# Advances in Indoor Localization: Comparative Study of RFID, Wi-Fi, and Visible Light Methods

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**Abstract.** Due to the limitation that the global positioning system cannot be used in indoor settings and the increasing demand for location-based services in indoor environments, indoor localization has become one of the hottest research topics in recent years. A variety of techniques have been proposed for indoor localization. This review paper aims to provide an overview of working principles of radio frequency identification based, Wi-Fi based and visible light localization techniques and their applications. The paper also presents a comprehensive analysis of the advantages and disadvantages of each technique, including their accuracy, cost-effectiveness, and ease of deployment. In the end, the paper predicts a few future research directions and potential opportunities for indoor localization. This paper will be of interest to researchers, practitioners, and industry professionals working on indoor localization and related fields.

**Keywords:** Indoor Localization, RFID Localization, Wi-Fi Localization, Visible Light Localization.

## 1. Introduction

At present, the technology of outdoor localization based on the Global Positioning System (GPS), as the most overwhelming localization method, has become mature and widely adopted by the public, playing a vital role in people's daily life, navigating them to wherever they want, tracking their belongings or checking global maps. However, it is known to all that this method cannot be used in indoor environments. The reason is that the signal transmitted from the satellites is unable to go through buildings. Thus, it is necessary that a practical way is needed to fill the blank space where GPS cannot provide localization services. Moreover, the widespread adoption of mobile devices and the growing demand for location-based services in indoor environments, such as shopping malls, airports, and hospitals, have motivated the development of indoor localization systems. Despite navigation, the ability to locate individuals or objects in indoor spaces has a wide range of applications, such as asset tracking and security monitoring. For instance, indoor localization can enable customers to receive personalized advertisements, emergency responders to locate people in need of assistance, and retailers to track the flow of customers in their stores.

Various techniques have been proposed for indoor localization, such as radio frequency identification (RFID) based localization [1-3], Wi-Fi fingerprint localization [4,5] and visible light (VL) localization [6-9], each with its own advantages and limitations. However, there are still various challenges that need to be addressed, including accuracy, robustness, scalability, privacy, and cost-effectiveness. For instance, Wi-Fi-based methods may suffer from interference from other Wi-Fi signals. Privacy concerns also arise with the use of indoor localization systems, as some may not want to have their location data shared with others, while some others worry if the transmitted data is vulnerable to attacks.

In this review paper, an overview of localization using RFID, Wi-Wi fingerprint and VL methods, their advantage and limitations, their present applications and future research directions is provided. The author holds a strong belief that these methods will be crucial in future interior localization systems and other smart building applications.

The structure of the paper is as follows. Section 2 describes the working principles of localization methods using RFID, Wi-Fi fingerprint and VL and their applications. A comparison between the features of the methods mentioned in the second section is given in Section 3. After that, Section 4 illustrates a few future research trends for indoor localization technology. Finally, the paper is concluded in Section 5.

## 2. Localization Methods

### 2.1. Localization Based on Radio Frequency Identification (RFID)

#### 2.1.1 Working Principle of RFID

RFID stands for radio frequency identification. It is mainly used to convey data between fixed devices and mobile devices. A typical system contains a processing unit (usually a computer) a reader (with an antenna to send signal) and a variable number of tags. When working, the reader sends out RF signal in a certain frequency, as tag enters and receives the signal, induced current will be generated and thus the tag gains energy and sends its information back to the reader. Once the received, the information will be sent to the processing unit, which retrieves information about the ID number from the database and acts on it accordingly [7]. The dataflow can be read-only or two-way and the tags can be active or passive based on whether they have internal power supply. Due to the system holds significant feature that one end of the it can be devices which are simple in technology and small in size while the other can be more complicated, it can be economically deployed in large numbers. Fig. 1 shows a typical layout of the system.

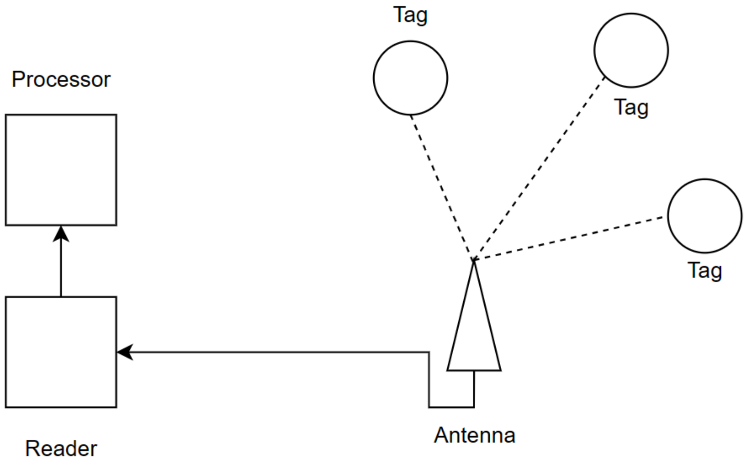


**Fig. 1** RFID based indoor positioning system structure diagram

When using received signal strength indication (RSSI) method, the strength of the transmitted signal can be processed through (1).

$$\mathrm{RSSI} = -(10\mathrm{n}\lg \mathrm{d} + \mathrm{A}) \quad (1)$$

In (1), n represents the propagation path loss exponent, d stands for the distance between the two sides in the communication process. A is a constant independent of path loss, which is often referred to as the sensitivity of the receiver. In practical, (1) can be used to obtain how far the transmitter and the sensor on the receiver are from. Once the distance is estimated, the antenna's position can be determined using trilateration technique, which involve using the distances to multiple tags to triangulate the antenna’s position.

When using phase-based localization method, a series of phase data can be collected and combined into an array as measurements are taken when the reader moves according to the tag. During the above process, the phase angle of the received signal changes as the distance between the receiver and the tag changes. Collecting such data gives a specific reference number. Also, an analysis on the amplitude of the received signal will be taken—based on k-nearest neighbor algorithm [2], the position can be roughly estimated. By combining the two above signals, a much more precise estimation on the position can be gained [3]. The reader can be either fixed or mobile depending on the practical situation.

### 2.1.2 Applications of RFID Localization

Due to the capability of being made lightweight and simple, RFID can be used to localize and track a massive number of objects or people without being costly. For instance, a gambling house in Las Vegas is planning to set up readers in its check stands and gambling tables as well as putting passive RFID tags in the chips to detect fake chips while keeping trace of the flowing of the players and the chips.

## 2.2. Wi-Fi Fingerprint Localization

### 2.2.1 Working Principle of Wi-Fi Fingerprint Localization

A Wi-Fi system is typically formed by a number of access points (AP) which are deployed in some easy-to-install locations, and the system or network administrators usually know where they are located. Every AP has a unique Media Access Control (MAC) address. As devices communicating with each other directly or indirectly through Aps, they can obtain the MAC address broadcast by APs regardless of whether the signal is encrypted, connected, or not strong enough to be displayed in the wireless signal list. The collected data will be sent to servers, combined with the strength of the received signal.

To make up the fingerprint algorithm, a training step that takes place offline and a localization phase that takes place online are needed [4]. In the first step, a site survey will be conducted, thus deciding various reference points. At these points, the RSS values of multiple APs will be collected to ensure the accuracy of the map. In the second step, measurements will be taken by mobile devices before being compared with the previously drawn fingerprint map to predict the position of the user. On the above basis, services constantly update and update their databases to keep them accurate, since wireless APs can vary because of the change of the indoor environment.

### 2.2.2 Applications of Wi-Fi Fingerprint Localization

Since Wi-Fi signals are widely spread in the city, the most significant strength of Wi-Fi fingerprint localization is that it is supported without any more unnecessary professional devices and is thus cost-friendly. For instance, a Korean team has established a Wi-Fi-based indoor localization system in the COEX complex in Seoul and it was proved to be practical and useful [5]. Many clients and suppliers have seen the value of Wi-Fi-based interior positioning and navigation systems for their enterprises, and more agencies are planning to provide indoor positioning services in the future.

## 2.3. Visible Light (VL) Localization

### 2.3.1 Working Principle of Visible Light Localization

Localization method of using light is becoming popular these days due to its feature that the transmission of light (electromagnetic signal) can only be slightly influenced by signal fluctuation and multipath effect, which can be challenging to high accuracy positioning using radio signals. As the lighting market grows, LEDs are gradually being more popular because of their high energy efficiency ratio, more environmental friendly and durability compared with incandescent light sources, and are likely to become the main light source in a majority of places [8]. Because being able to function as both a lighting and a communication transmitter, it considerably decreases power usage. There are generally two parts in a visible light localization system: the transmitter and the receiver. The transmitter has two types that will be discussed later, one uses modulated light signals while the other does not require any transformation in a regular LED light bulb. The receiver usually has a photo-diode (PD) or a camera to receive transmitted signals. The received signal will then be passed to a decoder to obtain the position of the receiver.

For the method using modified light source, the light bulb broadcasts its location and duty cycle. The receiver detects multiple signals and uses the received signal strengths to calculate the position. If the number of the light signals is not enough for precise positioning, additional sensors like inertial measurement units (IMU) will be used to assist the positioning process [6]. Fig. 2 shows the system structure of visible light localization using programmed light sources.

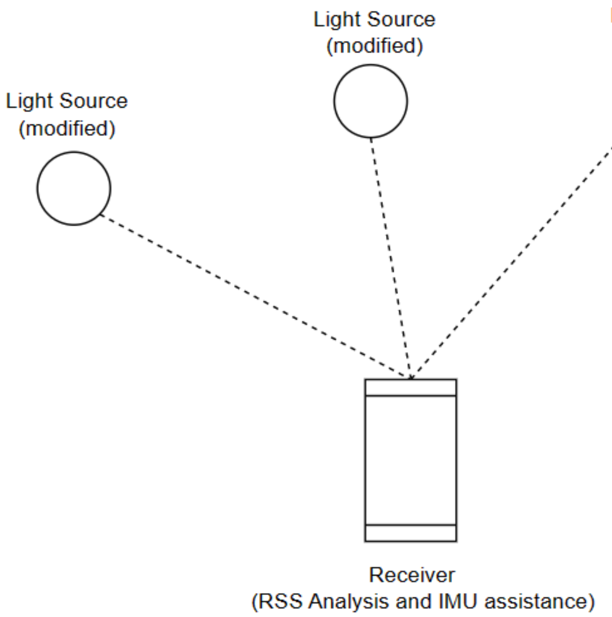


**Fig. 2** System structure of visible light localization using modified light sources.

For the method using the regular light sources, Chi Zhang and Xinyu Zhang claim that every fluorescent light emitting device has its unique recessive characters. Collecting these characters through cameras and registering them into a database form a set of landmarks. Then the sensors on the user's phone help photogrammetry compute its 3D location in relation to the light landmark based on the picture taken by the its camera and the output from its gravity sensor. When the user leaves the light covered range, the system will use another set of motion sensors to track the displacement from the original position. Fig. 3 demonstrates the typical system structure of visible light localization using regular light sources.

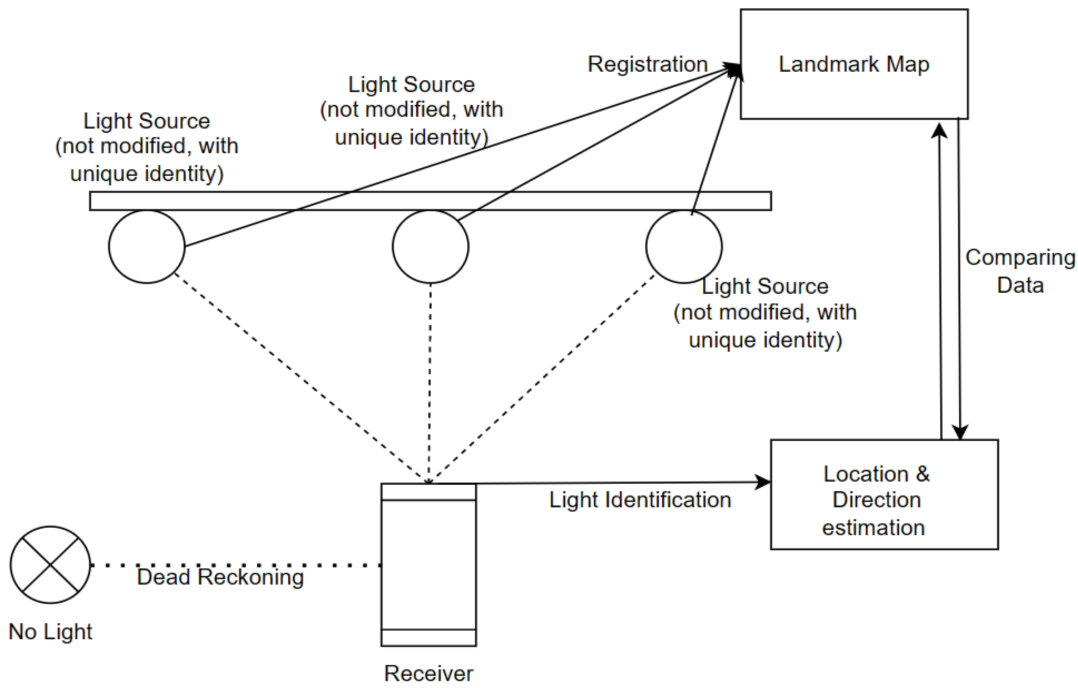


**Fig. 3** System structure of visible light localization using regular light sources.

### 2.3.2 Applications for Visible Light Localization

In recent years, since the visible light communication technology has been proved to have potential for development in the future, it is considered to be competent for an alternative method of indoor localization from RFID, Wi-Fi and other methods. The most significant advantage of visible light localization is that it is long life span and high energy efficiency of LED makes localization relatively economic and environmental-friendly without being less accurate [9] while providing additional lighting. Moreover, the system can be used in places that are sensitive to electromagnetic signals such as mines and planes.

## 3. Comparison

Three methods solving indoor localization have been reviewed above. They respectively have their own advantages and drawbacks. However, it is impossible to control all of the conditions to be the same to test all methods. It is only possible to compare their features through articles.

RFID localization technology tracks the position of the target device using a receiver to read the signal strength received from RFID tags. RFID can be energy efficient due to the RFID tags can be powered using batteries (active) or radio waves (passive). To apply RFID localization, more infrastructures, like reader and tags are needed, which may raise the cost. Also, RFID localization has a longer response time than the other two methods. This may not cause a severe influence on industrial corporations or business runners when localizing the cargos, but it can be fatal for big shopping malls which need to quickly locate moving customers. When it comes to accuracy, localization using RFID can proceed to 1-2m. Using specified algorithms, the accuracy can be improved to sub-meter level [10].

Wi-Fi localization determines the location of the device using the signal from Wi-Fi access points. By making comparison between received Media Access Control address and stored Wi-Fi fingerprints combined with the received signal strength, it can exceed an accuracy of 1 to more than 10 meters [5,11,12]. Because no additional hardware or devices are needed, Wi-Fi localization can be easily accessed by a variety of operating systems, such as smartphones, iPads, or laptops, which gives it a significant advantage as an inexpensive and straightforward solution that can be easily applied in most indoor settings and satisfies the needs of a wide range of customers. Despite its limited precision, the aforementioned advantages of Wi-Fi localization partly offset its shortcomings in terms of performance, as it offers significant cost savings. Moreover, its positioning accuracy is sufficient for civilian environments [12]. Nonetheless, this method is not as accurate as the other two alternatives and is vulnerable to disruptions caused by interference.

Visible light indoor localization uses LED lights to transmit data to a certain receiving device (usually a camera or a photodiode [13]). The receiver will then decode the information carried to estimate its position. As the most significant advantage, the spatial positioning accuracy of the system can reach several centimeters to tens of centimeters [14], making it the most precise method among the three compared. What makes it different is that in environments with complex electromagnetic conditions, localization technologies that use electromagnetic signals may suffer from interference. Visible light positioning, on the other hand, is not subject to electromagnetic signal interference, and therefore performs better in such environments [15]. Regrettably, despite the advantage of utilizing LEDs for illumination in visible light indoor positioning, the requirement for specific modulation of the light source at a particular frequency or luminance for positioning restricts the use of existing lighting equipment and necessitates the installation of custom-made light sources, leading to an increase in costs. Although an alternative method that employs regular light sources for positioning is available, the technology is still immature and not yet widely adopted. Visible light signals are also susceptible to interference from other light sources, such as natural light entering the indoor environment, the LEDs in the same communication range or obstructions blocking the light source, which can cause significant effects on positioning accuracy or even result in positioning failure [16].

In general, a summary of the comparison among the three methods is given in Table 1.

**Table 1.** General comparison of the three methods

| Technology | Accuracy | Advantages | Disadvantages |
|---|---|---|---|
| RFID | 1-2m | Low power consumption; Medium cost | High response time |
| Wi-Fi | 1-more than 10m | Able to use existing Wi-Fi devices; Lowest cost | Low accuracy; High cost for building fingerprint database |
| Visible Light | 1-several tens cm | Extremely high accuracy; Light sources can be used for lighting; RF sensitive areas friendly | May need to replace existing light sources; Vulnerable to other light sources; Light may be blocked |

## 4. Future Research Directions

Although researchers have found multiple ways to achieve indoor localization, each of them has some drawbacks in some way, which to some extent limit their practical application. In the future, there are some points that can be improved for indoor localization before its maturity.

Combination of methods: Since different methods have different features, it is advisable to combine more than one method to improve the reliability of the system or achieve a higher accuracy. Researchers have tried combining other sensors such as inertial measurement units to ensure accuracy or maintain tracking when the other method of localization fails to locate the user due to interference.

Introducing machine learning (ML) into indoor localization: Especially in recent years, the dramatic development of machine learning has put deep impact on the field of computer engineering. Regrettably, machine learning has not yet been widely adopted in indoor localization expect a few teams have used the K Nearest Neighbors (KNN) algorithm [17-19], another team used Neural Network(NN) [20]. With the aid of machine learning, accuracy and efficiency of the system can be enhanced while the cost can be lowered. Machine learning can also enable support for diverse application scenarios by recognizing user behavioral patterns and needs, and providing personalized positioning services based on varying contexts, providing targeted suggestions according to the customers' preferences and behaviors. With the availability of big data and powerful computing resources, the potential of machine learning in indoor localization is expected to be further explored and exploited in the near future.

## 5. Conclusion

Indoor localization is an active and rapidly growing research field that has attracted a lot of attention in recent years. This article has briefly reviewed three different methods used for achieving indoor localization. It can be seen that researchers have made great progress to find an alternative way to position in GPS blind spots. Nowadays, a variety of methods have been researched and applied, for instance, RFID, Wi-Fi and visible light. Although no single technique can provide an ideal solution to all indoor localization scenarios, the author firmly believes that with further developments of indoor localization, such as the involving of machine learning, will make indoor localization more feasible and reliable. The three mentioned methods may not be the ultimate solution of indoor localization, but they will definitely be of vital importance to future positioning & navigating system and smart building applications.

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