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IoT sensors for indoor positioning : A literature review

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Abstract

Indoor positioning is the process of getting the position of an object or person inside the indoor environment. There are cases in which the building architecture is complex and there is the possibility of a person or object getting lost. In such cases, Indoor positioning is helpful to locate a person or object. To locate an object in an indoor environment, various types of sensors are used. These sensors use different types of data to locate the object or person. This review paper aims to provide the various sensors and different parameters to compare sensors that are used in indoor positioning. There are various practical applications for Indoor positions. Navigation in shopping malls or museums, inventory management, robots' movement, and asset tracking are various practical examples of Indoor positioning.

Subject Classification: *68M18, 68T40, 51N35.*

Keywords: *Indoor positioning, Sensors for indoor positioning, Indoor navigation, Indoor localization, Indoor wayfinding.*

1. Introduction

The Global Positioning System (GPS) [1] is a system used to locate objects on Earth through satellites. It can operate in any place worldwide and in all weather conditions. GPS satellites transmit their signals to Earth, which are received by GPS trackers. However, this GPS doesn't function in indoor environments due to the signal being obstructed by roofs or walls. We need ways to find where people or things are inside buildings without

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using GPS. That's where Indoor Positioning Systems (IPS) come in. These systems use various sensors to accurately figure out the location of people or objects indoors.

In IPS, different sensors used refer to a set of technologies designed to locate the person or object in an indoor environment. This paper begins by introducing the different sensors used in indoor positioning and grouping them into different categories. These sensors are categorized into five categories which are radio-based, inertial-based, Optical-based, environmental-based, and Acoustic-based. It then explains the working of different categories and explains the advantages, and disadvantages of each category. By different comparisons, it can be seen that sensors behave differently because of their dynamic nature. Considering the above nature, achieving accuracy becomes a challenge. In section 1.2, there are various applications where Indoor positioning can be used. The subsequent sections of the document are structured as follows: Section 2 outlines the procedures employed in conducting the Systematic Literature Review (SLR). In Section 3, the paper discusses the outcomes of the SLR, providing detailed insights into empirical evidence and identifying existing gaps in the research domain. Finally, Section 4 brings the work to a conclusion and challenges are discussed in Section 4.1

1.1 *IoT Sensors for Indoor Positioning*

Indoor positioning sensors are varied technologies designed to ascertain the precise location of a person or objects within indoor environments. We have examined various papers on indoor positioning, and classified the sensors into five distinct categories: Radio-Based, Inertial-Based, Optical-Based, Environmental-Based, and Acoustic-Based as shown in Fig.1. Based on the above categories results are shown in Table 1 which gives the advantages, disadvantages, accuracy, range, and power consumption[2] of a variety of sensors that are used for indoor positioning. From the comparative analyses shown above, it is clear that every sensor has its strong points and not-so-strong points. That means the sensor that works best for a certain job will come down to what that job needs. For example, if we need a sensor that is widely available and has moderate accuracy, then Wi-Fi may be a good option. Yet, if we are looking for a sensor that's good at being accurate and can track things super precisely, we might want to consider UWB (Ultra-Wide Band)– it could be a better choice. It all depends on what the application needs i.e. navigation app,

and based on that, we might need a set of sensors to make it work. The following are the characteristics of different sensor categories:

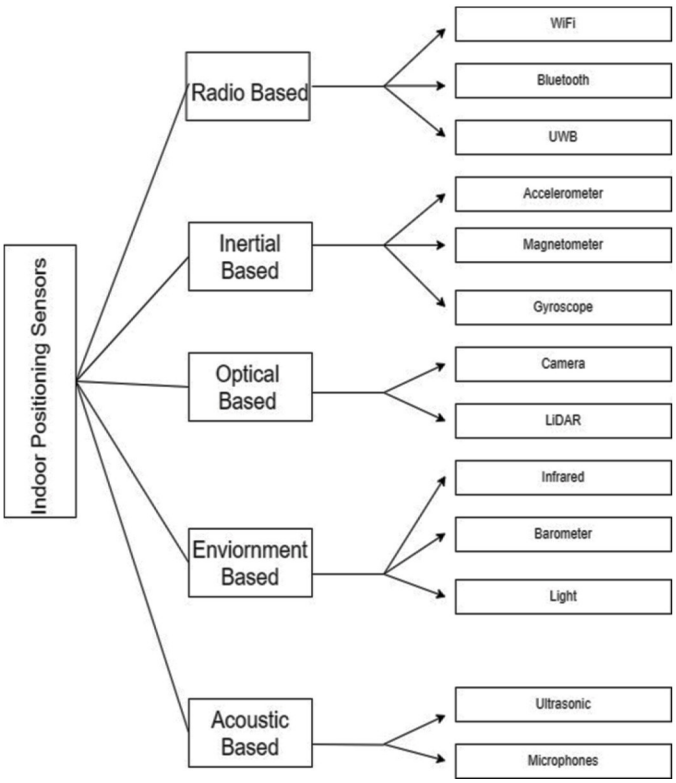


Figure 1

IoT sensors in Indoor Positioning

Radio-based sensors: Radio-based sensors, such as those using Wi-Fi signals are commonly used for positioning[3]. These sensors estimate a device's location by analyzing signal strength or time of arrival. Wi-Fi signals are available indoors and provide a moderate degree of accuracy in location estimation. Many existing environments have already Wi-Fi devices for Internet, so Wi-Fi based positioning becomes the cost-effective solution for such cases. Bluetooth Low Energy (BLE) is also used for indoor positioning. Beacons are small devices that emits Bluetooth signals and that are strategically placed within the area where we want to locate a person. This technology is widely used for IPS in retail, museums, and healthcare. Since the BLE device can be installed to new location for

expansion, this make the BLE technology more scalable. When more precision is required, UWB technology is used in-door positioning. By measuring the time, it takes for UWB signals to travel between devices, distance is calculated hence a device can be located. UWB is very useful in applications where precise location information is critical, such as asset tracking and industrial automation.

Table 1
Summary of IoT Sensors Used in Indoor Positioning

Category	Sensors	Advantages	Disadvantages	Accuracy	Range	Power Consumption
Radio Based	Wi-Fi [3]	Good range, widely available	Limited range, signal penetration	Moderate	Moderate to long	Moderate
	Bluetooth [4] [5]	Good accuracy, Low power consumption	Limited Range, Vulnerable to signal interference	Moderate to High	Short	Low
	UWB [6]	High precision, High accuracy	High cost, Limited availability	High	Moderate	Moderate
Inertial Based [7]	Accelerometer	Low cost, easy to use, Measures motion and acceleration	Vulnerable to errors, low accuracy and Drifts over time	Limited (relative)	N/A	Low
	Magnetometer	Measures magnetic field for orientation	Affected by external magnetic interference	Limited (directional)	N/A	Low
	Gyroscope	Measures angular velocity	Requires calibration, drift correction	Limited (rotational)	N/A	Moderate
Optical Based	Camera [8]	Visual information for positioning	Limited accuracy in low-light conditions	High	Moderate	High
	LiDAR [9]	Highest accuracy, can be used in a variety of environments	Expensive, complex to implement	High	Long	Moderate

Contd...

Environmental Based	Infrared Sensor [10]	Detection of heat, infrared radiation	Limited range, susceptibility to an environmental factor	Low	Short	Low
	Barometer [11]	Low cost and Altitude estimation	atmospheric pressure changes	Limited (Floor level)	N/A	Low
	Light [12]	Required Lighting infrastructure	Limited accuracy in varying lighting conditions	Low	Short	Low
Acoustic Based	Ultrasound / Ultrasonic Sensors [13] [14]	Low-cost, good for distance measurement	Limited range, sensitivity to obstacles	Low to Medium	Short to Medium	Low to Moderate
	Microphones [15]	Omnidirectional, captures ambient sound	Background noise, privacy concerns	Limited (directional)	Short to Medium	Moderate

Inertial sensors: Inertial sensors, on the other hand, measure a device's motion and can be used to estimate its location over time. Accelerometers, gyroscopes and magnetometer are the key component for IPS based on Inertial sensors. Data received from accelerometers, gyroscopes, magnetometers is used to calculate the steps count, heading angle and steps length of the person [16]. However, they are not typically relied upon for positioning due to issues such as drift and noise accumulation; thus, these sensors are not used alone for positioning. To address this, a new method using an IMU (Inertial Measurement Unit) for UWB positioning has been proposed to enhance the accuracy of sensors[6]. After combining the data from accelerometers, gyroscopes, magnetometers the position and orientation of an object can be determined through inertial sensor system. Inertial sensors are very sensitive to external factors and faces challenges because of cumulative errors over time. Hence, these sensors need periodic recalibration to predict correct location. So, integration with other sensor technologies is must to get improved location.

Optical sensors: Optical sensors are based on the light environment around a device. These sensors use light, image processing or other optical parameters to locate the object or person. Camera based positioning system uses captured images or videos of indoor environment then computer vision algorithm processes the visual data to track the object or

person inside the indoor environment. Camera can also recognize the visual feature to improve accuracy of camera-based system. LiDAR (Light Detection and Ranging) sensors emit laser beam and these sensors are used to calculate the distance between the known location and the device by calculating the travel time of light from the device to the location or the angle of arrival. These data are then processed to locate the object or person. However, optical sensors are accurate up to 1cm [8]. Also, the optical sensors are more expensive than other sensors. Since, these sensors data depend upon the light, so the lighting conditions can decrease the performance of these sensors. Implementing the IPS based on high-quality optical sensors can be cost-intensive.

Environmental sensors: Environmental sensors are sensors that measure the environmental conditions around a device. These sensors are used to find the location of a device based on environmental changes. However, environmental sensors are typically not as accurate as radio-based sensors, and they are not as widely available. Environmental sensors provide valuable data to IPC to improve the accuracy and reliability. Infrared sensors detect the infrared radiation which is emitted by person or object. So, these sensors detect the presence of person or object in the indoor environment. Barometers are used to measure the atmospheric pressure and can be used to know the altitude of the given location. By integration of the Barometer with in-door solution can be used to locate the floor of the complex buildings. Light sensors measure the intensity of the light in their surroundings and this data can be used to locate the person based on the proximity of the source of light. This can be used to distinguished between different rooms of the complex building. Combining data from different sensors as IR, barometer and light sensor allow more understanding of the indoor environment. A low-cost indoor positioning system using Bluetooth low energy is proposed to improve the accuracy of environmental sensors for indoor positioning [17].

Acoustic sensors: Sensors that pick up on sound waves are called acoustic sensors. Two commonly used acoustic sensors for indoor positioning are ultrasonic sensors and microphones. Ultrasonic sensors used the sound waves that are beyond the human hearing. These sensors emit the ultrasonic sound and calculate the time taken to bounce back after hitting the object. The distance is calculated from the time taken and the speed of the sound wave. The advantage of an ultrasonic sensor is that it has minimum interference with other electronic devices and has high accuracy to measure the distance. Microphone sensors convert sound wave to electric wave. Microphones can be placed in indoor environment

and analyzing the time difference between sound emission and when it reaches to microphone, the IPS system can determine the source location. They can help pinpoint the location of an object or individual by detecting sound wave echoes that bounce off objects [18]. Though not as readily accessible as radio-based sensors, they serve their purpose and provide a unique approach to gathering data about a device's acoustic surroundings.

So, selecting the sensor for indoor positioning depends on several factors, such as the accuracy requirements, the cost, and the availability of infrastructure. From Table 1 we can conclude that radio-based sensors are one of the options when there is a need for high-accuracy indoor positioning, but they require a network of known reference points. On the other hand, if there is a requirement for low cost and no need for high accuracy then Inertial-based sensors are a good choice. Building on the specified requirements and the selection of diverse sensors, there are many uses for indoor positioning. There are a variety of applications where Indoor positioning can be used, following are some examples.

1.2 *Applications of Indoor Positioning*

- Navigation [19][20]: There are some buildings where architecture is complex which makes a person or object lost in an indoor environment, so indoor positioning methods help to implement navigation services in indoor environments. Big stores are the example of such case. Customers can easily navigate through the store with the help of IPS. IPS will facilitate the shoppers find the required items or locate with ease without roaming aimlessly within a store. With the help of IPS, shoppers will be able to get specific aisle information in a shopping store along with the location of their desired products. This not only leads to increased sales but also increases customer satisfaction.
- Asset tracking [21][22]: Indoor positioning can be used to track the location of assets in a building. This is very helpful for the business that needs to know the location of objects or any inventory. Real-time location information for logistics including people and goods leads to increased productivity. Smart factories can be built using real time location information of the inventory.
- Security [4]: Indoor positioning can be used to increase the security [23] inside buildings. For example, people's movement can be tracked easily through indoor positioning, which will restrict the person from unauthorized access.

- Safety in Warehouses or Hospitals: Workplace accidents/collisions can be avoided when the devices are in their designated place with the help of tracking the equipment. Staff Sick leaves can be decreased with decreased number of incidents. Emergency alarm systems can be developed with the help of IPS. Nurses can attend to the patient urgently based on the emergency alarm system. Voice and text messages can be sent to the nurses and which room needs urgent attention can be easily found out by leveraging IPS.
- Energy Management: With the help of Real-time IPS data, the system can determine which areas are occupied and which are not. Based on the occupancy pattern in different rooms/halls inside the building, an energy-efficient system can be made which can automatically increase the brightness where required and turn off the lights where there is no occupancy, decreasing unnecessary energy usage/wastage. IPS can optimize unnecessary cooling/heating when there is no occupancy.
- Entertainment: Indoor positioning can be used for entertainment services inside the building. For example, indoor positioning can allow the application to know the location of a person inside a museum so it can provide real-time information about that location. Audio or multimedia content can be triggered as a person approaches at some points. Notifications about character locations, personalized recommendations can improve the overall experience of the visitor. Theme Parks can quickly determine and respond to potential emergencies by leveraging visitor movement. Visitors can enjoy it with complete peace of mind.

2. Systematic Literature Review (SLR) Process

SLR is a type of research that involves reviewing and analyzing existing information to answer research questions. It follows a set of steps to ensure that the results are unbiased and can be repeated by others. As outlined by Kitchenham[24], we followed a specific set of steps to guide our research.

2.1 *Source of Information*

The research work for sensors of indoor positioning was studied from online research databases like Google Scholar (https://scholar.google.com/), IEEE Xplore (https://ieeexplore.ieee.org/Xplore/home.jsp),

Science Direct (https://www.sciencedirect.com/), Springer (https://www.springeropen.com/), ACM digital library (https://dl.acm.org/).

Search criteria - In the research work of our study, we looked into various journals and conferences with solid research databases, such as IEEE, IEEE Access, and Springer. We focused on highly cited articles that covered different techniques for indoor positioning. Most of the papers are from 2015 and above are considered and assumed to have the best results and the latest algorithms used. With these latest researches, we also focus on papers that can follow strict review procedures. After that, a search was carried out to obtain studies given the papers that were chosen during the previous search. This needs to be done so that most of the relevant studies and results can be taken out without failing any desired topic in our field.

2.2 *Inclusion and Exclusion Criteria*

To find the right studies for our search, we need to use specific criteria. We looked at conference papers, research papers from places like IEEE and IEEE Access, and more to gather various ideas and information related to Indoor Positioning Systems. Studied papers showing various comparisons between different IPS techniques and papers with maximum citations during the search. Our study also included papers that practically implemented IPS methods and showed results on their methods. We excluded studies that were dealing with other issues related to indoor positioning as we were focusing on sensors.

2.3 *Aim of Research*

We turned our research goals into research questions to guide our search and find valuable information in the studies. Research questions are crucial for systematic literature reviews because they guide the research process and aim to identify relevant studies, analyze them, and extract useful information to answer the questions. Our research aims to address the following research questions*:*

Research question 1: What are the obstacles faced in positioning?

Research question 2: How can we create a reliable system for determining positions?

Research question 3: How can we improve security and protect user privacy in indoor positioning?

Research question 4: How can we create trustworthy and precise indoor positioning systems for vast and complex environments?

Research question 5: What types of Indoor positioning systems exist?

3. Literature Review Results

The findings from the review of many studies help us learn important things about the five main questions we had. These questions were about the difficulties and ways to solve problems in indoor positioning systems.

3.1 *Research Question 1: What are the obstacles faced in positioning?*

Answer: There exist challenges that can complicate positioning, which include Multipath propagation, Non-Line-of-Sight (NLOS)[25], and Noise. Multipath propagation refers to the situation where a signal can take routes to reach the receiver. Consequently, determining the source of the signal becomes challenging. NLOS propagation refers to the scenario where a signal can pass through obstacles, like walls. As a result, it becomes difficult to ascertain the location of the signal source. Noise is the interference from signals and environmental factors, like temperature and humidity, contribute to noise further complicating indoor positioning.

3.2 *Research Question 2: How can we create a reliable system for determining positions?*

Answer: Some techniques can be employed to enhance the accuracy of positioning like Sensor fusion, Machine Learning[26][27], and Increasing Anchor points. The sensor's fusion approach is to utilize sensors, IMU, and UWB in combination [6]. By leveraging the strengths of each sensor, we can improve the accuracy of indoor positioning. Machine Learning algorithms can be utilized to learn the signal propagation patterns within an environment further enhancing accuracy [28]. Increasing Anchor points involves increasing the number of anchor points deployed throughout the area. This provides reference points for devices to triangulate their location thereby improving positioning accuracy. Signal strength fingerprinting is another technique used in in-door positioning systems [3]. It involves creating an environment map based on the Received Signal Strength Indicator (RSSI) of Wi-Fi signals. This map can then be used to estimate a device's location by comparing its received signal strengths with those on the map.

3.3 *Research Question 3: How can we improve security and protect user privacy in indoor positioning?*

Answer: Since indoor positioning applications are open to users, it is vulnerable to security attacks, such as spoofing and jamming. Fake signals are sent to the positioning devices in a spoofing attack, causing the detection of the wrong location [29]. Jamming attacks involve generating a noise signal to interfere with the original signals that are being used for indoor positioning. This interference will cause it not to detect the correct position. To safeguard the privacy of users, indoor positioning systems should only gather the essential data needed to position individuals or devices. To prevent unlicensed access, encryption methods should also be implemented [30].

3.4 *Research Question 4: How can we create trustworthy and precise indoor positioning systems for vast and complex environments?*

Answer: There are a range of issues in vast and complex environments. Such environments, like airports and shopping centers, are frequently crowded, hindering the receipt of dependable Received Signal Strength (RSS) readings. Indoor positioning systems for large and complex environments need to tackle obstacles like noise that can disrupt wireless signals. Employing multiple methods can be beneficial in overcoming these hurdles. One such technique is multipath mitigation [25], which can mitigate the effects of signal bouncing and help identify the exact source. Another method is sensor fusion which can combine data from several sensors such as UWB and Visual for more precise positioning [31]. Machine learning can study and identify signal patterns in different environments and use that data to improve indoor positioning accuracy [32].

3.5 *Research Question 5: What types of Indoor positioning systems exist?*

Answer: Indoor positioning systems come in various forms:

- Fingerprinting [3]: In this type, the heat map is created by comparing signal strengths from wireless access points (APs) in different locations. The user's location is estimated by analyzing current signal strengths, based on the previously captured map.
- Trilateration [22]: Signals from multiple APs are used in trilateration to estimate the location of the user via the time difference of arrival (TDOA) or time of arrival (TOA).

- Ultra-wideband (UWB) [33]: This type of system utilizes short-range radio signals to locate the object, serving as a requirement for highly accurate localization.
- Visual positioning [31]: Based on visuals, new technologies like smartphones can be used for Visual Positioning and accurately determine the user's physical location.

3.6 *Research Question: What's the future of indoor positioning?*

Answer: The upcoming innovations in indoor positioning will probably be defined by several developments, as follows:

- The use of new technologies: Indoor positioning systems have been given a modern touch with the availability of newer technologies like visual positioning and UWB. Traditional systems are slowly being replaced with affordable options that promise greater accuracy and dependability.
- The integration of indoor and LBS: Integrated positioning systems are becoming a necessity as IoT expands, merging indoor and LBS technologies. As individuals navigate between the indoors and outdoors, a singular application can be utilized
- The use of machine learning: Indoor positioning systems are becoming more precise and dependable with the assistance of machine learning [32]. In an indoor setting, machine learning procedures can acquire knowledge about the correlation between signal strength and location, and address the influence of multipath propagation and NLOS propagation [25]. As a result of this, the utilization of machine learning algorithms is on the rise.

4. Conclusion

This paper presents the comparison of sensors with different parameters which helps in the selection of sensors for an indoor positioning system. The purpose of this review was to guide to selection of the sensors for indoor positioning based on the requirement of the application. Recently, Radio-based sensors like Wi-Fi, BLE, RFID, and UWB have gained prominence for indoor positioning, facilitating location estimation. Among these, the RSSI algorithm[34] stands out as the optimal choice for user location estimation due to its advantages over Environmental and Acoustic based sensors which entail extra hardware, higher costs, and

complexity. However, the selection of indoor positioning sensors, includes cost considerations, available resources, the specific environment, and the desired level of accuracy.

4.1 *Challenges and Future Directions*

Over the past decade, we have witnessed advancements in positioning. However, there remain challenges that require attention. The first challenge pertains to the absence of standardization that is making it challenging to compare the effectiveness of techniques. Additionally, the dynamic nature of environments poses another hurdle to overcome. Indoor sensors behave differently in different indoor environments. The signal strength of radio signals can vary significantly depending on the environment, which can make it difficult to obtain accurate indoor positioning results at different locations. Addressing the dynamic nature of indoor environments different applications need different varieties of sensors to locate persons or objects in indoor environments.

There are several applications where indoor positioning can be used, so the future of indoor positioning is bright. Different research directions are being explored, such as the use of Machine Learning for indoor positioning and the use of wearable devices for indoor positioning. So in the future, we can expect to see even more accurate and reliable indoor positioning systems.

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