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A Review on Indoor Positioning Technologies and its Principles

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Abstract: ***This paper aims to provide the reader with a review of the main technologies present in the literature to solve the indoor localization problem that is indoor positioning without GPS.***
Location detection has been implemented very successfully in outdoor environments using GPS technology. GPS has had a great impact on our daily lives by supporting a large number of applications. However, in indoor environments, the availability of GPS or equivalent satellite-based positioning systems is limited due to the lack of line of sight and attenuation of the GPS signal when they pass through walls. The goal of this paper is to provide a technical perspective on indoor positioning systems, including a wide range of technologies and methods.
Keywords: Indoor Positioning, Localization, Inertial Motion Sensors (IMU), Trilateration, Fingerprinting, Dead Reckoning, Received Signal Strength Indication (RSSI

I. INTRODUCTION

Real time knowledge of the location of people or objects has become a necessary condition for the deployment of services in many areas such as retail, logistics, urban planning and leisure activities. The success of the global positioning system and the mobile revolution have forever changed the location of people or objects and how we connect with technology in business and personal life. The advancement of location-based technology and the growing importance of ubiquitous computing and context-sensitive information have led companies to become increasingly interested in location-based applications and services. Today, most of the application requirements are precise positioning or real-time tracking of physical objects in buildings; therefore, the demand for indoor positioning services has become a key prerequisite for certain markets. In addition, indoor positioning technology solves the shortcomings of global positioning systems in closed environments (such as buildings).
However, when there are people in a building, the GPS cannot always locate them. This is because GPS technology uses signals from orbiting satellites. When there is no line of sight, these signs will seriously degrade, making positioning indoors difficult. The indoor positioning and navigation system seems to play a role in providing real-time location information in an indoor environment. Radio frequency (RF) signals, computer vision, and sensor-based solutions are best for tracking users indoors. This paper provides a comprehensive overview of the evolution of indoor positioning and navigation technology.
As shown in the Fig. 1 below shows the Indoor positioning systems employs wide range of different technologies :

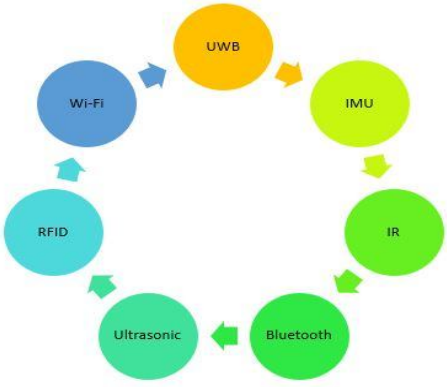

Fig. 1 Different IPS techniques

Each of these technologies and their principles will be discussed in this paper.

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II. INFRARED

Infrared-based indoor positioning systems use pulses of infrared light (like TV remote controls) to locate signals in buildings. Infrared receivers are installed in each room, and when the infrared tag emits pulses, the infrared receiving device will read them. Infrared is a near-foolproof method that ensures room-level accuracy. This type of system can be used as a very reliable room detector. Since the light cannot pass through the wall, it is impossible for the tag to detect the light from the anchor without being in the same room. Although tags are cheap and durable, the disadvantage of infrared is that each room needs to install a wired infrared reader on the ceiling and for accurate positioning, they need to install many anchors and may encounter difficulties due to the poor quality of the signal strength measurements required to calculate the positions of various anchors. If you install it in a new structure, that's fine, but as with acoustics, modification will be very expensive. This is why infrared systems are usually used in newly-built hospitals, where the rooms must be segmented. In an empty warehouse, infrared will be a challenge: if three receivers read a light pulse, it is difficult to measure the relative strength of the infrared signal, so it is impossible to tell which receiver the tag is closest to. Generally speaking, radio technology works best in open spaces that feature warehouses and manufacturing facilities.

III.ULTRASOUND

Ultrasound systems use sound instead of light. "Ultrasound is a mechanical wave, a pressure oscillation transmitted through a medium". It does not interfere with electromagnetic waves and does not require sight. The system requires a set of anchor points and a tag. It uses the time of flight, which is the time it takes for sound to travel from one anchor to another or from one tag to another, to estimate the distance between them. Once at least three distances are available, the position can be calculated using the trilateration method. The

Ultrasound system is not the most common application. They need to place several anchors and perform a time synchronization between the anchor of the Bluetooth beacon (anchor) and the tag. They can reach an accuracy of less than a meter. However, ultrasonic signals are affected by interference from solid objects, so if these factors are not considered, the accuracy can be poor.

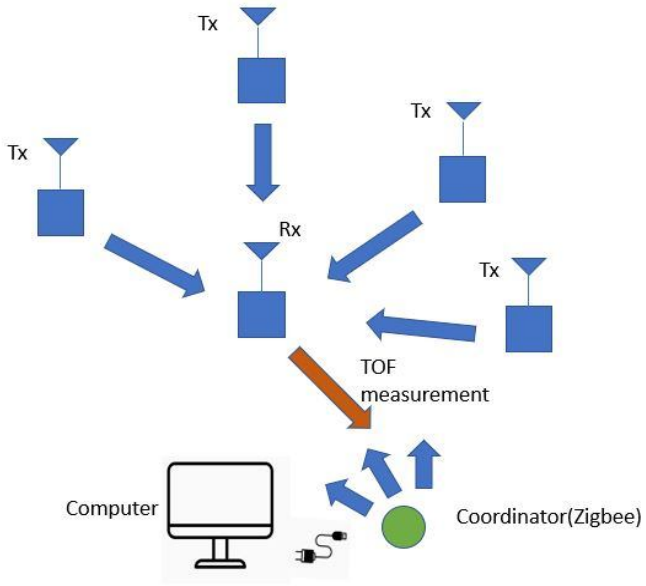

Fig. 2 UltraSound for IPS

IV.RADIO FREQUENCY TECHNOLOGIES

The most common IPS is based on radio frequency signals. There are two reasons. First, some systems will reuse existing technologies, including WIFI, Bluetooth and mobile phones. This greatly reduces implementation costs and makes the technology easier to use for more people (for example, when installing applications). The second point of is that because these signals can pass through obstacles, they can play a role in the real environment of inevitable obstacles (including commercial areas). In some cases, these systems can also provide greater coverage.

So here we describe about the widely used IPS systems that use radio frequencies are :

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A. RFID

RFID-based systems belong to "contactless automatic identification technology". RFID uses electromagnetic fields to identify and track tags attached to people or objects. This type of system uses RFID tags and readers. The reader sends pulses detected by the tag. The tag responds to the reader's request by returning a small amount of information (such as identification). Although these systems usually use the ISM frequency band, they send and receive radio frequency signals from 125KHz (short-distance system) to 5.8GHz (long-distance system). RFID can be passive, active or semi-passive. The simplest RFID systems use passive tags that get the necessary power to send a response directly from the reader's pulse. Passive tags are very cheap, they can only store a few kb of memory, and the reader must be semi-passive RFID has batteries to power labels and other simple functions, but the antenna and general functions are similar to passive RFID. These can provide a wider range of work. Active RFID has different antennas to provide a longer range of about 100m. These tags can also store more information. However, they are more expensive and are usually larger. As mentioned above, RFID systems are a good option to identify and detect the presence of people and objects. They don't need a line of sight like an infrared system. However, they do not provide tracking information and are often combined with other technologies that can provide positioning.

However, they may be interfered with in the environment by liquids, metals, or other sources of radio interference about 1 m away from the tag to get the information.

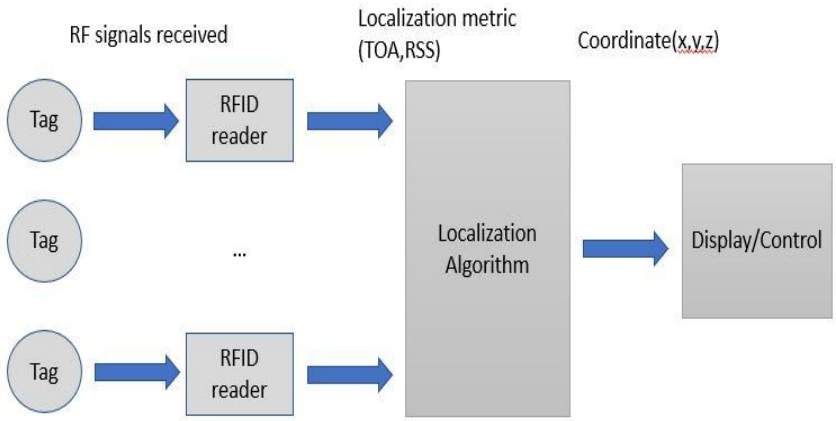

Fig. 3 RFID for IPS

B. Wi-Fi and Bluetooth

Some IPS systems use known Bluetooth and WIFI technologies. The main advantage of these systems is that they can use pre-existing network infrastructure, and WI FI and Bluetooth can be used on mobile phones and other portable devices. This makes them easy to implement and inexpensive compared to temporary installations. The main working principle of is to use Received Signal Strength (RSS). The signal strength depends on the distance between the transmitter and receiver. By simply measuring RSS from tags (for example, mobile phones) to multiple WI FI access points or Bluetooth beacons (acting as anchor points), the position of the mobile phone can be estimated using trilateration, which is the same as that used in ultrasound. The principle is the same. IPS. The main difficulty of these systems is that in the presence of obstacles and people in motion, the WIFI and Bluetooth signals are very different. Similarly, different materials will also have different effects on the signal, thereby affecting the accuracy. To overcome this problem, some IPS create specific RSS mapping for a given area based on temporary calibration. The accuracy obtained with this type of system can reach 1-2 m.

Although they have the same basic principles, there are still some differences between Bluetooth and WIFI. On the one hand, although the energy consumption is high and it is necessary to take into account some factors, the WIFI coverage is wide. On the other hand, Bluetooth requires less power, especially Bluetooth Low Energy (BLE) technology. However, reducing power consumption also means reducing coverage. The ideal maximum range of Bluetooth 4.0 is 100m, with a high data rate (up to 2.1Mbps), while BLE is about 60m with only LOS, and the data rate is greatly reduced (125kbps) . ZigBee is another little-known wireless communication protocol that runs in the 2.4 GHz frequency band and is also used in IPS systems.

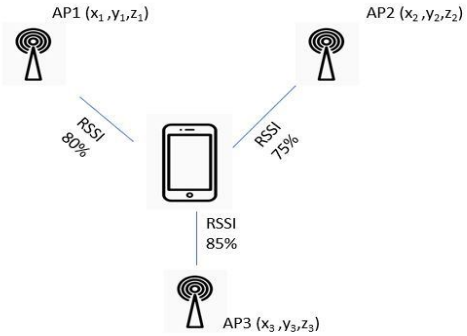

Fig. 4 Bluetooth for IPS

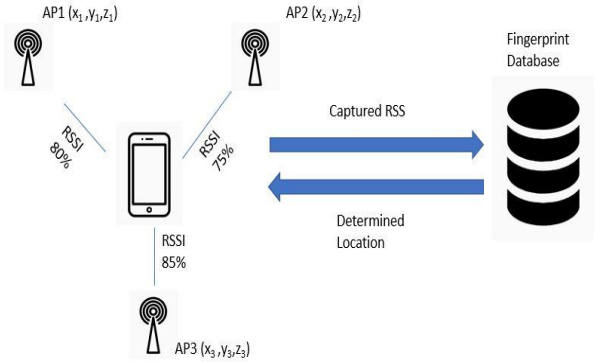

Fig. 5 Wifi Positioning System

C. UltraWide Band

The main advantage of this technology is the ability to penetrate materials such as concrete, glass and wood, making it suitable for typical indoor environments where the line of sight is usually not visible. Likewise, higher bandwidth means higher time resolution. In this way, the flight time between the sender and the receiver can be measured to obtain a better distance estimate than RSS. Therefore, the UWB system uses trilateration to estimate the location of the tag from the distance to a set of at least three anchors deployed in the environment. The accuracy of UWB is currently the best of IPS, and its error is about 30 to 50 cm. The UWB IPS has some disadvantages. First, the technology is not available in the user's building or mobile phone and needs to be implemented temporarily. Because it occupies a larger bandwidth, there are relevant legal restrictions to avoid interference between other radio frequency signals: 1) The allowable frequency band is from 3.1GHz to 10.6GHz, and 2) the signal power is limited, thus limiting the working range If data load transmission is required in the system, the maximum distance is 100m or less.

V. INERTIAL MOTION SENSORS

The inertial system reports the relative movement of the tag by integrating various sensors such as accelerometer, magnetometer and gyroscope in a small module. These sensors are useful for determining the direction and direction of movement. Together, they can provide an estimate of relative motion relative to the previous position. This information is usually obtained by combining all available signals using algorithms such as dead reckoning. Dead reckoning is "the process of estimating the current known position based on the past position, and increasing the position based on the known or estimated speed in the elapsed time"

One of the advantages of this technology is that it does not require the use of anchors in the environment. Unfortunately, the accuracy of this type of system is usually poor, because errors accumulate over time and can reach the order of meters in a few seconds. For this reason, is often used in combination with other techniques to smooth the results and eliminate outliers. In addition, the ability to detect movement may be useful in detecting tags and whether the participant has stopped.

VI. BASIC PRINCIPLES OF INDOOR NAVIGATION

First, in order to summarize the basic positioning system, some position-related signal parameters corresponding to the wireless communication between the target and the sensor are measured. Then, the physical position of the target is calculated based on these parameters of the signal .

So the localization is divided into 2 phases as shown in the Fig. 5

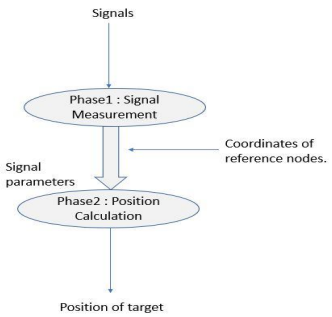

Fig. 6 Phases in IPS

A. Signal Measurement Techniques

So here are the different Signal measurement techniques

1) *Time Of Arrival:* TOA is sometimes called TOF; it is the time it takes for a signal to pass from the transmitter to the receiver. For example, if the receiver can obtain TOA as evidence, it will use the speed of light m/s to estimate the range. Then, several reference devices combine their range estimates. From the perspective of multilateralization, ToA describes the circle around the reference device, although two circles are sufficient Solve the coordinate problem, but still need a third circle to disambiguate, as with the GPS application, In the Fig. 7 ,A, B, and C will be transmitters, and P will be receivers. This setting allows you to keep the position of P. As TOA measurement may have errors, whether it is due to small errors due to noise and measurement accuracy, or large errors due to reflection, multipath or signal dispersion, we will not be able to determine a single point as a solution, but rather determine A region, usually, we choose the point that is considered to be the best guess. In the case of IPS, some problems of TOA will be exacerbated: First, in GPS, the position of a satellite is known in advance through its orbital parameters, but this is not the case in IPS, because there is no universal consensus reference. Secondly, for very short distances such as indoors, and for RF signals, the time difference will be very small, so high accuracy is required.

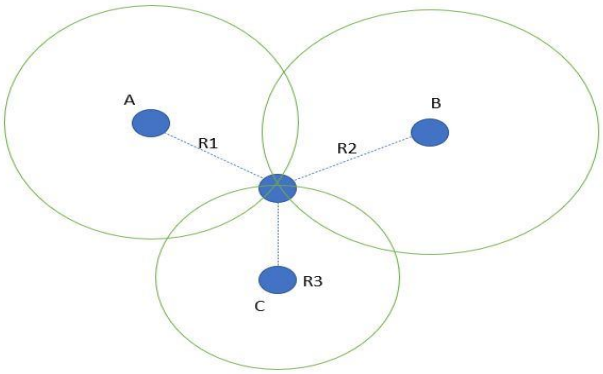

Fig. 7 Time of Arrival

2) *Time Difference of Arrival:* TDOA is related to TOA because it uses the propagation time from the transmitter to the receiver to estimate the distance, but sometimes the transmission time is unknown. Therefore, the travel time difference of each receiver is used to estimate the distance to each receiver. Calculating the time difference eliminates the known transmission time . As with TOA or any other time-based method, synchronization between devices must be achieved to make accurate measurements. However, since TDOA does not use the distance between the transmitter and the receiver, it is not necessary for the transmitter to synchronize with the receiver. Just calculate based on the time / distance difference between all receivers, it is necessary to have synchronization between all receivers

3) *Angle of Arrival:* Provides a measure of the angle at which the signal is received at the reference device. The reference device defines a line that leaves its position at such a measurement angle, where the target object should be. Combine multiple lines from multiple reference devices to place the target object at the intersection of multiple lines. Use at least two reference points and two angles as shown in Fig. 8. The advantage of this measure is that there is no need for time synchronization between references. The disadvantage is that complex hardware is required to determine AOA

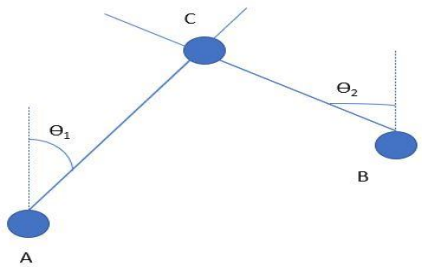

Fig. 8 Angle of Arrival

4) *Received Signal Strength:* RSS is the field strength of the signal at the point of reception. The RSS is measured at the receiver, see Fig. 8, and then the distance can be estimated using signal propagation models or other methods. In particular, the Friss propagation equation is often used. At other times, more complex models will be considered. RSS technology needs to use multilateralism.

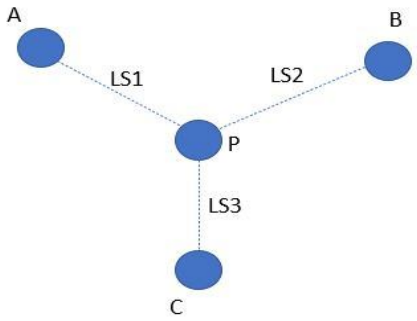

Fig. 8 RSSI

B. Position Calculation

1) *Trilateration:* The Triplex method is used to determine the relative position of by measuring the distance using geometry. The three-order method does not have an offline phase than in the fingerprint method. However, it is the coordinate position of the AP, as well as the AP's MAC address stored in the centralized database. The positioning technology based on test retention uses three non-colinia fixed reference nodes to calculate the physical location of the target node Fig. 9 shows a positioning based on Trilateration technique.

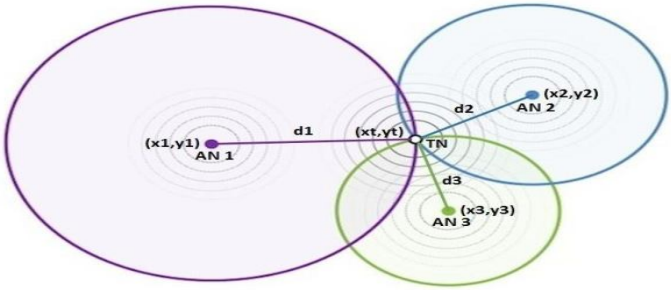

Fig. 8 Trilateration

Based on the three coordinates of three reference nodes: A(x1, y1),
B(x2,y2), C(x3,y3) and the corresponding distance from each reference node the target node which can be obtain from following equation where (x, y) denotes the (unknown) coordinates of the target T.

So the equations go like this :

$$(X_1 - X)^2 + (Y_1 - Y)^2 = d_1^2 \quad (1)$$
$$(X_2 - X)^2 + (Y_2 - Y)^2 = d_2^2 \quad (2)$$
$$(X_3 - X)^2 + (Y_3 - Y)^2 = d_3^2 \quad (3)$$

There are no downsides to using this trilateral measurement method. It is difficult to obtain an accurate distance measurement from the signal intensity. Additionally, multipath signal propagation, penetration through objects, and signal attenuation across distance make this method difficult to implement in indoor signal propagation.

2) *Triangulation:* Triangulation uses the geometric properties of the triangle to determine the location of the target. It has two clues: lateration and angle. Techniques based on time-of-flight system measurement (for example, TOA, RTOF, and TDOA) and phase methods based on RSS and received signals are called latency techniques [8, 9]. The AOA estimation technique is also called the angulation technique

3) *Fingerprinting:* Fingerprint recognition is a method used to calculate approximate location. The term has been used in particular as a way to obtain location from detections recorded on mobile devices such as Wi-Fi signals, but this is a technology that has been used in Bluetooth and magnetism. It consists of two stages: training and position determination. During the training phase, radio maps of signal strength values observed from different locations are recorded. Then, in the position determination stage, a proximity matching algorithm such as a nearest neighbour (k-NN) is used to compare the signal strength value observed on the user equipment with the radio map value to infer the current position. User , And interpolation.
4) *Dead Reckoning:* Dead reckoning is the process of estimating a known current position based on the last determined position and increasing the position based on the known or estimated speed of the elapsed time. Inertial navigation systems that provide inertial navigation systems use dead reckoning algorithms and have been used extensively . One of the disadvantages of dead reckoning is that the inaccuracy of the process is cumulative, so the positioning deviation will increase over time. The reason is that the new position is fully calculated based on the previous position. Dead reckoning has been used to study indoor positioning .Pedestrian Dead Reckoning (PDR) is a pedestrian positioning solution by adding distance travelled to the known starting position. Pedestrian distance travelled can be determined by using accelerometer sensor to detect steps and estimate displacement. Accelerometer sensor must be attached to the body to record the acceleration. Some related research has been done in previous studies using a special sensor modules that is attached on the helmet , attached at the foot, or using low-cost sensor integrated in smartphone and placed it to the trouser pocket . The most basic principle for PDR technique is Step Length estimation.
5) *Step Detection:* A pedestrian's walking distance is represented by his steps. Therefore, it is necessary to accurately detect the stepper to get a better estimate. There are two -step detection methods commonly used to analyze acceleration signals: peak detection [4] - [6] and zero-crossing detection [2], [7], [8]. The zero crossing method counts the zero crossing level of the signal to determine the occurrence of the step. Researchers typically use time interval thresholds to reject false step detection. This method is generally not suitable for detecting the user's step count, because it requires a certain time interval threshold to determine if the zero crossing represents a valid step. The problem occurs when the time interval between the steps of some objects is different, so without the calibration process, it is difficult to use the zero crossing method to accurately detect the steps. Another method is to detect the maximum acceleration value. According to [4], the peak value of the vertical acceleration corresponds to the occurrence of step , because the vertical acceleration is , which is generated by the vertical collision when the foot is on the ground. In article , we also use the peak detection method. However, for we use the acceleration amplitude instead of the vertical acceleration to solve the tilt problem. Because the acceleration will remain the same regardless of whether the smartphone is tilted or not

6) *Step Length Estimation*

a) *Static Based:* The static method assumes that any valid steps have the same length of , which can be determined from equation.

$$step\_size = k*height \quad (4)$$

b) *Dynamic based :* Dynamic method assumes any valid steps having their different step length which can be estimated using certain approaches, such as:

Weinberg approach - Assume that vertical rebound (occurs as an effect of walking activity) is proportional to the length of stride [9]. Vertical rebound is calculated using peak-to-peak differences at each step.

$$step\_size = K* \sqrt[4]{(A_{MAX} - A_{MIN})} \quad (5)$$

VII. IMPORTANT FEATURES OF INDOOR IPS

To determine which technology is suitable to build your own IPS, some features have to be taken into account and balanced for the required specifications of the project.

A. Accuracy

It is defined as "Euclidean average distance between the estimated position and the true position". The accuracy is considered the most difficult role and the improvement of most interior mapping systems. The best solutions generally require ad hoc implementation that increases costs and complexity. Therefore, if the precise positioning is not important, cheaper and simpler technologies are used. The following table generally shows the best precision that is generally obtained by the system described above.

B. Coverage and Scalability

Coverage and scalability-this is the second most important feature that can match accuracy. Coverage is the area where location information can be provided. The coverage of IPS usually ranges from a room to a scalable system, which can cover a multi-room environment or a large area, such as a warehouse or shopping center. There is usually a trade-off between coverage and accuracy, where a technology with a larger coverage usually means a lower accuracy.

When choosing a technology, it is important to consider its scalability, that is, the ability to cover a larger area by adding more anchors, access points, or card readers. Another important point is the ability of the system to locate multiple targets at the same time.

C. Adaptiveness

Changes in the environment will affect system performance. Therefore, when accuracy is required, the ability to cope with these changes is critical.

D. Cost

This includes implementation costs, operating costs and maintenance during the life cycle of the system. Some technologies require a fixed installation, while others may be mobile or use existing infrastructure. Techniques that use trilateral measurement often require calibration, which can be time consuming, especially if the installation of the system is not permanent.

VIII. COMPARISON OF VARIOUS IPS TECHNIQUES

Table I
Performance comparison

S.no	Technology	Accuracy	Cost
1	WI-FI	5-10 m	Low
2	RFID	1-2 m	High
3	BLUETOOTH	2-5 m	Low
4	IMU	1-2 m	Low
5	ULTRASOUND	1-2 m	High

IX. CONCLUSION

Indoor positioning system have numerous advantages and have the potential to make the world a more efficient place. The objects/devices/ people can be tracked down even in indoors where the GPS signal cant pass through using these various technologies and techniques as discussed in this paper. These techniques can be employed based on the the requirements . These technologies can be used together to make a hybrid indoor positioning system for better accuracy and range .

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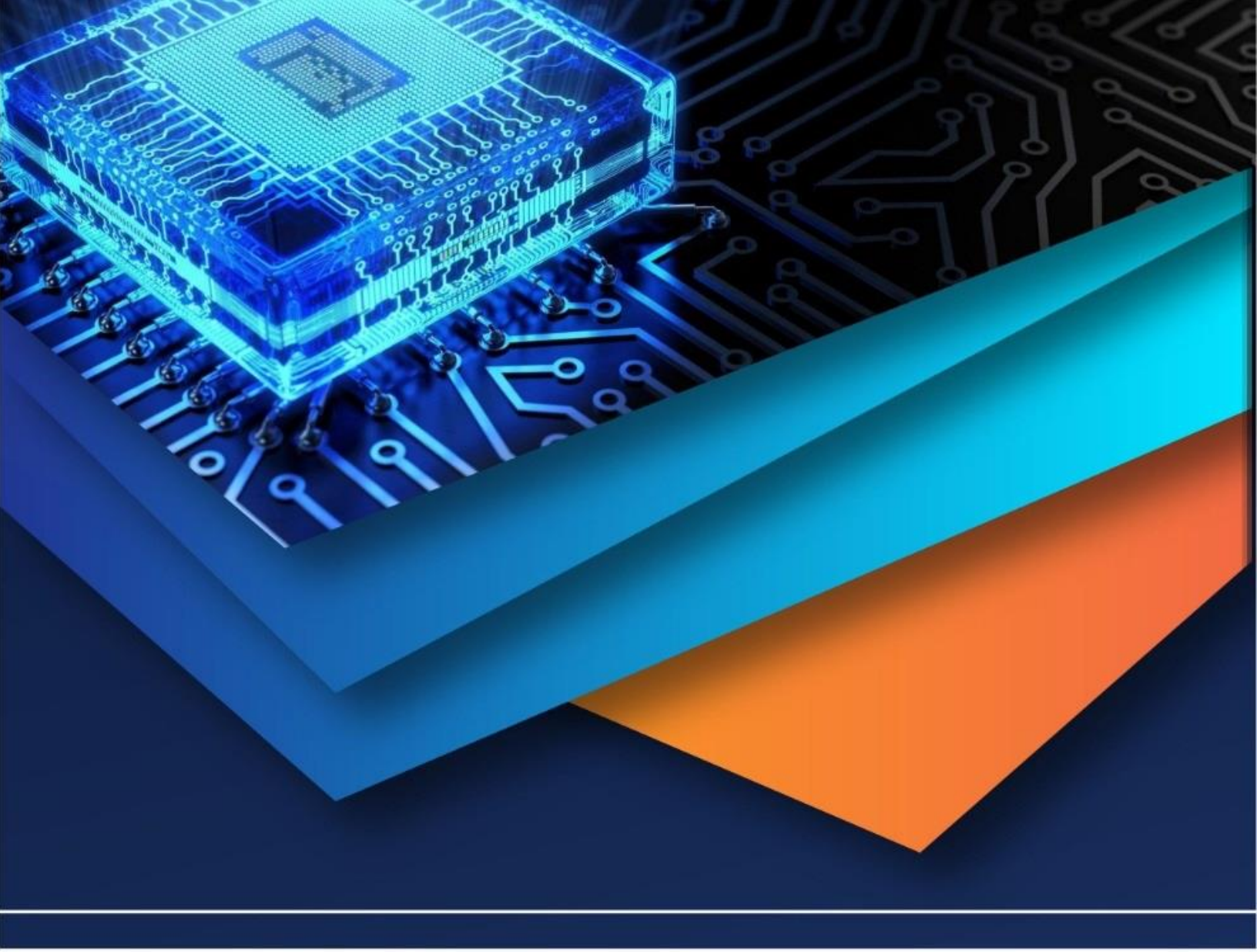

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