Navigation System Using Gaussian Filter

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***Abstract*— This research paper explores the concept and implementation of indoor positioning systems (IPS) and analyzes the challenges and opportunities of using IPS in various indoor environments. The paper reviews the different types of IPS technologies and their corresponding approaches, including Bluetooth Low Energy (BLE), Wi-Fi, Ultra-Wideband (UWB), and Inertial Navigation System (INS). Additionally, the paper evaluates the performance metrics of IPS, such as accuracy, precision, and latency, and identifies the factors affecting IPS performance, such as signal interference. Finally, the paper discusses the potential applications of IPS, such as indoor navigation, asset tracking, and security monitoring, and highlights the research directions for future development of IPS.**

***Keywords* – BLE, Indoor Positioning System (IPS), Received Signal Strength Indicator (RSSI), Signal Strength, Navigation, Data, Sensors, Accuracy.**

I. INTRODUCTION

Indoor positioning systems (IPS)[10] have emerged as a critical technology for a range of applications in indoor environments, such as navigation, asset tracking, and safety monitoring. IPS technology utilizes a variety of techniques to locate individuals or objects in indoor spaces where GPS signals are not available. Over the past decade, significant advances have been made in IPS technology, driven by the growth of the Internet of Things (IoT)[1], the increasing demand for indoor location-based services, and the emergence of new communication standards.

The accuracy and reliability of IPS are vital for many applications, including emergency response, healthcare, retail, and logistics. However, IPS faces several challenges, such as the complexity of indoor environments, the presence of signal interference, and the need for efficient power management. Therefore, it is essential to evaluate the performance of different IPS technologies and their corresponding approaches, analyze the factors affecting their performance, and identify opportunities for further development.

This research paper aims to make an IPS technology that can monitor assets, track distance, and improve the efficiency of older variations. The objective of our study is to improve accuracy & reduce signal interference.

II. CHALLENGES IN PREVIOUS SYSTEMS

Previous indoor positioning systems have faced several challenges, which have limited their effectiveness in providing accurate and reliable location information. Some of the challenges include:

A. Limited Accuracy: The accuracy of indoor positioning systems heavily depends on the sensors and algorithms used to estimate the location. In many cases, existing systems have limited accuracy due to the use of single-sensor solutions, which are susceptible to interference and do not provide accurate location estimates.

B. Signal Interference: Signal interference can occur due to the presence of obstacles, noise, or other wireless devices in the environment. This interference can affect the performance of indoor positioning systems by causing errors in location estimation and reducing system reliability.

C. High Power Consumption: Indoor positioning systems require continuous data collection and processing, which can be a significant drain on battery life. High power consumption limits the practicality of many indoor positioning systems and can make them impractical for use in certain applications.

D. Limited Scalability: Many indoor positioning systems are designed for specific applications and may not be easily scalable to other environments or use cases. This limits the applicability of these systems in real-world scenarios and reduces their potential for widespread adoption.

E. Cost: Many indoor positioning systems require specialized hardware, software, and expertise, which can make them expensive to implement and maintain. This cost can be a significant barrier to adoption, particularly for small businesses and organizations.

III. LITERATURE REVIEW

[1] This paper discusses the asset management and tracking applications for any business or organization, the human assets such as human resources, the moving assets such as vehicles and cranes, and non-movable assets like industrial equipment, materials, etc.

[2] Proposes a behavior modeling approach for a beacon-based indoor location system. Presents a method to model user behavior patterns based on BLE beacon signals and uses machine learning techniques to classify user activities. Evaluates the proposed approach using real-world datasets and compares it with other approaches. Discusses the advantages, limitations, and potential applications of the proposed behavior modeling approach for indoor location systems, including tracking user activities and providing personalized services in indoor environments.

[3] For indoor positioning, the area of the stair corner is narrow, and far away from the access point, leading to poor positioning accuracy. To solve this problem, the paper proposes a positioning algorithm that uses Bluetooth + Wi-Fi based on the location fingerprint in this area and calculates the coordinates at the decision-making level by fusing the results of Bluetooth and Wi-Fi. Other spacious areas still only use the Wi-Fi for positioning, it not only improves the positioning accuracy but also does not cost too much.

[4] Proposes an optimization approach for BLE beacon placement in indoor environments for static smart devices using a Gaussian filter for improved accuracy. Presents an optimization algorithm for determining optimal beacon placement based on environmental characteristics and accuracy requirements. Discusses the impact of the Gaussian filter on positioning accuracy and presents experimental results. Provides insights into optimizing BLE beacon placement and filtering techniques for indoor positioning of static smart devices.

[5] This paper discusses the different technologies of wireless networking that can be used for tracking objects with greater accuracy. It becomes difficult in the case of indoor positioning since the surrounding objects or materials prevent or obstruct the signals that need to be received by the receiver.

[6] Presents a method for tracking a moving user in indoor environments using Bluetooth Low Energy (BLE) beacons. Describes the system architecture, ranging algorithm, and positioning algorithm. Evaluates the proposed method through experiments in a real indoor environment. Discusses the accuracy, limitations, and potential applications of the proposed method for indoor positioning and tracking of users in various scenarios.

[7] This paper proposes an indoor positioning system that utilizes a Double-Gaussian filter for improved tracking accuracy. The paper presents the algorithm of the Double-Gaussian filter and its application in the indoor positioning system. Experimental results based on real-world datasets demonstrate the effectiveness of the proposed system in reducing measurement noise and improving tracking accuracy compared to traditional approaches. The paper also discusses potential applications, limitations, and future research directions of the proposed system.

[8] Proposes a location tracking system using BLE beacons and a Double-Gaussian filter for improved accuracy. Presents system architecture, ranging algorithm, and calibration techniques. Demonstrates performance improvement using real-world datasets. Discusses potential applications, limitations, and future research directions.

[9] This paper discusses the object tracking approaches done in the previous two decades since this is one of the trending and efficient technologies and the importance for an organization to track their assets by grouping them. This paper also discusses different methods that are used to track objects that might be single or in a group.

[10] This paper presents an indoor positioning system that utilizes the Savitzky filter for noise reduction in received signal strength (RSS) measurements. The paper discusses the implementation of the Savitzky filter and its effectiveness in reducing noise in RSS measurements, leading to improved positioning accuracy. Experimental results based on real-world datasets demonstrate the performance improvement of the proposed system compared to traditional RSS-based indoor positioning techniques. Potential applications and limitations of the system are also discussed.

[11] This paper compares RSS-based indoor positioning techniques using Wi-Fi signals in 2.4 GHz and 5.8 GHz frequency bands. The paper investigates the performance of popular techniques such as KNN, fingerprinting, and probabilistic approaches, providing insights into the advantages and limitations of these techniques in different Wi-Fi frequency bands.

[12] This paper presents an indoor positioning system using Bluetooth Low Energy (BLE) technology. It discusses the system architecture, ranging algorithm, and calibration techniques, along with experimental results demonstrating the system's performance. The paper also discusses the advantages and limitations of using BLE for indoor positioning and potential applications in areas such as indoor navigation and location-based services.

[13] BLE beacons have two roles: broadcasting (by beacons) and receiving (by sensing devices), enabling short-distance information exchange. Researchers are exploring beacon-based positioning methods due to limitations in existing distance measurement accuracy. This article proposes a novel 3-D positioning system that uses BLE beacons to improve accuracy by obtaining 3-D coordinates (x, y, z), surpassing conventional 2-D methods. Comparison with existing methods reveals a 27.3% reduction in positioning error rate. This research advances indoor asset tracking with potential industrial applications. Further development in this field could enhance the precision and reliability of asset-tracking systems.

[14] In this paper, they deal with location determination which is also known as positioning using BLE (Bluetooth low energy beacons) Radio. The main goal is to implement a low-Cost Indoor positioning system that utilizes the existing hardware. In this project, 2 main methods are being investigated and checked & assessed for their viability.

IV. HARDWARE REQUIREMENTS

1) Mobile devices: Smartphones, tablets, and other mobile devices with Wi-Fi, Bluetooth, or other wireless connectivity are often used as part of an IPS. These devices can act as receivers for signals transmitted by beacons or other sensors.

2) Beacons: Beacons are small Bluetooth Low Energy (BLE) devices that can be placed at fixed locations within the indoor environment. They transmit a unique identifier that can be used by mobile devices to determine their proximity to the beacon and hence their location.

3) Sensors or Gateways: IPS may also use various types of sensors, such as cameras, infrared sensors, or ultrasonic sensors, to detect the location of mobile devices or BLE beacons and track movement within the indoor environment.

4) Access points: Wi-Fi access points can also be used as part of an IPS, particularly for Wi-Fi-based positioning methods. The access points can provide information about the signal strength and other characteristics of Wi-Fi signals, which can be used to estimate the location of mobile devices.

5) Servers: IPS may also require servers or cloud-based infrastructure to store and process location data, perform analytics, and deliver location-based services.

Fig.1. Image of Hardware Components Needed for the Project

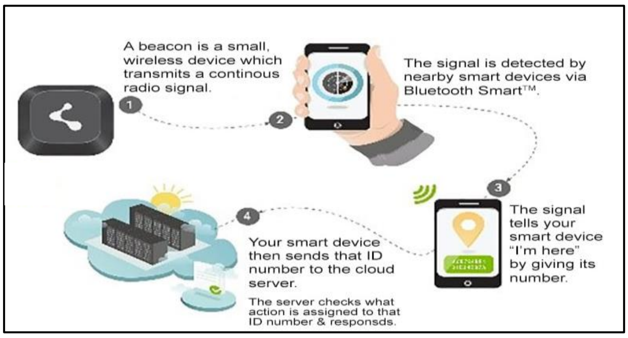

Fig.2. How the Beacons Work

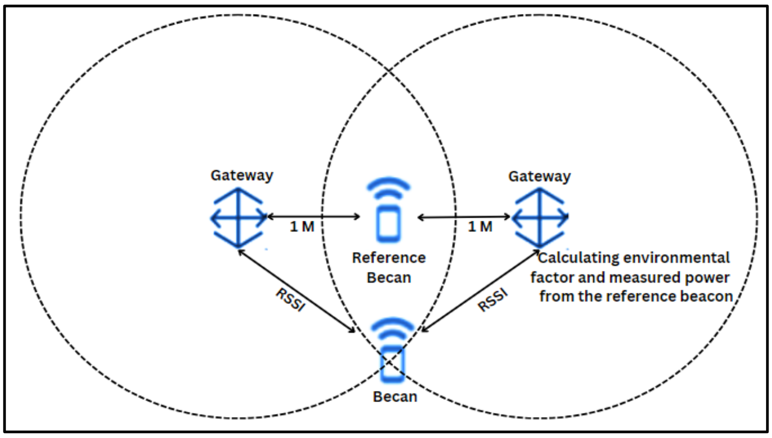

Fig.3. Image of System Architecture

V. PROPOSED METHODOLOGY

The proposed methodology for designing and evaluating the indoor positioning system (IPS) architecture includes the following steps:

1) System Design: The IPS architecture will be designed to utilize multiple sensors and positioning algorithms to improve the accuracy and reliability of the system. The selection of sensors and algorithms will be based on the requirements of the application, the complexity of the environment, and the desired level of accuracy. Fig.3. shows the system architecture of how the sensors (i.e. gateway) and beacons will be placed to estimate the distance taking the RSSI (received signal strength indicator) as the input.

2) Data Collection: Data will be collected from the selected sensors in various indoor environments, including open spaces, narrow hallways, and rooms with different layouts and obstacles. The data will be used to train and validate the positioning algorithms and evaluate the system's performance. Fig.4. shows a sample data collected from a gateway. This data consists of the following:

a) Gateway MAC : It shows the MAC addresses of the gateways used.

b) AP MAC: It shows the MAC addresses of the Wi-Fi access point (AP).

c) AP RSSI: It contains the RSSI values of Wi-Fi access point.

d) Timestamp: It contains the date and time during which the data was collected.

e) Beacon MAC: It contains MAC addresses of each beacon.

f) Beacon RSSI: RSSI values from the beacons.

S.NO.	Gateway MAC	AP MAC	AP RSSI	Timestamp	Beacon MAC	Beacon RSSI
1	AC67B2C29744		-59	2023-01-18 10:01:13	C645C401019D	-65
2	AC67B2C29744		-59	2023-01-18 10:01:13	C645C40101A6	-77
3	AC67B2C29744		-58	2023-01-18 10:01:13	C645C4010199	-65
4	AC67B2C29744		-59	2023-01-18 10:01:13	C645C4010180	-63
5	AC67B2C29744		-58	2023-01-18 10:01:14	C645C401019D	-67
6	AC67B2C29744		-58	2023-01-18 10:01:14	C645C40101A6	-81
7	AC67B2C29744		-58	2023-01-18 10:01:14	C645C4010199	-67
8	AC67B2C29744		-58	2023-01-18 10:01:14	C645C4010180	-68
9	AC67B2C29744		-59	2023-01-18 10:01:15	C645C40101A6	-83
10	AC67B2C29744		-57	2023-01-18 10:01:15	C645C4010180	-64
11	AC67B2C29744		-57	2023-01-18 10:01:16	C645C401019D	-65
12	AC67B2C29744		-57	2023-01-18 10:01:16	C645C40101A6	-77
13	AC67B2C29744		-56	2023-01-18 10:01:16	C645C4010199	-65
14	AC67B2C29744		-57	2023-01-18 10:01:17	C645C4010180	-64
15	AC67B2C29744		-57	2023-01-18 10:01:17	C645C401019D	-67
16	AC67B2C29744		-57	2023-01-18 10:01:17	C645C40101A6	-79
17	AC67B2C29744		-56	2023-01-18 10:01:17	C645C4010199	-66
18	AC67B2C29744		-57	2023-01-18 10:01:18	C645C401019D	-65
19	AC67B2C29744		-60	2023-01-18 10:01:18	C645C4010180	-65
20	AC67B2C29744		-60	2023-01-18 10:01:19	C645C401019D	-65
21	AC67B2C29744		-60	2023-01-18 10:01:19	C645C40101A6	-74
22	AC67B2C29744		-60	2023-01-18 10:01:19	C645C4010199	-65
23	AC67B2C29744		-59	2023-01-18 10:01:20	C645C4010180	-64
24	AC67B2C29744		-59	2023-01-18 10:01:20	C645C401019D	-67
25	AC67B2C29744		-59	2023-01-18 10:01:20	C645C40101A6	-79

Fig.4. Screenshot of Data Collected

3) Algorithm Development: Trilateration, Savitzky-Golay, and double Gaussian filter will be developed to estimate the location of the mobile device accurately. The algorithms will be optimized to reduce latency and improve system reliability.

a) Savitzky - Golay Filter: The Savitzky-Golay filter is a widely used digital filter for smoothing or differentiating one-dimensional signals. It locally approximates data points with a low-degree polynomial using a least-squares fitting approach, allowing for local adaptation to the data's curvature. It preserves important features such as peaks or edges while effectively smoothing data. The filter's behavior can be customized by adjusting parameters, providing flexibility in controlling the trade-off between smoothing and preserving features. However, the filter may not be suitable for complex or non-linear data and may require modification for higher-dimensional data. Proper parameter selection and understanding of the filter's limitations are crucial for obtaining accurate results.

b) Double Gaussian Filter: The double Gaussian filter is a non-linear digital filter that uses two Gaussian functions to smooth images in image processing and computer vision applications. It can preserve edges or boundaries in the image while smoothing the background, making it useful for certain applications. The filter's behavior can be customized by adjusting parameters such as the standard deviations of the two Gaussian functions and the weights assigned to them. However, the filter may not be suitable for all types of images or data and may introduce blurring or loss of details. Proper parameter selection and understanding of the filter's behavior are crucial for obtaining accurate results.

c) Trilateration : Trilateration is a method that is used to determine the unknown coordinates of a point of interest. The underlying principles of trilateration are rooted in the geometric concept of Pythagorean theorem. It requires atleast 3 anchor points from which the distances to the target will be taken and using that position of the device will be determined. It will be used to find the exact coordinates of the target device by using the collected RSSI (Received Signal Strength Indicator) data. The RSSI can be converted to distance using the formula:

$$Distance = 10^{\frac{Measured\ Power - RSSI}{10*N}} \tag{1}$$

In equation (1), measured power refers to the factory calibrated expected RSSI value at 1m. RSSI refers to the obtained RSSI value at an instant and N is a constant that depends on environmental factor which ranges from 2 – 4 (i.e., low to high strength). Using the calculated distances, trilateration will be done to locate the target device.

Table I. shows the results of a comparative study between the Savitzky – Golay filter and the Double Gaussian filter.

TABLE I. COMPARISON BETWEEN THE 2 FILTERS

Category	Savitzky-Golay Filter[10]	Double Gaussian Filter[7]
Filtering approach	It is a type of polynomial regression filter that uses the least-squares fit of a polynomial function to local data points for smoothing or differentiation.	It involves an image with two Gaussian functions of different scales to achieve image smoothing or blurring.
Linearity	It is a linear filter, meaning it applies a linear operation to the input data.	It is also a linear filter, as it performs a convolution operation on the input image
Noise reduction	It is effective in reducing noise in signals or data by locally fitting a polynomial function to data points.	It is also effective in reducing noise in images by convolving with Gaussian functions of different scales.
Preservation of image structures	It can preserve sharp features in the data, such as peaks or edges while reducing noise.	It can also preserve important image structures while reducing noise, as it smooths the image at different levels based on the two Gaussian functions.
Customization	It allows customization of the filter behavior by adjusting parameters such as window size, polynomial order, and weighting coefficients.	It allows customization of the filter behavior by adjusting the parameters of the two Gaussian functions, such as their variances or standard deviations.
Application domains	It is commonly used in signal processing, spectroscopy, chromatography, and biomedical data analysis.	It is commonly used in computer vision, image processing, and computer graphics for image enhancement, image segmentation, and image synthesis tasks.
Performance	It can be computationally efficient and is well-suited for one-dimensional signals or low-dimensional data.	It may be computationally more expensive, especially for large images, due to the convolution with two Gaussian functions.
Limitations:	It may not be suitable for data with complex or non-linear patterns, and the choice of window size and polynomial order may impact the filter's performance.	It may result in the loss of fine details or texture in the image, and the selection of appropriate Gaussian function parameters is crucial to achieving the desired smoothing or blurring effect.

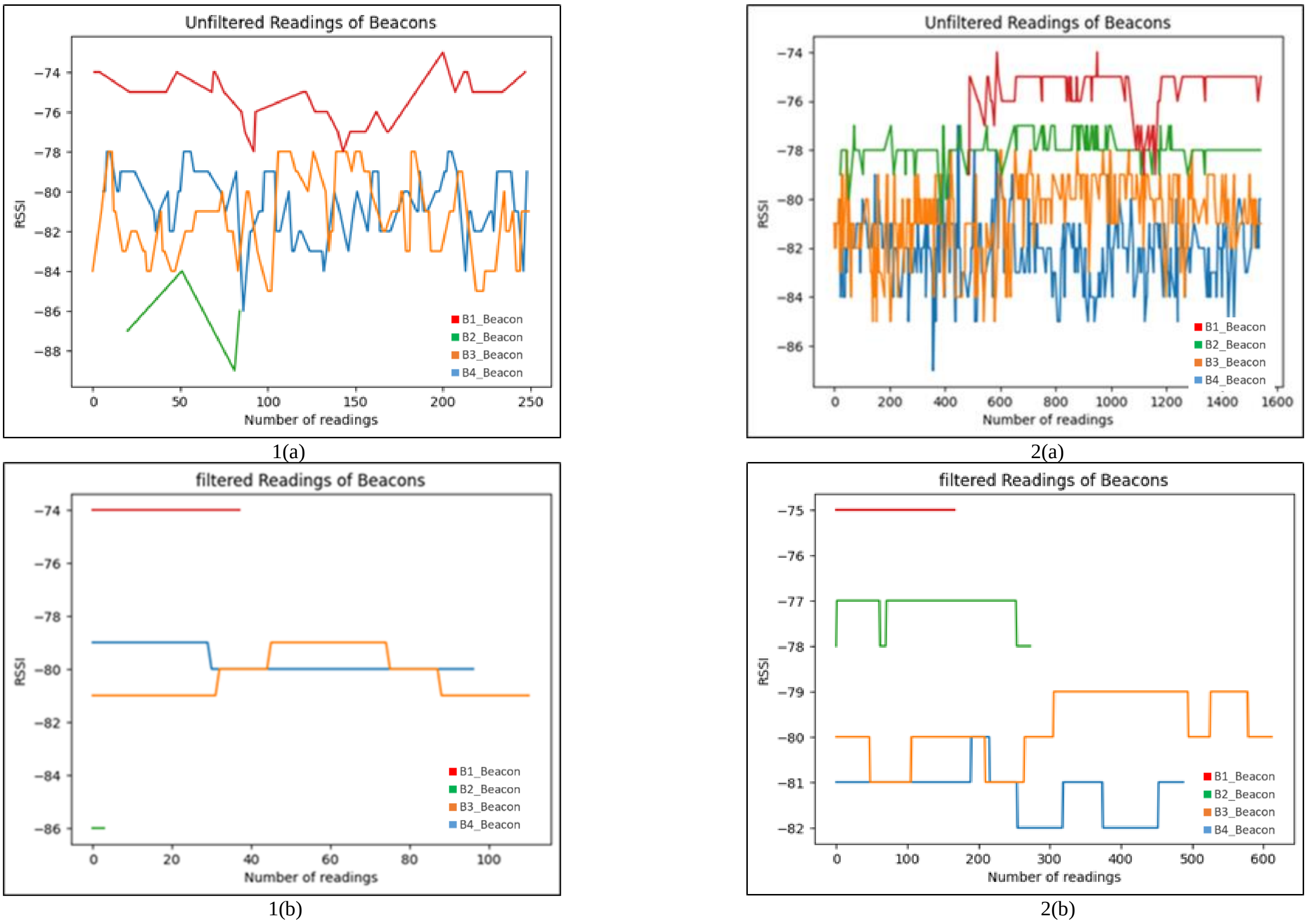

Fig.5. The graphs depicted in 1(a) and 2(a) show the unfiltered readings from two tests taken and the graphs depicted in 1(b) and 2(b) show the filtered readings of respective tests.

TABLE II : OBSERVATION TABLE

Test No.	Beacon 1		Beacon 2		Beacon 3		Beacon 4	
	Actual Distance	Output Distance	Actual Distance	Output Distance	Actual Distance	Output Distance	Actual Distance	Output Distance
1	3 Meters	2.5 Meters	7 Meters	6.46 meters	1 Meters	1.2 Meters	4.5 Meters	5.1 Meters
2	2.5 Meters	2.32 Meters	2 Meters	2.58 Meters	1 Meters	1.24 Meters	7.5 Meters	7.15 Meters

4) Performance Evaluation: The performance of the IPS system will be evaluated in terms of accuracy, precision, and latency. The evaluation will be conducted in various indoor environments, and the results will be compared to existing IPS technologies to determine the effectiveness of the proposed IPS architecture. Fig.5. shows the graphs which represents the data before and after filtering.The description of beacons from which the data was collected are as follows:

- *B1_beacon – Red - C645C401019D*
- *B2_beacon – Green - C645C40101A6*
- *B3_beacon – Yellow - C645C4010199*
- *B4_beacon – Blue - C645C4010180*

5) Optimization: Based on the performance evaluation results, the IPS architecture will be optimized to improve accuracy, reduce latency, and increase reliability. The optimization will involve adjusting the parameters of the sensors and algorithms to achieve the desired level of performance.

6) Validation: The optimized IPS system will be validated in real-world scenarios to determine its effectiveness and practicality. The validation will involve testing the system in different indoor environments and use cases to ensure its scalability and applicability.

VI. FUTURE WORK AND CONCLUSION

Indoor asset tracking systems have the potential to revolutionize asset management processes by providing real-time visibility, reducing manual efforts, optimizing asset utilization, and improving operational efficiency. While technology has made significant advancements, there are still areas for improvement, such as accuracy, scalability, real-time monitoring, and integration with other emerging technologies. Future work in these areas can further enhance the capabilities of indoor asset tracking systems and drive innovation in the field of asset management. With continued research and development, indoor asset tracking systems are poised to become an essential tool for various industries, enabling organizations to effectively manage their assets, reduce costs, and improve overall productivity.

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