachusetts Institute of Technology (MIT) is another well-known ultrasonic based indoor positioning system. The Cricket system has two types of nodes, beacons and listeners. Beacons' locations are fixed and they are attached to the ceiling while the listeners are attached to the target objects and people. Beacons send periodic information to the BS containing its ID, range of coverage or physical space associated with it and its coordinates. Cricket uses the Time Difference of Arrivals (TDOA) attribute in order to compute the coordinates of the target object. That is by calculating the difference between the Radio Frequency signal Time Arrival and the ultrasonic signal Time Arrival. The Difference of the time of arrival of the two signals is calculated using equations in (2), since the Radio Frequency is much faster than sound. Then, the TDOA is equal to the distance the signal traveled over the velocity of the signal.

$$\Delta T = \frac{d}{\vartheta_{RF}} - \frac{d}{\vartheta_{US}} \tag{2}$$

The Cricket system is claimed to provide an accuracy of up to 2 cm. However, when facing NLOS error, the Cricket system does not provide an accurate calculation of the coordinate. Popa [19] suggests combining Cricket with Inertial Navigation sensors. This combination provides a better accuracy and mitigation of NLOS error as claimed by Popa. That is because Inertial Navigation sensors have a wider coverage and their signal is not affected by the NLOS error.

c. RF Positioning Systems

The mostly used wireless technology is Radio Frequency (RF). This is due to the low cost and the high range of coverage of the systems developed based on RF technology. Some RF based systems that we will discuss in this paper are RADAR, Spot-On, LANDMARC, and UWB systems.

LANDMARC system [20] is based on Radio Frequency signals and RFID tags. LANDMARC reduces the cost of using RFID readers by reducing the number of readers and using reference tags instead. These reference tags have a well-known location and they transmit to the readers the location of the target objects. LANDMARC is a very good system but its accuracy is 1-2 meters. This accuracy is not the best accuracy that can be found as we will see in section IV.

Guang [21] provided a mechanism to improve the performance and accuracy of LANDMARC. This mechanism works by reducing the number of candidates of reference tags when calculating the position of an object. This reduces the calculation effort and results in a faster calculation and a better accuracy. When testing LANDMARC using this mechanism, Guang claims the accuracy of LANDMARC was better using this mechanism than using the traditional LANDMARC. Guang's mechanism provides an error rate.

Jiang [22] proposed a system that provides outdoor positioning using GPS and UWB to provide indoor positioning. Jiang's system contains PDA, UWB sensor network and a Base Station. GPS software is installed on the PDA as well as an interface for the UWB sensor network. When the user moves outside the building the GPS application is activated and when the user moves inside the building the network recognizes the device and the UWB application is activated to enable the user to navigate through the building and allows the Base Station to position this user. The accuracy was found to be within 10 meters which needs a lot of improvements in the future.

d. Optical Indoor Positioning

Optical Indoor Positioning is another type of fixed indoor positioning where we have a system installed in the building and a camera carried by the user.

Tilch [23] proposed CLIPS (Camera and Laser based Indoor Positioning System). This system combines both technologies to position objects indoor. The camera acts as the mobile device for positioning objects. The laser device is oriented towards the ceiling and laser beams are on the ceiling. The camera tracks the laser beams and adjusts its orientation with regards to the laser beams location. Optical indoor positioning is used more for robot self-localization within an indoor environment.

B. *Indoor Pedestrian Positioning*

Pedestrian positioning, as mentioned earlier in the paper, happens when locating people who are carrying localization sensors while the building is not equipped with an indoor positioning system. In these types of systems Inertial Navigation Systems or dead reckoning are mostly used. Dead Reckoning is defined as navigation technique that starts from a well-known location [24]. Then, adds the position changes in the coordinates of the starting point. It also adds the changes to the heading (direction), speed or distance. Moreover, Pedestrian Dead Reckoning (PDR) is defined as estimating the speed of movement and the heading or direction of movement. We will show some of the interesting contribution to this type of positioning.

Several approaches in Indoor Pedestrian Positioning use Particle Filters such as Bayesian Filter and Kalman Filter. A Bayesian filter [25] is used to estimate the step of the pedestrian at a certain time when knowing the previous steps of the same pedestrian at number of times before it. Kalman Filter [26] is a mathematical model which is used to accurately estimate the position with the existence of noise.

Beauregard [27] uses the Pedestrian Dead Reckoning approach in order to position. He uses helmet mounted sensors as a novel approach for pedestrian positioning. That is because the helmet is the highest position the sensor can reach as stated by Beauregard. The algorithm used in this system has two steps, step detection and estimation and heading detection and estimation. In detecting and estimating the step, they detect speed of the movement and the length of the step while in heading detection and estimation the direction of movement. The limitation in this system is that the sensor on the helmet has to be directed to the direction of the pedestrian's movement.

Another approach provided by Robertson [28], he suggests using foot mounted inertial sensors which provide the pedestrian dead reckoning. He provided a system called FootSlam. This system uses foot mounted Inertial Measurement Unit (IMU). Moreover, it builds a 2D map of the building without any prior knowledge of the structure of the building. The knowledge of all user intention helps with forming the map of the building and guiding the user through it. However, the more times places are visited within the building the better information or map built in regards of that place. Simulation results show an accuracy of 1-2 meters.

Fischer [29] suggests using Ultrasound beacons to provide better accuracy and less heading errors in Pedestrian Dead Reckoning. His approach combines Ultrasonic and PDR. The PDR algorithm contains two types of phases within the steps, a stance phase and a swing phase. Fischer noticed there are also two types of errors that can occur within PDR, these errors are the heading error and the distance error. As discussed earlier, the heading is the direction of the movement; therefore, the heading error is the error occurs in the shown direction of the pedestrian. The distance error as stated by Fischer has fewer occurrences. Fischer's system is applied mainly to the rescue team first responder. The system works as follows; the first responders put the ultrasonic sensors on their way as they proceed within the building. PDR system is used to get the location of the pedestrians. However, ultrasonic sensors make the adjustments in order to reduce the heading error. His algorithm has four steps (i) Estimate person's position, (ii) Project onto path, (iii) Find the target position, and (iv) Compute the guidance angle.

Woodman [30] proposed Bat system. Bat system uses Foot-Mounted inertial unit for Pedestrian Dead Reckoning and a Wifi technology to position pedestrians within a multi-story building. Bat system uses particle filter algorithm which is Bayesian filters. Woodman proposed a correction algorithm to correct the drift in inertial measurements with pedestrian movement. Woodman's algorithm helps in estimating the position of the pedestrian at time k when knowing his position at time k-1.

Shao [31] discusses a relative area; he implemented autonomous pedestrians in a 3D environment. He showed how his autonomous pedestrians interact within the environment and how they build maps of the environment. He classified the maps as Topological map, perception map and path map. The topological map represents the environmental regions and the arrows represent the accessibility between them. The perception maps comprises of stationary objects, which are the local objects. Where the mobile objects are the global objects. Finally, the path maps can be either grid, which are for short path mapping (e.g., seat) or Quadtree which are for long path planning. Shao's maps method of his autonomous pedestrians might be very useful if used for pedestrian guidance through indoor positioning.

C. *Enhancements on principles and algorithms*

In this section, we show some interesting ideas that could be used to enhance indoor positioning systems.

Chin [32] proposed a new technique to improve the positioning accuracy in triangulation method. This technique is based on fuzzy logic. The technique denotes d as the triangulation result distance between the target object and the corresponding sensor nodes. The fuzzy mechanism consists of the fuzzifier, interface engine and defuzzifier that d goes through.

Cases [33] suggests using Least Median of Squares Algorithm (LMedS) in order to mitigate the None Line Of Sight error. The main benefit of LMedS [34] is that it reduces the outliers when calculating the coordinates of the target object. It chooses the solutions with the lowest median. The LMedS algorithms works as follows, we have at least three Bases Stations in the building. Therefore, we calculate m pairs of Base Stations. Then, we refer to every pair of Base Stations as Ps which is a possible solution. For each Ps we calculate d. For all possible solutions we calculate the residuals using (3) where $\hat{d}_{is}$ is calculated using (4). The solution selected is the solution with the lowest median of all.

$$R_S = (([d_1 - \hat{d}_{1S})]^2, \ldots, [d_n - \hat{d}_{nS})]^2) \quad (3)$$

$$\hat{d}_{is} = \sqrt{(x_{ps} - x_i)^2 + (y_{ps} - y_i)^2} \quad (4)$$

V. DISCUSSION

In this section we compare different fixed positioning systems and pedestrian positioning systems. The comparison is shown with respect to the challenges of providing the best indoor positioning systems which are discussed in section II. Table I shows a comparison among Fixed Indoor Positioning Systems. Note that in the table we refer to Trilateration as (T) and Triangulation as (R) and S is the data rate which is measured by Hz. Information in this table collected from [15], [19] and the references shown in the table. We notice that the active badge which is the only infrared based system provides an accuracy of centimeters which is better than many other systems. However, it only covers 5 m of range and its data rate or speed is 0.1 Hz. On the other hand, Ultrasound based indoor positioning systems provide an excellent accuracy compared to the other systems based on Radio Frequency. This might be because of the structure of the ultrasound systems. However, ultrasound systems do not perform well when facing None Line of sight error. Active bats have the highest data rate of all systems while its cost is moderate since ultrasound needs a fixed structure within the building to operate efficiently. One can notice that the cost of Active badges is high because it is based on Infrared which is an expensive technology. Moreover, UWB has also a high manufacturing cost compared to the other Radio Frequency based systems. LANDMARC and Active Bats have the highest coverage of 50 meters within the building. None of the systems is provides a security feature.

TABLE I. COMPARISON OF FIPS

System	Parameters					
	Accuracy	***2D/3D***	***Principle***	***Range***	***Robustness***	***S***
Active Badge	7 cm	2D/3D	T/TOA	5 m	LOS Light	0.1
Active Bats	9 cm	2D/3D	T/TOA	50 m	LOS Reflection	75
Cricket	2 cm	2D/3D	T/TOA	10 m	LOS Reflection	1
Dolphin [25]	2 cm	2D/3D	T/TOA	Room	LOS Reflection	20
Radar	2 -3 m	2D/3D	R/RSS	Room	Low accuracy Not reliable	4
Wave LAN [35]	3 m	2D	R/RSS	Room	One story building	4
UWB [15]	10 cm	2D/3D	T/TOA	15 m	Enough sensor to cover the area	1
LANDMARC	1-2 m	3D	R/RSS	50 m	Good	70
Horus [36]	2 m	2D	R/RSS	10 m	One story building	5
COMPASS [37]	1.65 m	3D	R/RSS	15 m	User's device must contain digital CAMPASS	-
WhereNet [38]	2 – 3 m	3D	R/RSS	20 m	Frequency of signals	0.5

Table II shows a comparison among the Pedestrian Indoor Positioning systems. In this table we collected the four most interesting systems proposed by researchers. These systems were discussed in section III. A table 2 shows that the best accuracy found in the available pedestrian positioning systems is 0.5 meters which is provided by the Bat system. That might be because of the Wifi correction that modifies the drift that occurs when using Pedestrian Dead Reckoning.

TABLE II. COMPARISON OF PIPS

System	Parameters				
	Tech	***Accuracy***	***2D/3D***	***Range***	***Robustness***
Beaurgard's	PDR	10 m	2D	Room	1. No change in heading 2. No drift caused by PDR
FootSLAM	PDR	1-3 m	3D	2m	Improves with larger number of visits to locations in the building
Fischer's	US + PDR	<1m	3D	3m	1. No harsh light 2. Not noisy env. LOS
Bat System	Wifi + PDR	0.5	3D	building	Existence of Wireless

VI. ANALYSIS OF RESEARCH AREA

In this section we discuss the possible improvements that can be used in the future. We analyze Indoor positioning as a research area and the classification of the indoor positioning in our paper.

Throughout our research we found many contributions in the fixed indoor positioning systems and algorithms. Most of the possible enhancement that might be suggested is already proposed in the field and there is a very narrow space for new ideas. Our discussion shows that Fixed Indoor Positioning Systems reached the accuracy of centimeters which is a very good result. Some errors faced the systems based on different wireless technologies. However, researchers proposed many different solutions to overcome these errors such as Bluetooth Systems [48], and many new algorithms. Therefore, we believe that the Fixed Indoor Positioning area is saturated.

On the other hand, we believe that there are many improvements to be done within the area of Pedestrian Indoor Positioning. Through our research we found multiple systems proposed to solve the indoor pedestrian positioning problem. However, the accuracy reached within this area is not a satisfactory as the accuracy reached within Fixed Indoor Positioning Systems. Indoor Pedestrian Positioning best accuracy reached only 0.5 meters. Therefore, we believe many enhancements can be added to this area.

VII. CONCLUSION

In this paper, we have reviewed indoor positioning systems, the principles of positioning and algorithms used in various environments. We discussed the challenges that can be faced when designing an indoor positioning system, elaborated on different solutions proposed to overcome these challenges and provided a possible area of application and enhancement within indoor positioning systems. We noticed Indoor

Positioning is a huge area with many applications and many improvements to be carried. As mentioned earlier in this paper, researches within indoor positioning could be more useful if carried for pedestrians positioning since the accuracy reached is not as accurate as the accuracy reached in fixed indoor positioning.

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