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A Survey of Indoor Localization Techniques

Sana
Department of Computer Science and Engineering Indian Institute of Technology Roorkee Roorkee - 247667, India

Abstract: Localization is the technique to determine the position of people or assets. The position information enables location-based protocols to navigate, to track or to monitor a person or an asset. Recently, indoor localization systems have been designed to provide location information of persons and devices in the indoor environment. The techniques used for location detection in the outdoor environment (like GPS) cannot be used in the indoor environment because there is no line-of sight communication possible and no sky-view in indoor environment. In big cities with plenty of high rise buildings GPS cannot work properly. The deployment of a system for obtaining location information in the indoor environment is a challenging task because of a large number of obstacles and interference of different frequencies. In this paper we studied the existing approaches and classify them based on the enabling technology. We further compared the existing approaches based on some parameters (like cost, accuracy) and compiled the result in tabular format.
Keywords*— GPS, Indoor Localization, Indoor Positioning System,Wireless Sensor Network.*

I. INTRODUCTION

Localization is the technique to determine the position of an object or a person [1]. Indoor localization system is a system that attempts to find the accurate position of the object inside a building, mall, etc. The popularity of mobile computing [2-6] stimulates extensive research on the localization of persons or assets. In present era of mobile devices, location information is crucial in a wide range of applications such as manufacturing, healthcare etc. In order to meet the user's needs, the location information of persons or assets are required which can be provided by indoor localization system. The localization systems try to identify the position of moving devices with the help of some fixed nodes and some mobile computing devices.

The position information can be used for navigating [7, 8], tracking [9], monitoring [10], etc. We cannot use same localization methods for identifying location in both indoor and outdoor environment because 1) indoor environments are more complex, 2) there is signal interference and reflection inside building 3) it is highly dependent on the environment such as position of objects, behavior of person, 4) indoor communication link is unreliable [11]. Many location based protocols and services are proposed by authors for outdoor and indoor environment. The design and deployment of a system for obtaining location and spatial information in an indoor environment is a challenging task for several reasons like user privacy, management overheads, system scalability and harsh nature of indoor wireless channel (i.e. metal reflection, interference with noise) [8, 12].

For outdoor environment, we can use fixed sensors or GPS based sensors [13, 14]. GPS is the most widely used satellite based positioning system, which offers maximum coverage [15]. GPS cannot be deployed inside buildings, because 1) It requires line-of-sight transmission between receivers and satellites which is not possible in indoor environment, 2) It requires clear sky-view for proper working, 3) Cost of GPS device is high for indoor environment; 4) GPS signals are not available in confined environment or high rise buildings.

Many options [9, 16] are available for the design of positioning system in indoor environment such as infrared, ultrasound, radio-frequency identification (RFID), sensor networks, audible sound, light, color of walls, etc. Depending on the priority of the user, different positioning systems are developed. Some of the centralized schemes include the use of self-organizing maps (SOM) [17] to concurrently estimate node locations given hop counts over entire network. There are some hybrid approaches which combine advantages of two or more different techniques.

All of the existing surveys concentrate on either of the one technology. The majority of the existing surveys of localization approaches are based on the wireless sensor networks [18-20]. In [1], a survey of indoor positioning systems (IPS) for wireless personal area networks is given. The existing commercial and research-oriented IPSs are compared from the view point of user. In [21], performance based evaluation is given for RFID based localization techniques.

An attempt has been made to present a survey on the localization techniques based on different enabling technologies such as radio frequency, ultrasound frequency, wireless sensor nodes, and smart phone. A classification has been done on the basis of these enabling technologies. We further compared the existing approaches based on certain parameters such as cost, accuracy, robustness, efficiency, etc. and represent the results in tabular format.

The rest of the paper is organized as follows. Section II tells the need of localization system and gives the overview of localization problem. Section III classifies the existing localization techniques based on different taxonomies. In section IV a detailed study of enabling technologies is given. Section V provides a comparison of indoor localization techniques based on certain parameters. Finally, section VI concludes the paper.

II. INDOOR LOCALIZATION SYSTEM AND ITS NEED

Indoor Localization System (ILS) can be defined as "A system that continuously and in real-time can determine the position of something or someone in the indoor environment". Most of the ILSs work in two steps. First, "Where the person is" and second, "how to reach to the target person". An ILS can provide three types of location information for location-based applications.

First, the absolute location information specifies the exact location of the person. For this, map of the locating area should be available and saved in the ILS. It requires large computation overheads because we have to give the exact coordinates of the person. It is very helpful when there are a large number of people in a big room and you have to identify an unknown person.

Second, the relative position information measures the motion of different parts of a target and provides the location related to some fixed part. For example, an ILS which tracks whether the door of car is open or closed. For this, some normal or fixed positions are already stored in ILS and changes are noticed related to the fixed position information. It is helpful in tracking a particular object.

Third, the proximity location information specifies relatively big area where the target is. For example, when the target is inside a particular room in a very large building, proximity location information will be used. It works efficiently if there are less number of people in the environment, but, in case of noisy environment, it may track the wrong person.

The problem of localization technique is to determine the location information of all or a subset of sensor nodes, given the measurements of pair wise spatial relationships between the nodes [20]. The problem overview is given in Figure 1.

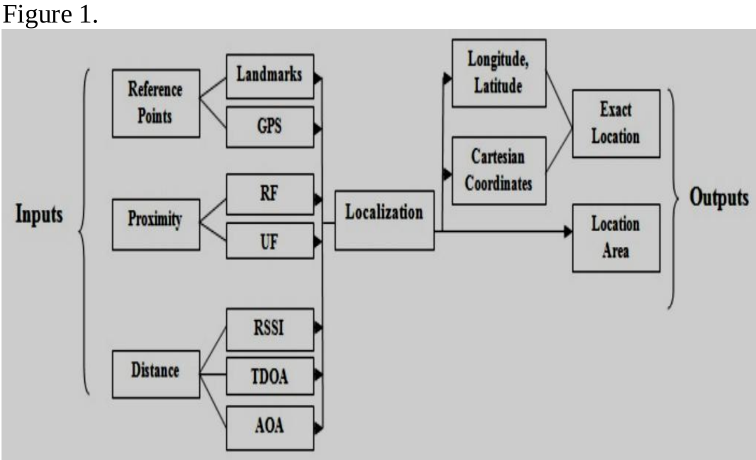

Figure 1: Localization Problem Overview [20]

The inputs to the localization system is some reference points (like popular landmarks or GPS data), some distance measurements based on received radio signal strength, angle of arrival of signal or some proximity values using Radio frequency, Ultrasound frequency. Based on these inputs, localization system either tells the exact location (using Cartesian coordinates on map or some longitude, latitude values) or some location region (e.g. building, conference room) of the unknown node.

Location information is crucial in a wide range of applications such as transportation, smart homes, healthcare etc. In order to meet the user's needs and offer adaptive and convenient personal services, the location information of persons or assets are required which can be provided by indoor localization or positioning system. With the help of localization systems we can easily locate the unknown person in crowded environment. We can easily reach to our destination by proper guidance using sensor nodes and mobile phone. In [1] the need of positioning system in different scenarios are explained. We need indoor localization systems everywhere because we spent most of our time in the indoor environment. Some of the applications are discussed below.

In a smart fitness center, when a person enters the fitness room, his mobile estimates his location and accordingly displays all available fitness equipments. When he uses any equipment his mobile will offer a personal training guide. In an intelligent home, when a person enters in the room then temperature sensors, light sensors, RFID sensor sense the physical environment and accordingly switch on AC or move the curtains. It will automatically start giving the direction to some new person about the food, television etc. The indoor localization systems can be used in parking for locating the appropriate empty place. One of the sensor nodes acts as a guide and gives the proper direction to the driver. It can be used for building smart healthcare centers for better coordination between doctors and patients. It helps in providing better first-aid to the patients. Indoor localization systems can be used in school campus, museum, asset tracking in warehouse, malls etc.

III. CLASSIFICATION OF EXISTING LOCALIZATION SYSTEMS

Localization systems can be classified in several ways based on different taxonomies as shown in Figure 2. The most commonly used division is based on the area in which localization system needs to be deployed i.e. whether in indoor or outdoor environment. Although, we can use the same system for indoor and outdoor but there are some drawbacks of using them in the same environment. For example, infrared has short range to be used for outdoors. The system cannot work with the same efficiency in both environments.

Another division is based on the distance measurement technique i.e. absolute or relative. Absolute systems identify the exact location while relative systems identify the location of node with respect to other nodes. Absolute systems are more expensive than relative systems. A range based systems use absolute distance measurements like the time difference of arrival (TDoA) which is the time required by signal to propagate from sender to receiver, received radio signal strength (RSS) which is the power level received by the sensor, angle of arrival (AoA) which is the angle at which signal arrives at receiver. A range free system use techniques that give the relative locations of the objects.

There are two types of range free localization systems, either using high density local seeds or number of hop counts using flooding. In these systems location of assets is determined using sensor nodes which are very close to the asset (i.e. within the small range) or by sending a large number of packets on the network and then distance is calculated based on number of hop counts.

Another division is based on the system architecture i.e. tightly coupled or loosely coupled. In the tightly coupled systems nodes transmit the data to fixed central server through wired or wireless connection. The whole computation of location process is performed on that server. In the loosely coupled system nodes communicate with each other in a decentralized way. There is no central server. Each node determines its own location by communicating with other nodes.

A localization system can be secure or open [19]. In the open system attackers could easily spoof the location to various locations. Attackers can easily disrupt the localization scheme by creating wormhole or passing fake messages across the network. The secure systems are resilient to these attacks. Secure system uses encryption techniques for exchanging credential information. Moreover, in the secure localization techniques only necessary information which user wants to exchange, is transferred. They require more resources than open systems.

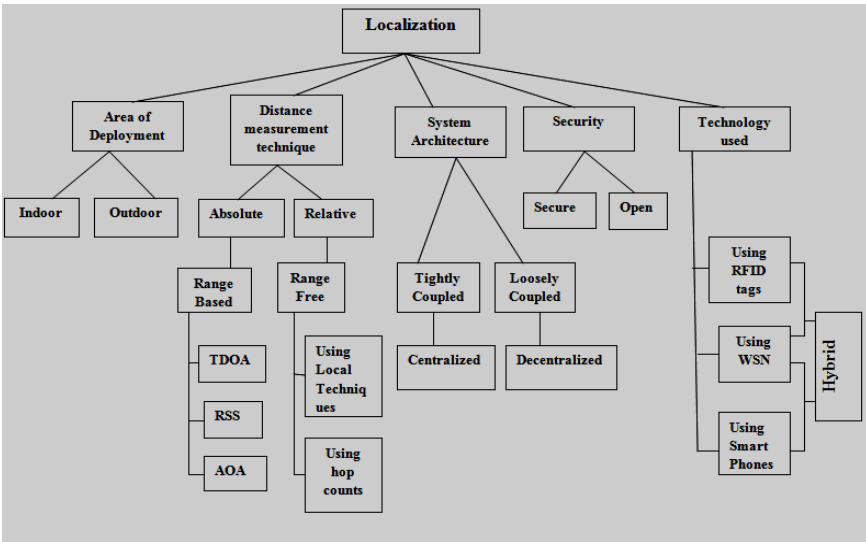

Figure 2: Classification of Localization [1, 19]

The localization systems can be classified based on the technologies which they are using for identifying the position i.e. using RFID tags, wireless sensor nodes, smart phones etc. There are also some hybrid systems which give the benefits of two separate technologies, for example, if sensor nodes and smart phones are used in combination we can track the person more efficiently.

IV. ENABLING TECHNOLOGIES

In this section a detailed study of some of the enabling technologies has been made. Using this study a classification has been prepared which helps in better understanding the various indoor localization techniques. These technologies do not require sky-view for identifying the position. That's why they work efficiently in indoor environment.

a. Radio Frequency (RF)

Radio frequency is an important technology which is used in RFID based localization. The main benefit of radio waves is that waves can travel through walls, thus localization systems has a larger coverage area and require less hardware. It enables flexible and cheap identification of objects. In the localization system using RF technique, moving nodes exchange the radio signal with the fixed nodes and then based on the received signal strength the position of the person or object is determined. The fixed nodes are considered as the reference points. The position is estimated using triangulation or proximity distance measurement methods. A detailed study of RFID based localization techniques will be done in the next section.

b. Ultrasound Frequency (UF)

Like radio signals, ultrasound signals are also very helpful in position estimation. The idea of using ultrasound signals in navigation is inspired from the bats (they use ultrasound signals for finding obstacles at the night). Usually, UF signals are used in combination with RF signals for better performance. The use of RF and UF in combination increases the system coverage area. The ultrasound localization systems are not very costly. But the problem with these kinds of systems is that they are affected by other ultrasound signals and noise sources which affect its overall efficiency.

c. Wireless Sensor Nodes

Sensors are devices which respond on the changing environmental conditions like temperature, light, pressure, object's movement etc. Sensor nodes also use RF and UF technologies described above for the localization. The localization approaches based on sensor nodes can be categorized as fine-grained and coarse-grained localization techniques [22]. The fine- grained localization techniques give the exact position of the unknown nodes. The time difference of arrival (TDoA), received radio signal strength (RSS), angle of arrival (AoA) are the approaches used in fine-grained localization. The coarse-grained localization techniques give the proximate value of the node position or comparatively large region where node may be located. Proximity, centroid, approximate point in triangle (APIT) are the approaches used in coarse-grained localization.

In this type of localization technique, a large number of sensor nodes are deployed at predefined fixed positions. The position of person or asset is estimated by taking measurements from these fixed sensors. The sensor nodes are very small in size and are not very costly. The positioning system based on sensor nodes is cost effective. However, there are some drawbacks of using sensor nodes such as, less accuracy, limited battery power, and limited processing capability.

d. Smart Phones

The use of smart phones in identifying the position of the person is an emerging research area. There are so many built-in functionalities in smart device which help in localization. The internal sensors present in the smart phones like accelerometer, compass, and gyroscope estimates the person motion and position. Built-in camera and microphones are also used to guide the people to reach to the appropriate position. For example, a person enters in the mall. The camera automatically takes the picture of the surrounding and then based on the ambience of the surrounding it guides the person about the best thing present in the mall.

V. COMPARISON OF TECHNOLOGY BASED INDOOR LOCALIZATION TECHNIQUES

In this section, some of the existing indoor localization techniques based on technologies has been explored in detail. The existing techniques are compared based on certain parameters like cost, security, robustness, complexity, accuracy, centralized or not, etc. The comparison results of 16 existing techniques based on the above parameters are shown in Table I.

a. Localization using RFID tags

RFID technology is used in supply chain management for scanning the items while earlier the barcode technology was used [18]. RFID tags used radio signals for exchanging information. RFID technology is applicable in the indoor environment because of its non-line-of sight characteristics and its wide use in the industries. In some of the earlier research RFID tags with Wi-Fi are used to identify the exact location of asset. RFID tags can be passive or active [21] based on the power supply to operate them. Passive tags need to be activated by the electromagnetic energy the reader emits, while active tags rely on internal batteries. Active tags consume more power than passive tags.

In this type of localization technique, different RFID tagged sensor nodes are present in the environment and when any user comes in the range of tags then the distance between reference positions are measured using triangulation or proximity methods. Taking fixed tagged nodes as reference points target can be located easily. Some of the existing approaches are RADAR [23], AIT [24], GPS-less indoor sensing [25], and Bluebot [26].

b. Localization using Wireless Sensor Networks (WSN)

Localization schemes using wireless sensor networks use small number of seed nodes (nodes that know their own location), and protocols. Together they help other nodes to estimate their location. The new nodes exchange messages with the seed nodes and then estimate their position with respect to seed nodes. The tracking systems in WSNs can be active or passive [27].

TABLE I. SUMMARY AND COMPARISON OF EXISTING INDOOR LOCALIZATION TECHNIQUES

Technique	Security and Privacy	Cost	Support Network Heterogeneity	Centralized	Complexity	Accuracy	Robustness	Limitations
Cricket Location Support System [43, 44]	Yes	Low	Yes	No	Low	59% more accurate than passive mobile system.	Good (Only LSQ module is affected by noise).	1. RF interference. 2. Multipath reflection with devices.
RADAR [23]	No	Low	No	Yes	High	Accuracy increases with time.	Position measurements are not reliable.	1. Centralized RF signal database. 2. Only works with one network.
Localization using SOM [17]	No	Low	Yes	Yes	Low	Error is reduced by 75%.	Work efficiently in resource constrained network.	1. Centralized approach. 2. Each sensor node communicates with only fixed set of neighbors.
Bluebot [26]	No	Low	Yes	Yes	Low	Estimate position to within 1.5m range.	Good (Updates new position based on previous position).	1. Large amount of time is required for large number of samples. 2. Signal strength is easily affected by surroundings.
AIT [24]	No	Low	No	Yes	Medium	86% accurate in area decision.	Depends on intermediate routers.	When number of mobile entities becomes larger there is serious packet loss.
Surround-Sense [35]	Yes	High	No need of sensor nodes	Yes	High	Average accuracy is 87%.	Reliable if ambience of all places is unique.	1. More energy consumption. 2. Only works in business location. 3. Requires some time for convergence.
Escort [40]	No	Medium	Yes	Yes	Medium	On an average user is brought within 8m.	Efficiency depends on the internet connection.	1. Not energy efficient. 2. May give directions to turn through obstacles. 3. Sometimes provide long routing paths.
Dynamic Localization for transport logistics [31]	No	Low	No	Yes	Low	Maximum localization error is 0.8m.	Reliability depends on the centralized sensor node.	A large database with RSS fingerprints is required.
SMART [42]	No	Low	No	Yes	High	89% on an average.	Robust against sensing errors.	1. More energy consumption. 2. Communication is very expensive. 3. Less secure.
iLight [30]	Yes	High	No	Yes	Low	Accuracy in height estimation with in 2cm.	Reliable if one or two sensor nodes fail.	1. Increasing sensor nodes for better performance also increases the cost. 2. Multiple light sources can affect the reading of the sensors.

Technique	Security and Privacy	Cost	Support Network Heterogeneity	Centralized	Complexity	Accuracy	Robustness	Limitations
Robust indoor localization [41]	No	Low	Yes	Yes	Low	Order of 5m.	Highly Robust	1. Magnetic interference in the in-door environment. 2. Performance depends on RSSI database.
GPS-less indoor location sensing [25]	No	Low	No	Yes	Low	1.3m in detecting co-ordinate with 0.17 error rate.	Reliability depends on predefined fingerprint.	1. A large storage requirement. 2.k-nearest classification is used for zone detection so, value of k should be chosen wisely
Fall alarm [33]	Yes	Low	No	Yes	Low	98.4% fall recognition accuracy.	If message sending system fails then whole system fails.	1. Only works in known senor areas. 2. Offline training required.
Online localization for visually challenged people [39]	Yes	Low	No need of sensor nodes	No	Low	With an average of 1.5-2.75m distance range.	Highly dependent on user's behavior.	1. Highly dependent on user's behavior. 2. Compass sensors perform poorly due to electromagnetic noise.
Zee [37]	Yes	High	Yes	No	Low	80% errors are within 2.3m range.	Zero effort on the part of user.	Multiple paths may lead to same location (i.e not always unique path).
LiFS [38]	Yes	Low	Yes	Yes	Low	Room error rate is 10.91% with localization error of 9m.	Reliability depends on the fingerprint database.	Not feasible in every environment.

In active system, user carries some device with him, which helps sensor nodes to determine its location. Passive system uses some other methods (e.g. height of the person as a parameter) to detect the presence and exact location of the person. The main assumption of this localization method is that a sensor node is able to detect the existence of any moving object faults in its sensing range [28]. One approach uses sequential Monte Carlo method [22, 29] for range free localization in sensor network. Their results show that mobility improves the accuracy and reduce the costs of localization. Some of the existing approaches are iLight [30], spatial dynamic RSSI-filtering [31], and localization using SOM [17].

c. Localization using Smart Phones

In the present era of technology, most of the people carry smart phones. There are so many built-in functionalities of smart phones, which are used in localization systems to detect the exact location of person. The internal sensors present in the smart phones like accelerometer, compass, and gyroscope are used for tracking persons in the indoor environment. Built-in camera and microphones are also used with above mentioned facilities for constructing identifiable fingerprints.

The dynamic activities of a person (i.e. static or moving) can be observed using accelerometer. Gyroscope can be used for measuring their received radio signal strength (RSS) from different access points and magnetic compass for their directions. Ambient sound, light and color of the wall also help in determining the location [32]. By combining all these, exact location of the user can be determined efficiently.

This approach is used in FallAlarm system [33] for detecting the fall of person and to provide first aid as fast as possible. A prototype urban monitoring system [34] has been developed which uses mobile phones for localization. But the problem with most of these techniques is that persons have to carry phones in particular position and a little deviation from that may give the wrong location information. Some of the existing smart phone based approaches are FallAlarm system [33], SurroundSense [35], coarse indoor localization [36], Zee [37], LiFS [38], online localization for visually challenged people [39], and Escort [40].

d. Hybrid Approach for Localization

In hybrid approach for localization, the benefits of existing approaches are combined to develop a new improved system for localization in indoor environment. Techniques are proposed to maximize the benefits, and minimize the drawbacks of existing individual approaches. Various works have been done and new approaches have been proposed by combining smart phones with Wi-Fi or sensor nodes, sensor nodes with RF; UF; and light, and color effect with smart phones etc. For example, in smart parking application sensor nodes with RFID tags are used to direct people to suitable parking slots depending on the vehicle size. Some of the existing hybrid approaches are robust indoor localization on commercial smart phone [41], SMART [42], and Cricket location support system [43, 44].

VI. CONCLUSIONS

In the next generation of the communication networks, most of the applications will require various types of context information of the environment, persons and devices to offer flexible services. Location is one of the context service required in the present era. Based on the measured location information, tracking, navigation, and monitoring services can be designed for the users. In this paper, we studied the concept of indoor localization systems and compared the existing techniques. We can see that each technique has certain limitations. Cost-benefits tradeoff is not achieved properly. In order to get high performance, cost increases and vice-versa. Instead of using single technology if we combine them then we can get better results as in the case of hybrid approaches. Combining these technologies will improve the quality of location services and will make the overall system efficient.

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