Indoor Positioning System: A Review

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***Abstract*—Global Positioning System (GPS) has been developed in outdoor environments in recent years. GPS offers a wide range of applications in outdoor areas, including military, weather forecasting, vehicle tracking, mapping, farming, and many more. In an outdoor environment, an exact location, velocity, and time can be determined by using GPS. Rather than emitting satellite signals, GPS receivers passively receive them. However, due to No Line-of-Sight (NLoS), low signal strength, and low accuracy, GPS is not suitable to be used indoors. As consequence, the indoor environment necessitates a different Indoor Positioning System (IPS) approach that is capable to locate the position within a structure. IPS systems provide a variety of location-based indoor tracking solutions, such as Real-Time Location Systems (RTLS), indoor navigation, inventory management, and first-responder location systems. Different technologies, algorithms, and techniques have been proposed in IPS to determine the position and accuracy of the system. This paper introduces a review article on indoor positioning technologies, algorithms, and techniques. This review paper is expected to deliver a better understanding to the reader and compared the better solutions for IPS by choosing the suitable technologies, algorithms, and techniques that need to be implemented according to their situation.**

Keywords*—Global positioning system (GPS); indoor positioning system (IPS); real-time location system (RTLS)

I. Introduction

The positioning system is a method to determine the position of the object in space. In today's economy, many positioning systems are employed in all areas. In general, the positioning system can be divided into three types which are Global Positioning System (GPS), Local Positioning System (LPS), and Hybrid Positioning System (HPS) which have been highly useful in a wide variety of outdoor and indoor environments [1]. GPS is one of many satellites orbiting around the universe. GPS has several uses in a variety of fields in outdoor environments such as military, weather forecasting, vehicle tracking, mapping, farming, etc. [2]. An exact location, velocity, and time can be determined by using GPS. Rather than emitting satellite signals, GPS receivers passively receive them. The object's precision ranges from 2 to 6 meters. However, GPS is not suitable to determine the location indoors because there is No Line-of-Sight (NLoS), low signal strength, and low accuracy.

LPS is one of the positioning technologies included in electronic performance and tracking systems, as it determines the position of an object in the Cartesian coordinate system [3]. It usually allows users to collect data to keep track of external load needs. Zone (up to 20 meters) and precise placement (from 0.1 to 3 meters) are types of LPS. The use of optimal LPS in an indoor environment becomes necessary with good accuracy, precision, cost, power consumption, and coverage. Wireless Fidelity (Wi-Fi), Bluetooth Low Energy (BLE), Radio Frequency Identification (RFID), and Ultrawideband (UWB) are an example of common wireless communication that is involved in LPS. However, LPS is more complex and expensive compared to GPS due to the deployment of infrastructure and hardware.

Meanwhile, HBS is a combination of GPS with LPS to track items in both outdoor and indoor environments. These systems were created to address the limitations of GPS, which is extremely accurate in open spaces but fails to perform well indoors or between tall buildings. Better position estimations can be determined by hybridizing the positioning information from different technologies. This way, the combination can enhance the system's accuracy and availability in diverse locations [4]. The solution is highly optimized, with opportunistic fingerprint selection and floor change detection minimizing time-consuming processing and a battery-saving subsystem reducing power consumption by turning off unnecessary technologies.

Through all of the positioning systems available, it can be divided into outdoor positioning and indoor positioning. For outdoor positioning, the GPS can always support with high accuracy, but Indoor Positioning Systems (IPS) face more challenges than outdoor positioning due to pervasive hindrances and interaction interference [5], multi-path effect, fading, reflecting, deep shadowing effect, and delay deterioration.

IPS refers to the technology that helps to locate the position of people or objects inside the buildings. The location data is sent into some sort of application software to make the data useful. The design of IPS depends on what type of indoor positioning technologies, indoor positioning algorithms, and indoor positioning techniques are used in the system. IPS technologies provide a variety of location-based indoor tracking solutions [6], such as Real-Time Location Systems (RTLS), navigation, inventory management, and first-responder location systems.

IPS also can be divided into self-positioning and remote-positioning systems. A self-positioning happened when a system the positioning was measured by the node (device) itself. The node will act as a receiver and the transmitter will be the anchor node surrounding. By using this system, it guarantees privacy, but in another way, it burdens the node with the computational service to measure its location or position. The example of this system should have a reference sensor node also known as an anchor node with a known position and a target such as a node, object or people to be located (device). The reference sensor node sends a range request to the target's compatible mobile device such as a smartphone. Smartphones receive the signals and respond to the reference sensor node with a response. Sensors will calculate the traveling time between sensors and smartphones. The computed time sent by the sensors will then be received by the calculating center. A computation center is often a Personal Computer (PC) or a Base Station (BS). The calculating center, which had a strong computational capability, used a positioning algorithm to process the provided data and obtain the target's location result.

While, for the remote-positioning, the receiver will be placed at the anchor node surrounding while the node (device) will be reacted as the transmitter. The computational system will be a burden on the infrastructure (the server) while the node (device) can have lower power consumption. In this positioning system, the node (device) uses signals, transmitted by the anchor node to calculate its position.

IPS can be divided into two phases which is signal measurement is the first phase. The physical position of the target node will be calculated in the second phase using the signal characteristics collected in the first phase. The most frequent approach is ranging, which involves obtaining distance or angle estimations. Geometric techniques will be used to determine the target node's position as the intersection of position lines derived from position-related parameters at reference nodes. The two most popular geometric approaches are Trilateration and Triangulation. To filter the measurement noise and improve the accuracy, optimization-based statistical techniques are often used. The communication entity associated with individuals is represented in the first phase by certain signals transmitted between the target node and sensor nodes, as well as the number of reference nodes represented by the sensor nodes. At this moment, receivers will be gathering information about the signal's characteristics such as arrival time, signal intensity, and direction.

II. Literature Review

Recently, Wi-Fi technologies in indoor positioning system have been topic of interest among researchers. The subsections that follow present some existing works for indoor positioning that implemented RSSI algorithm and Trilateration technique. RSSI algorithm are the most popular range-based. The primary concept is to use the power of the received signal, knowledge of the broadcast power, and the route loss model to estimate the distance between a transmitter and the receiver [7]. Trilateration technique is used to determine an object position using simultaneous range measurements from at least three reference APs at known locations.

The BLE with RSSI algorithm were proposed in [7]. Positioning algorithm were implemented in Java using Android SDK and been tested in Huawei B199 smartphone. Four Beacon devices were placed in one room and mobile device were placed in four different positions. The distance between mobile devices with Beacon devices were calculated by using RSSI and filtered by using Kalman Filter. Triangulation was used to calculated the current location of mobile devices. The average accuracy achieved in this system was 0.2 – 0.4m.

Researchers in [8] presented a Beacon Bluetooth device to overcome the limitation of other technologies. The distance estimation of the beacons, the number of signals collected by Android devices, and the internet connection from the Android smartphone all impact the accuracy of the user position. The Trilateration technique was employed in this study, along with a measuring methodology based on RSSI value. The result shows that accuracy achieved is 84%. According to the findings of the test, objects with thickness and density have a significant impact on the RSSI of the Beacon devices. Calibration on Beacons is important for fine-tuning RSSI values at a distance of 1 meter in order to improve the accuracy of the estimated distance between the beacon and the device. Disadvantages of using Bluetooth beacon is, to get high accuracy, more beacon devices need to be installed and resulting high in cost.

Therefore, after reviewing the limitations of other projects, this review suggests an implementation of existing Wi-Fi infrastructure with received signal strength values. In addition, the integration of RSSI algorithm and Trilateration technique with been suggested to determine the improvement of accuracy in the system.

III. Indoor Positioning Technologies

There are many different types of technologies that can be implemented in IPS. It is important to use the correct technology based on the type of positioning that needs to be developed. Satellite-Based, Magnetic-Based, Inertial Sensor-Based, Sound-Based (Audible Sound, Ultrasonic Sound, Acoustic Sound), Optical-Based, Radio Frequency-Based (Wi-Fi, BLE, RFID, and UWB), and Vision-Based [9] are examples of technologies as shown in Fig. 1.

A. Satellite-based

The most popular system for outdoor systems is the Satellite-Based. It is based on a global network of satellites that transmit radio signals in medium-earth orbit. The basic GPS service provides users with an approximately average User Range Error (URE) of less than 7.8 meters 95 percent of the time, anywhere on or near the surface of the earth [10]. Satellite control systems take little effort and cost to set up, but their operation necessitates the installation of monitoring systems and dispatching software.

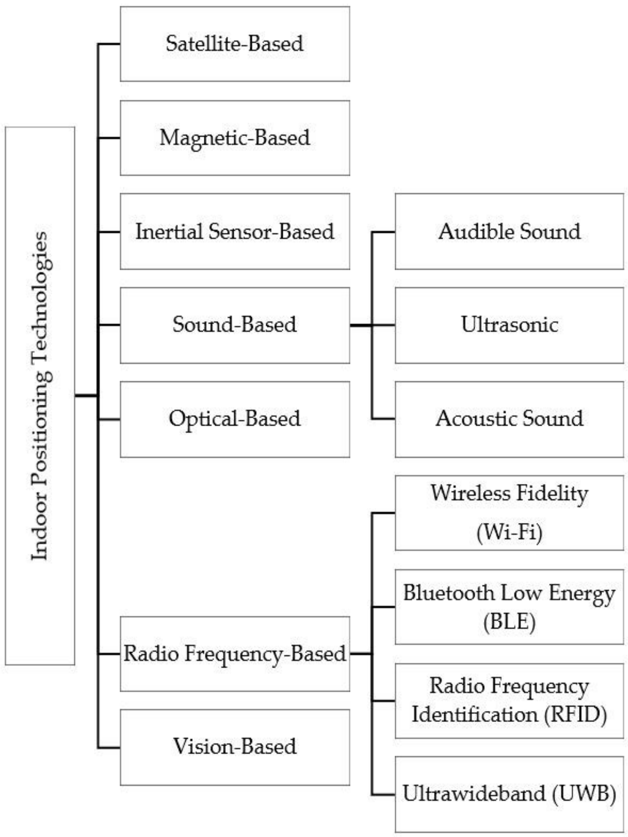

Fig. 1. Types of Indoor Positioning Technologies.

Despite all of the benefits, GPS only works in open areas where satellite signals are consistently received. The scope of the global system is limited to transport and in some cases, mobile personnel [11]. However, due to technological limits of signal re-reflection in the premises, even with wide windows, satellite technologies will not be useful for premises, manufacturing, or deep mining.

B. *Magnetic-based*

To determine the locations which relate to magnetic indoor positioning, the use of geomagnetic fields has been distorted [12]. Magnetic fields can be used in IPS in two methods [13]. The first method is when one makes use of anomalies induced by disruptions in the earth's magnetic field to perform positioning. Another method is using artificially generated magnetic fields in which coils of current-carrying wire are installed in strategic areas throughout the structure. On receiving node, each coil's magnetic field strength is measured.

To build an efficient magnetic field map, a map-building system for magnetic fields is needed. The magnetic field system consists of sensors such as an array, odometry, and a data alignment system. The position of the system is estimated by using odometry when the system is moving in a test area. At the same time, magnetic field data is measured. Finally, a magnetic field map is built when the data are aligned with the position. Earth's geomagnetic-based positioning system which is based on Earth does not require any additional hardware because it enables a smartphone compass to locate the position in an indoor environment [14]. It also has a stable signal [15]. The robustness can be obtained when using magnetic fields as fingerprinting in indoor environments [16]. When constructing indoor positioning systems, resilience is important since it may significantly minimize the number of measurements and time required to create a large fingerprint database.

External factors such as device diversity and user diversity need to be aware. Magnetic sensors may be made using a variety of sensing technologies and materials. As a result, multiple magnetic sensors at the same position may produce different results. Magnetic reading might be slightly different when using different sensors [17]. In addition, the different user has different step lengths; hence they generate different magnetic fingerprints.

C. *Inertial Sensor-based*

Sensors based on inertia and associated measurement principles are known as inertial sensors. Accelerometers and gyroscopes are an example of inertial sensors. It does not require any external references [18] and installation since it does not depend on the environment.

The orientation inaccuracy will develop with time owing to sensor drift and recursive computation. Because accurate orientation information is a requirement for personal tracking/positioning and movement monitoring, incorrect orientation will impair the calculated accuracy of position. Magnetic field sensors are fused with inertial sensors using a Kalman filter to offer a long-term stable orientation solution.

In addition, the Inertial Navigation System (INS) is another localization navigation technology that is capable of calculating the location by a self-contained navigation technique that uses the existence of computers, motion sensors, and rotation sensors to be as the reference point. INS is normally used for a wide range of applications such as navigation of aircraft, tactical and strategic missiles, and submarines.

D. *Sound-based*

Another technology used for localization systems is Sound-Based which is normally used in underwater monitoring and tracking. This technology can be classified into three categories which are Audible Sound, Ultrasonic, and Acoustic Sound. Sound waves travel at a slower rate than electromagnetic waves leading to the major problem which is to make time synchronization easier.

1) Audible sound: Due to its intrinsic qualities, Audible Sound has recently been studied as an emergent technique. Audible Sound can be used to store the data for location systems [19]. It has similar qualities to ultrasound but is less expensive and more acceptable for use in everyday life because of the availability of off-the-shelf equipment with broader coverage, such as loudspeakers and mobile phones, which may be utilized with just modest modifications. Audible Sound was assumed that it would disrupt the acoustic environment unfavorably [20], so it was not tackled.

2) Ultrasound: Ultrasonic systems employ sound frequencies above the hearing range (above 20 kHz) to establish the user's location by measuring the time an ultrasonic signal takes to travel from a transmitter to a receiver.

“Active” and “Passive” are types of ultrasonic systems. The ultrasonic positioning system can be implemented in various applications such as healthcare, hotel business, offices, and other indoor building. The Time-of-Flight (ToF) approach, which involves measuring the signal propagation time from the sensor to the receiver, is the basis for ultrasonic positioning. Special tags use to transmit ultrasound impulses are applied to measure the distance. The receiver network analyses these signals and delivers data to the central system, which calculates the position with a 3 cm precision using multilateration.

The advantage of ultrasonic is it can work in real-time. The frequency of the signal varies can be up to 3 seconds. It also can carry out the system's operational deployment with fine-tuning. Apart from that, the accuracy of ultrasound can be identified within several centimeters.

However, an ultrasound signal is only slightly influenced by its surroundings and has very little penetration through walls [21], which might help it be more useful in the suggested ultrasonic indoor locating system.

3) Acoustic sound: Due to its unique benefits, audio-based indoor positioning technology, which functions by producing and receiving acoustic signals between nodes and the placement target, has recently gotten a lot of attention. An Angle of Arrival (AoA), Time of Arrival (ToA), Time Difference of Arrival (TDoA), and Frequency Difference of Arrival (FDoA) are measurements that depend on acoustic signal measurement. The measurements have been implemented in audio-based indoor positioning.

E. Optical based

Optical-Based positioning used for localization is normally in the form of an Electro-Magnetic (EM) spectrum since the techniques and challenges are quite different. This system is a flexible navigation system for deep space operations. Optical positioning can be characterized into two, which are Infrared (IR) and Visible Light Communications (VLC).

1) Infrared (IR): An IR communication technology is extensively used, low-cost, and widely available [22]. Infrared signals are employed in a variety of applications, from consumer remote controls to data transmission. In [22], the researcher proposed a low-range IR signal with AoA estimation. The proposed concept is applied to overcome the localization problem that prevents NLoS issues. It has been applied to navigate a grocery cart in a difficult environment. The results of the tests range from centimeter-level accuracy in a static 1 Dimension (1D) environment to 1 m mean localization error in a 2 Dimension (2D) setup for a mobile cart moving at 140 cm/s. These findings suggest that utilizing easily accessible IR technology and low-cost hardware components, suitable localization precision, and real-time navigation support may be accomplished in the supermarket.

Other than that, [23] stated that IR Light Emitting Diode (LED) with a wide emitting angle is less complex than a laser-based. However, to have a sufficiently high Signal-to-Noise Ratio (SNR) for effective demodulation, a complex sensor design is required.

2) Visible light communications (VLC): VLC has been deemed an appealing alternative for indoor location systems. Triangulation is one of the algorithms that has been applied in the VLC positioning system due to its low cost and accuracy. The location can be estimated using the geometric properties of the triangle, where the light-emitting diodes (LEDs) serve as anchors and the receivers serve as agents in VLC systems, by measuring the distances between multiple reference anchors. In harsh environments, however, the triangulation positioning algorithm may fail.

The advantages of VLC are illuminance that can be dimmed [24], intrinsic security, and a spectrum that is generally available. Furthermore, because VLC-based systems are less susceptible to multipath propagation and disturbance from other wireless devices, they should give superior location accuracy to radio-wave alternatives. VLC does not produce electromagnetic interference and it can be implemented in restricted buildings such as hospitals [25].

F. Radiofrequency

Radiofrequency (RF) technology was commonly used in IPS. It is a mixes narrow-band with spread-spectrum transmissions and is based on signal strength technologies [26], which are especially useful for wireless communication devices.

Wi-Fi, BLE, RFID, and UWB are among the common wireless communication technologies involved in RF. While RF-based systems offer various advantages for positioning, they have a severe flaw in the indoor environment. Accuracy, cost of implementation, and power consumptions are the important parameters that need to evaluate to choose the best and most affordable technologies.

1) Wireless fidelity (Wi-Fi): Now-a-days, Wi-Fi, which is based on the IEEE 802.11 standard, is well-known and widely used in radio technology. When there are enough Wi-Fi access points and no dedicated infrastructure is required, Wi-Fi-based procedures are employed in interior scenarios; alternatively, existing building infrastructure may be utilized because most current buildings are equipped with Wi-Fi access points. Wi-Fi-based indoor navigation systems commonly used RSS Fingerprinting, Triangulation, or Trilateration techniques [27] for location estimation.

Access points are commonly utilized in a building's planned or current Wi-Fi wireless networking capacity whose position has been optimized for data connection. It calculates the distances between three or more Wi-Fi access points using the Wi-Fi receiver in a smartphone.

The accuracy of Wi-Fi for interior locating is normally 5-15 meters. The precision of this measurement is determined by the amount of shielding provided by walls, ceilings, and people, as well as the number of entry points. The inclusion of smartphone sensors can enhance the findings, and the floor level can also be determined. The implementation of Wi-Fi might be low due to the existing Wi-Fi structure in each building; however, power consumption for a Wi-Fi-based positioning system is high.

2) Bluetooth low energy (BLE): BLE is a kind of wireless communication optimized for short-range communication. It is virtually as accurate as Wi-Fi-based systems, and they employ RF signal sources to monitor users' whereabouts via proximity sensing or RSSI fingerprinting.

Smartphones are now often utilized as receivers for both Bluetooth and Wi-Fi signals, following recent advancements. Beacons are small devices for BLE that be mounted on the walls [28]. Beacons device use battery power supply, as for that, it requires battery placement.

For BLE, complex signal processing is needed to reach good accuracy. The implementation cost for BLE is low as it is one of the most popular and easily used in indoor positioning. The power consumption for BLE can be high due to high data throughput.

3) Radiofrequency identification (RFID): RFID is a traditional method of automated identification that is based on RF wireless communication technology. A typical RFID system contains tags such as transponders, smart tags, a reader, and a host computer and software/ infrastructure. A wired or wireless connection connects the reader to the host computer. For tracking reasons, on electromagnetic transfer between RFID readers and RFID tags [29]. It mixes narrow-band with spread-spectrum transmissions and is based on signal strength technologies, which are especially useful for wireless communication devices. The electromagnetic field of sources or equipment produces radio waves.

The accuracy of RFID can be determined in a short range of 0.5 to 1m and does not suitable for high-range scale location usage. The batteries of RFID tags also have to be replaced if it needs to do a large coverage. The complexity is getting high due to the implementation of complex algorithms such as the Kalman filter, K-Nearest Neighbor (KNN), and Radio map. RFID has low power consumption.

4) Ultra-wideband (UWB): UWB is a radio technique that uses a wide section of the radio spectrum to distribute high-bandwidth communications. It allows UWB to transmit large amounts of data with consuming minimal energy for short-range communication [30]. UWB pulses have a low frequency that allows them to travel through walls, equipment, and other impediments. It also will not interact with current Radio Frequency (RF) systems if it were properly constructed. Since reflected signals do not overlay directly with received signals, UWB's brief transmission pulses make it easy to differentiate between direct and reflected signals. As a result, multipath interference is not a problem with UWB. Fixed-location sensors receivers and tags are used in UWB.

The accuracy of UWB can be achieved by 0.1 to 0.3 meters which is much better than Wi-Fi and BLE. However, this technology is a unique solution that necessitates the use of certain components that it is best suited to industrial applications. Compared to other positioning technology systems, UWB utilizes less power, allowing for greater power efficiency and longer device battery life. The implementation of UWB is quite complex because it requires signal acquisition, synchronization, and tracking with high precision.

G. Vision-based

This method is based on video data processing and assessment. In general, there are two ways [31] to conduct video-based localization which are fixed camera systems and mobile camera systems.

1) Fixed camera system: Fixed camera systems are used when they can be mounted in fixed locations. For example, the moving objects have been captured using one or more cameras. The tracking target's characteristics must be utilized. If the target's prominent characteristics show in the camera's field of vision, the target's location may be determined by the camera's fixed position. The target's location is determined by its location inside the recorded picture and the spatial distribution of its conspicuous characteristics.

2) Mobile camera system: The camera in the mobile camera system is already equipped to perform the localization with the known position in several landmarks. There are two stages in localization to determine the mobile camera's location and orientation; the offline stage and the online stage. mages of the environment are captured at predefined locations and each image is processed to extract its unique features that are stored in a database in the offline stage. During the online stage, the camera captures a picture, which is then extracted and matched to previously recorded attributes to determine the camera's position.

IV. Indoor Positioning Technologies Discussion

Each one of the technologies has its specialty. From the table below, we can conclude that GPS is not suitable to use in an indoor environment. Magnetic-based is suitable to determine the accuracy of position; however, it is complex and high in cost. In addition, inertial-based also can be used to determine the high accuracy and can be developed in a wide range of applications. However, fused with magnetic-based to get a long-term stabilization, it makes the system complex. Due to the high cost and its complexity, sound-based is the least suitable for indoor positioning systems. Optical-based and visual-based are low in cost system; however, it is complex and less accurate compared to other technologies.

Recently, the RF communication technologies such as Wi-Fi, BLE, RFID, and UWB are widely used in indoor positioning to develop location estimation. Their characteristic such as power consumption, accuracy, and cost are the factors that have been evaluated due to the benefits of an indoor positioning system as shown in Table I.

TABLE I. SUMMARY OF TECHNOLOGIES IN IPS

Technologies	**Advantages**	**Disadvantages**
Satellite-Based	• GPS easy to navigate • Low-cost implementation	• Cannot be implemented in an indoor environment • Less accurate
Magnetic-Based	• High accuracy	• High-cost implementation • Complex
Intertial-Based	• High accuracy • Wide range application • Does not require hardware installation • High accuracy	• Fused with magnetic to get long-term stabilization • Complex
Sound-Based		
Audible Sound	• Less expensive • Easy to implement	• High-cost implementation
Ultrasonic	• Close range distance measurement	• High-cost implementation
Acoustic sound	• Low-cost implementation • Easy to implement	• Complex
Optical-Based	• Low-cost implementation	• Complex • Low accuracy
Radio Frequency (RF)-Based		
Wi-Fi	• Low-cost implementation	• High power consumption
BLE	• Low power consumption • High accuracy	• Complex • High-cost implementation
RFID	• Small size • High accuracy • Low power consumption	• High-cost implementation • Complex
UWB	• High-in accuracy • Low power consumption	• High-cost implementation
Vision-Based	• Low-cost implementation	• Low accuracy • Complex

V. INDOOR POSITIONING ALGORITHMS

Signal characteristics with geometrical parameters made up of metrics like angle, distance, and the signal may be used to compute the position of an object or user. The algorithms for indoor positioning as displayed in Fig. 2 are divided into two which are directly based and distance-based. The Angle of Arrival (AoA) and Angle Difference of Arrival (ADoA) can be categorized as direction-based. In addition, distance-based [32] are Phase of Arrival (PoA), Phase Difference of Arrival (PDoA), Reference Signal Received Power (RSRP), Received Signal Strength Indicator (RSSI), Channel State Information (CSI), ToA, TDoA, and Round-Trip Time (RTT).

A. Direction-based

1) Angle of arrival (AoA)/ angle difference of arrival (ADoa): The word 'Angle of Arrival' (AoA) is used in a simplified technique for 2D operation, calculating angles in a single plane [33]. Using multiple AoAs with known receiver absolute position, any multilateration approach may be used to determine the sender's absolute coordinate. An equipment upgrades at receiver AoA [34] and error in non-linear dependent are primary difficulties.

The localization of AoA is determined by using directional antennas or antenna arrays as shown in Fig. 3. An antenna array may be used to determine the angle at which the broadcast signal impacts directly on the receiver by leveraging and measuring the difference in time of arrival at selected antennae array members. The position of the source is restricted along a line along the predicted line of bearing by a single AoA measurement. A triangulation technique may be implemented to produce position estimation when numerous AoA measurements are collected concurrently according to the environment.

To determine mobile node location, at least two reference nodes are required to perform the AoA algorithm. An equation for AoA is as follows [35]:

$$x = d_i cos(\emptyset_i) + x_i,$$

$$y = d_i cos(\emptyset_i) + y_i,\ i = 1,\ 2,\ 3 \quad (1)$$

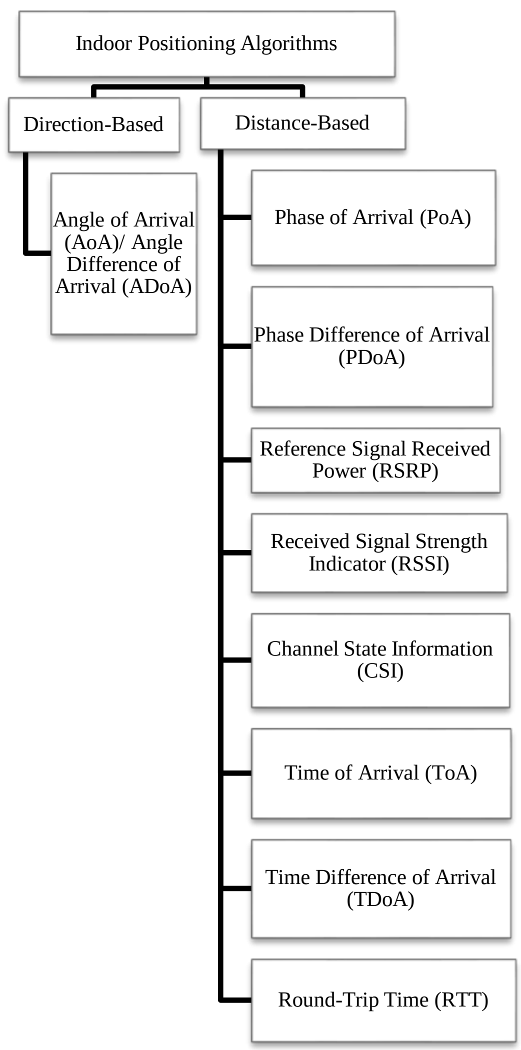

Fig. 2. Types of Indoor Positioning Algorithms.

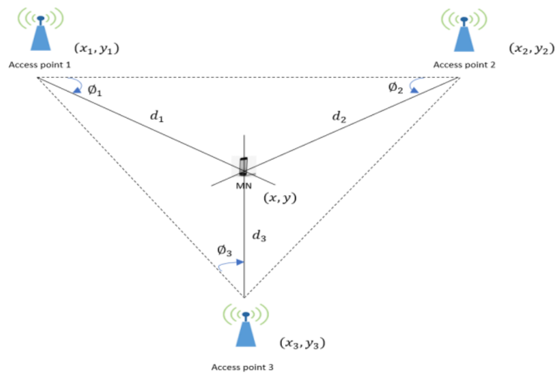

Fig. 3. AoA based Localization.

B. Distance-based

1) Phase of arrival (PoA): The phase of the carrier signal is used to calculate the distance in PoA ranging methods [36]. In a passive RFID 2D localization system, the PoA positioning approach was applied to improve the accuracy [37] and reduce the disruptions caused by multipath propagation.

To improve their effectiveness, PoA techniques can be used with other techniques like ToF, TDoA, and RSSI. However, for great accuracy, PoA positioning techniques may require LoS.

2) Phase difference of arrival (PDoA): PDoA methods, which employ the delta between phases of the receiver to determine the angle between receivers and transmitters, were originally used in radar systems [38]. PDoA only requires two antennas. It does not need time to synchronize among base stations compared to TDoA positioning.

3) Reference signal received power (RSRP): RSRP variables are physical layer data from a 4G cellular system that are used to anticipate a user's position with absolute precision [39]. RSSI algorithm is used to determine RSRP. It uses cell-specific reference signals to compute the mean achievable strength. As a result, compared to regular RSSI, it may provide more signal strength information linked with varied locations.

4) Received signal strength indicator (RSSI): The Received Signal Strength (RSS), also known as the Received Signal Strength Indicator (RSSI), is a measurement of the strength of a radio signal that has been received. [40]. RSSI is also known as a measurement to show the condition of received power in the anchor nodes and it is used in most wireless communication methods [41]. RSSI-based localization has the advantage of simplicity [42]. RSS-based target localization is a popular issue in wireless sensor networks, with several applications [43]. This method is based on video data processing and assessment.

The traditional approach to RSS-based localization is to use RSS data to derive distance information between the sensor and the target. Unfortunately, when the number of sensors is insufficient, the traditional RSS-based localization approach fails to attain adequate accuracy due to the deteriorating effects of fading, shadowing, and reflections of the radio signal. Furthermore, many targets are active at the same time in multiple target localization settings, and target signals overlap at each sensor. The traditional approach is no longer practicable since it is difficult for a sensor to directly extract distance information from every target. As a result, developing an effective RSS-based localization technique for various targets is quite important.

Hardware modifications such as the smartphone's form factor, receiver module due to a number, internal circuitry architecture, and antenna design such as built-in signal processing and data loss can all affect RSSI readings [44]. RSS readings may be acquired with little effort and without additional circuitry, resulting in significant cost and energy savings for sensors. With the estimation, position information can be acquired. Fig. 4 shows an overview of how signal strength affects distance. The user node is to be estimated. RN_1, RN_2, and RN_3 as reference nodes. There are three processes to determine the user position [45]. First, collect and measure RSSI. The second process is determining the RSSI distance using the path-loss equation. Lastly, position estimation uses the Trilateration method.

The distance between Mobile Node (MN) and each APs can be determined using RSSI from the Distance Power Law equation [46]:

$$P_r(d_i) = P_r(d_0) - 10nlog(\frac{d_i}{d_0}) + (-T) \times WAF \quad (dBm) \quad (2)$$

$P_r(d_0)$ represent the initial value, d_0 is received power at a close-in reference distance of one meter, d_i is the distance between transmitter and receiver, n is the path loss exponent between 0 to 5, T is several walls between transmitter and receiver, WAF is Wall Attenuation Factor. Based on the equation above, the distance d_i can be calculated as follows:

$$d = e^{(\frac{P_r(d_0) - P_r(d_i) - T * WAF}{10})} \quad (3)$$

5) Channel state information (CSI): In Wi-Fi indoor positioning, Channel State Information (CSI) is commonly been applied. It is because of the features based on the physical layer and descriptions of amplitude and phase information; CSI can represent fine-grained channel information. As a result, most researchers are interested in CSI-based positioning [47]. Signals are propagated in a Wi-Fi network using Orthogonal Frequency Division Multiplexing (OFDM) modulation. The signal is received by the terminal after being broadcast across the multipath channel by OFDM, which divides the communication channel into orthogonal sub-channels of various frequencies [48]. The properties of the communication link between the transmitter and the receiver are represented by CSI. CSI can be expressed as [48]:

$$Y = HX + N \quad (4)$$

Y represents the received signal vector. H is the channel information matrix, X is the transmitted signal vector, and N is additive white Gaussian noise. CSI also can be expressed as:

$$\hat{H} = \frac{Y}{X} \quad (5)$$

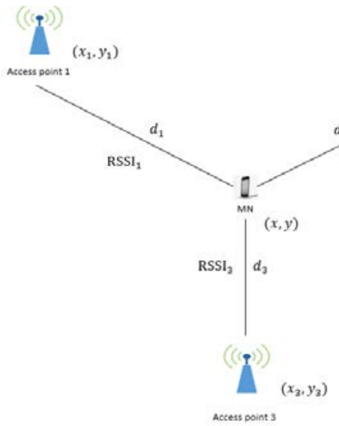

Fig. 4. RSSI-based Localization.

$\widehat{\mathrm{H}}$ represents the Channel Frequency Response (CFR) for each subchannel. Researchers in [49] proposed deep learning-based indoor fingerprinting using CSI named as DeepFi. The system architecture is divided into offline and online training. Deep learning is used to train all the weights in offline training. Moreover, to decrease complexity, a greedy learning technique is employed to train all the weights layer by layer. During online training, the researcher used the probabilistic method to obtain the location. The result shows that DeepFi successfully minimizes location error when compared to three current approaches.

The extreme multipath and shadow fading effects, as well as the sensitivity to the dynamic environment, are two major obstacles to a functional CSI-based indoor positioning system. Short and long-term interference will cause the signal unavailable:

6) Time of arrival (ToA): The absolute time when a radio signal from a transmitter reaches a distant receiver is known as the Time of Arrival (ToA) [50]. The simplest and most popular ranging approach is a ToA, which is most famously utilized in the GPS [51]. This algorithm is based on determining the time when the signal was sent to the target, the time when the signal arrives at the target, and the speed at which the signal travels. When all of these are known, the distance can be calculated by using [51]:

$$d = c * (t_{arrival} - t_{sent}) \quad (6)$$

C is the speed of light. The set of probable target locations may be identified using this distance. Many radiolocation systems employ ToA readings to accomplish true-range multilateration geo-positioning. When signals move at a constant velocity, the real range or distance may be determined directly from the ToA. The measured ToA depicts a circle with its center at the receiver in two-dimensional (2D) space, and the source must be on the circumference. In 2D, an equation is as follows [51]:

$$d = \sqrt{(x_{ref} - x)^2} + (y_{ref} - y)^2 \quad (7)$$

(x_{ref}, y_{ref}) is a known position of reference point. At least 3 or more reference points are needed to determine the target position by finding the intersection. Fig. 5 states that 2D location estimation required a minimum of three sensors where A, B, and C are the distances between transmitter and receiver. An intersection can be required if there are at least three sensors. Meanwhile, for 3-Dimensional (3D) position estimation, it required at least four sensors [52] as shown in Fig. 5.

The clocks of the tag and the reader must be synchronized to get a perfect measurement of elapsed time. However, the cost for implementation is high and it is more complex.

7) Time difference of arrival (TDoA): TDoA is a common approach for identifying targets using a set of sensor nodes with known positions. [53]. It is the second most used range technique, and it is more versatile than ToA in some ways. The time signal was received and the speed at which it traveled is all that is required for this technique. It is not the time when the signal was transmitted from the destination. Unlike previous geolocation methods, TDoA delivers accurate geolocation even for signals with power levels below the noise floor.

To achieve high-accuracy TDoA, precise synchronization between receivers is required. Anchors must be precisely synced, which necessitates the usage of synchronization beacons. Fig. 6 shows the working principle of TDoA.

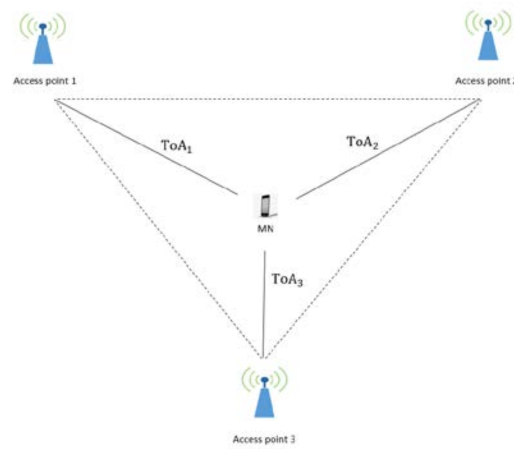

Fig. 5. ToA-based Localization.

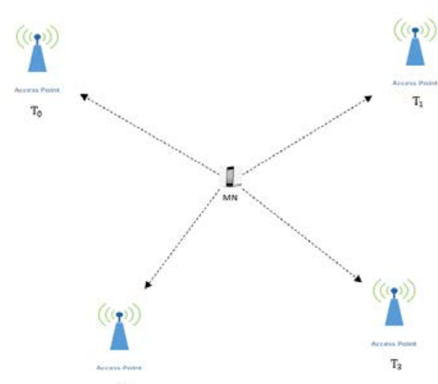

Fig. 6. TDoA-based Localization.

At a specific moment of timestamp at reception, T_0, the tag will blink and four access points receive the message at various times ($T_1 \ldots T_4$). The difference time of arrival has to be computed to estimate the position of the tag using this equation [51]:

$$\triangle d = c * (\triangle t) \tag{8}$$

where c is the speed of light, Δt is the difference in arrival times at each reference point. Meanwhile, for 2D, the equation is as follows [54]:

$$\triangle d = \sqrt{(x_2 - x)^2} - (y_2 - y)^2 - \sqrt{(x_1 - x)^2} - (y_1 - y)^2 \tag{9}$$

where (x_1, y_1) and (x_2, y_2) is a known position. This equation may be changed to the form of a hyperbola via nonlinear regression. After calculating a sufficient number of hyperbolas, the intersection may be used to determine the target's location.

8) Round-trip time (RTT): Indoor positioning systems based on distance estimates were given Wi-Fi Round-Trip Timing (RTT). Unlike the Wi-Fi fingerprint approach, which necessitates the creation of a massive database known as a radio map, this protocol may be readily implemented in an indoor positioning system using only the AP's installation coordinates. In addition, Wi-Fi RTT is determined by Fine Timing Measurement (FTM).

Fig. 7 shows the FTM is a ping-pong technique that measures the signals of RTT. Firstly, a smartphone needs to transmit the request to RTT AP [55]. The AP and smartphone then begin sending the FTM message and recording the transmission timestamp, as well as waiting for the acknowledgment packet and recording the receipt timestamp. As a result, ToA and Time of Departure (ToD) may be acquired and used to determine the ToF of the signal from transmitter to receiver. The distance between the AP and the smartphone is calculated using ToF.

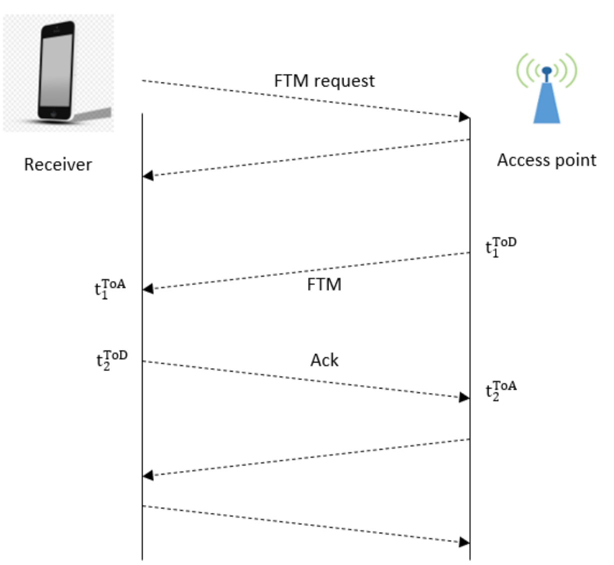

Fig. 7. RTT-based Localization.

An Android system has RTT Application Programming Interface (API). It is used to obtain ToF using [55]:

$$\boldsymbol{ToF} = \frac{(t_2{}^{ToA} - t_2{}^{ToD}) + (t_1{}^{ToA} - t_1{}^{ToD})}{2} \tag{10}$$

where $t_i{}^{ToA}(i = 1, 2, 3, ..)$and $t_i{}^{ToD}(i = 1, 2, 3, ..)$ is ToA and ToD measurements. The distance between transmitter and smartphone then been calculated using the equation as follows:

$$d_{rtt} = ToF * c \tag{11}$$

c is representing the speed of light. Meanwhile, d_{rtt} is the distance between transmitter and smartphone.

VI. Indoor Positioning Algorithms Discussion

In summary, the signal-based is critical in determining position since it is used in the computation and estimation of a location. The algorithms that are commonly involved are AoA, ToA, TDoA, and RSSI positioning-based. However, due to complexity, high cost, and required additional hardware for AoA, ToA, and TDoA compared to RSSI. Therefore, the RSSI algorithm is the best solution for determining the user/ object position. The comparison of the indoor positioning algorithm is shown in Table II.

TABLE II. Summary of Algorithms in IPS

Algorithms	**Advantages**	**Disadvantages**
AoA	• Easy to implement • Required at least two APs for localization	• Low accuracy in a large area • Specialized antenna • High-cost implementation • Complex
ADoA	• No need for an angle phase	• Required additional sensor
PoA	• Signal change is easy to obtain	• Require LoS for high accuracy
PDoA	• High accuracy • Reduce multipath effects	• Accuracy is depending on the multipath effect
RSRP	• Provide more signal strength	• Station interference and thermal noise have an influence
RSSI	• Low-cost implementation • Easy to implement	• Low accuracy in a large area
CSI	• Good stability • High accuracy	• High-cost implementation • Complex
ToA	• Easy to implement • Time measurement required for TDMA/ CDMA network	• Need a synchronized network • High-cost of implementation • Complex
TDoA	• The receiver does not need the time of transmission • Time measurement required for TDMA/ CDMA network	• Need a synchronized network • Complex
RTT	• High range measurement • No need a synchronize between nodes	• Multipath effects • Complex

VII. Indoor Positioning Techniques

The current position or location of the target item was calculated using positioning techniques [56]. The algorithm and the output of the position are processed by the positioning technique. Triangulation, Trilateration, Proximity, Scene Analysis, Fingerprinting, and Pedestrian Dead Reckoning are the main technique for indoor positioning as shown in Fig. 8.

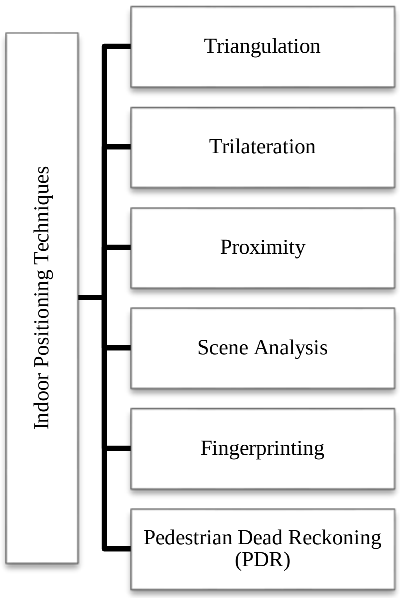

Fig. 8. Types of Indoor Positioning Technique.

A. Triangulation

Triangulation is a method of calculating a position based on the predetermined distance between three measuring devices and the measured angles from those three locations of an object [57]. Triangulation provides high accuracy if AoA has good precision. By increasing the number of access points, high precision may be obtained. However, a small error in angle calculation may affect the location accuracy.

This technique is particularly well suited to line-of-sight communication [58]. Calculating the angles and distance between reference points, as well as determining the position of a transmitter, are used to determine the position of an object. Triangulation can be divided into two categories: a) Lateration and b) Angulation. The basic localization for triangulation is shown in Fig. 9. From three access points, an angle measurement was made by the lines from distant points intersecting with the baseline.

These angles are then utilized to calculate unknown distances and, as a result, distance place was found [59]. The equation is as follows [60]:

$$
\begin{aligned}
x &= d_1 sin(\theta_1) + x_1 \\
y &= d_1 cos(\theta_1) + y_1 \\
x &= -d_2 sin(\theta_2) + x_2 \\
y &= d_2 cos(\theta_2) + y_2
\end{aligned} \tag{12}
$$

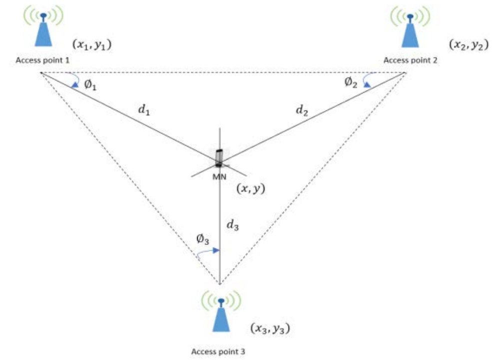

Fig. 9. Triangulation Technique Localization.

B. Trilateration

Trilateration is a more widely used technology that GPS also employs [59]. Trilateration is a method to determine an object's position using simultaneous range measurements from at least three reference nodes at known locations [61]. Measurements of angle do not involve trilateration [62]. Fig. 10 shows the three access points used in the trilateration technique in an indoor positioning system.

In practice, the edge-to-edge intersection of all reference circles is difficult to obtain due to the continuously changing in an indoor environment. The dependence of all three or more circles on edge-to-edge intersection reduces the estimation accuracy [63] of the trilateration technique.

The distance can be estimated using this equation [60]. It can be solved by using the matrix method:

$$
\begin{aligned}
{d_1}^2 &= (x - x_1)^2 + (y - y_1)^2 \\
{d_2}^2 &= (x - x_2)^2 + (y - y_2)^2 \\
{d_3}^2 &= (x - x_3)^2 + (y - y_3)^2
\end{aligned} \tag{13}
$$

C. Proximity

Localization based on proximity is a type of range-free localization. Proximity is the simplest method for localization [64]. It also might be the primary option if the user doesn't know the specific Mobile Devices (MD) radio settings or the architecture of the surroundings. Many researchers have utilized proximity-based localization to locate objects in ad hoc and wireless sensor networks.

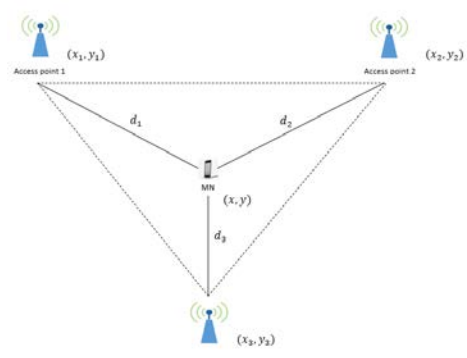

Fig. 10. Trilateration Technique Localization.

Fig. 11 shows the proximity method for indoor positioning. In proximity methods, the MD's position is determined relative to the AN position instead of explicit distances to the ANs. The precision needed for proximity detection in interior contexts is less than one meter, while it is roughly 5-10 meters for GPS [65]. This is because 5-10 meters precision is possible for street-level navigation, and the substantial localization/ proximity mistake such as meter-wide library isle cannot be tolerated.

In contrast to triangulation and trilateration, proximity offers location information, not an absolute or relative position prediction. A grid of antennas with known positions is used to identify the location. When a mobile device detects mobility, the closest antenna is used to compute the position. If a mobile device detects more than one antenna, the location is calculated using the strongest signal. To calculate the access distance between mobile devices and determine mobile location, RSSI is used.

Apart from that, proximity is used in various systems that use Wi-Fi, Bluetooth, RFID, and UWB and requires minimal calibration. Larger spread readers are required to produce a dependable and wider coverage area. With huge spread readers, there is a risk of increased complexity.

D. Scene Analysis

Scene analysis is one of the most popular approaches, as it is based on the observation of space features, is independent of direct sight, and produces good results even in contexts with many impediments [66].

Most of the scene analysis that has been proposed is based on the IEEE 802.11 standard due to its broad application. The scene analysis technique has several benefits over previous techniques, including increased resistance to the multi-path fading problem and the fact that it is not dependent on spatial-temporal variables like propagation time and signal reception angle. When there is NLoS between the radios in the network [67], these properties are extremely vulnerable to mistakes.

However, memory requirements for data storage and the human effort necessary [66] to execute the training step in the operational environment are the technique's key flaws.

E. Fingerprinting

Environmental surveys are frequently required for scene analysis-based localization approaches to acquire fingerprints or properties of the environment where the localization system will be employed. One of the most often recommended ways for indoor positioning is the location fingerprinting approach. The potential of location fingerprinting is to reduce multipath and NLoS propagation difficulties [68]. Fingerprinting also has high accuracy compared to other methods [69]. Furthermore, because Wi-Fi access points (APs) are already installed indoors, and the RSSI data are easily available from mobile devices, Application Programming Interface (API), requires no new infrastructure gear.

Fingerprinting technique includes offline (training) and online (positioning) stages [70]. It's necessary to develop a reliable fingerprinting database. Fig. 12 shows an illustration of fingerprinting in the offline and online stages. At an offline stage, each AP was collected at the Reference Point (RP) and extracted to generate fingerprints, which are then entered into a fingerprinting database. It is designed to learn the RSSI at each reference point.

During the online stage, the RSS of the test point is measured in real-time and compared to the offline fingerprints to establish location. The set is then orthogonalized to fulfill the essential criteria for the compressive sensing technique. The RSSD between APs is used to determine the processed set. The distance between offline and online values can be determined using [69]:

$$D_j = \sum_{i=1}^{m} \sqrt{\left(RSSI_{i(online)} - RSSI_{i(offline)}\right)^2} \quad (14)$$

where, i is the number of beacons ranging from 1 to the total number around tags, m. To compare the measured value to the database, determine the most similar fingerprint, and achieve localization, the RSSD value is utilized as the new fingerprint. Finally, precise localization is achieved using the compressive sensing theory.

F. Pedestrian Dead Reckoning (PDR)

The PDR positioning technique is a self-contained positioning system. Its main premise is to use an accelerometer, gyroscope, and geomagnetic meter to acquire real-time motion direction and step information to determine the location information of the moving target. PDR positioning achieves excellent positioning accuracy in a short amount of time; however, it can only produce relative positioning findings, and cumulative mistakes exist [71]. If the heading inaccuracy in PDR can be corrected, it is dependable for consistently precise positioning.

Fig. 11. Proximity Technique Localization.

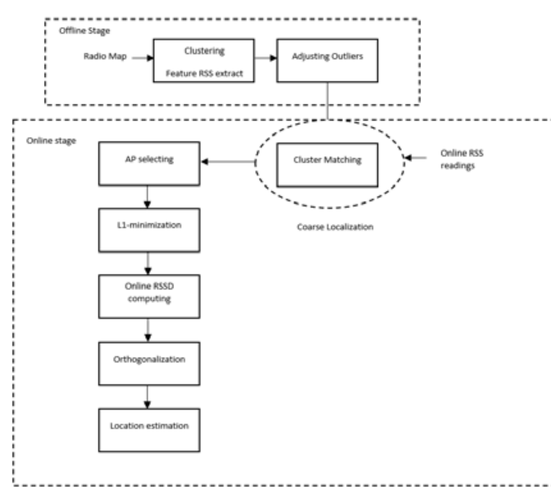

Fig. 12. Illustration of Fingerprinting Technique.

Researchers in [72] proposed to enhance PDR with RSSI. Erroneous headings will be corrected based on linear regression of locations computed using RSSI data derived from Wi-Fi signals to assure PDR's high dependability for extended duration placement. The outcomes of the experiment proved that the proposed strategy is practicable.

The user's position is calculated by combining the user's step length, several steps, and heading angle [73]. The step of the walking pedestrian can be expressed in [74]:

$$\begin{bmatrix}\widehat{x_k}\\ \widehat{y_k}\end{bmatrix} = \begin{bmatrix}x_0\\ y_0\end{bmatrix} + \sum_{i=1}^{k} \widehat{L_i} \bullet \begin{bmatrix}sin\ (\widehat{\theta_i})\\ \cos(\widehat{\theta_i})\end{bmatrix} \quad (15)$$

Where $\begin{bmatrix}\widehat{x_k}\\ \widehat{y_k}\end{bmatrix}$ represent the estimated position of the step, $\begin{bmatrix}x_0\\ y_0\end{bmatrix}$ represent an initial position, $\widehat{L_i}$ is estimated step length, and $\widehat{\theta_i}$ is estimated heading angle.

VIII. Indoor Positioning Techniques Discussion

According to the discussion above, the signal property used in a positioning technique has a big impact on how effective the positioning approach is. As a result, it is critical to comprehend positioning algorithms and techniques to employ the most relevant attribute. The comparison of the indoor positioning technique is shown in Table III. The table stated that triangulation, proximity, scene analysis, and PDR techniques are complex.

In addition, fingerprinting technique is complex because it involved offline (training) and online (positioning). Therefore, in this review, the Trilateration technique is suggested due to its low cost, ease of implementation, and high accuracy.

TABLE III. Summary of Techniques in IPS

Technologies	**Advantages**	**Disadvantages**
Triangulation	• Low-cost implementation • High accuracy within room level	• Low accuracy in a large area • Complex • Required angle measurement
Trilateration	• Simple • Low-cost implementation • High accuracy	• Accuracy may occur due to environmental changes
Proximity	• High accuracy	• High-cost implementation • Complex
Scene Analysis	• High performance	• High-cost implementation • Complex • Medium accuracy
Fingerprinting	• No infrastructure needed	• Accuracy is depending on fingerprinting data resolution • Complex
PDR	• Accuracy within a short amount of time	• Complex

IX. Conclusion

The overview of the positioning system and indoor positioning system was introduced. This review aims to provide a full understanding of indoor positioning technologies, algorithms, and techniques involved in an indoor environment. RF communication technologies such as Wi-Fi, BLE, RFID, and UWB are widely used in indoor positioning recently to develop location estimation. RSSI algorithm is the best algorithm to determine the user location estimation compared to AoA, ToA, and TDOA which required additional hardware, high cost, and are complex. Trilateration technique is suggested due to its low cost, ease of implementation, and high accuracy However, the use of technology, algorithm, and technique of indoor positioning are depending on many factors such as cost, available resources, type of environment, and the level of accuracy.

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