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A Rigorous Taxonomy Based Survey of Location Systems for Ubiquitous Computing

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Abstract

Emerging ubiquitous computing applications must know where things are physically located. To meet this must, many different location systems and technologies have been developed. In this work, we discuss the basic techniques used for location detection, describe taxonomy of location system features, present a survey of research and commercial location systems, and finally, compare these location systems using the identified features. It is our hope that this paper is a useful reference for a newcomer to the area of location detection for understanding and evaluating the many options in this domain.

Keywords: Location system, taxonomy, location detection technique, performance, deployment.

1. INTRODUCTION

Computing is needed any time in any place. This requirement poses a new field in the area of computing, namely ubiquitous computing. To continue the pace of ubiquitous computing, huge research is going on. Many research thrusts in ubiquitous computing have been posed. One of the major thrusts is location detection. In a ubiquitous computing environment, any service cannot be provided to users unless their locations are computed.

There exist many location systems in present. They implement one or a combination of these location detection techniques. None of the location systems is perfect rather they are relative. Their deployment varies with respect to applications. This paper describes different location detection techniques, location systems with a rigorous taxonomy and some location detection models based on signal strength which can help researchers work on new location detection techniques. Researchers and developers can find it useful for choosing the best one among various alternatives of location detection techniques while working on location systems.

2. LITERATURE REVIEW

A small number of attempts have been made for survey of location systems [1-4]. Most of them have concentrated on information collection, where few of them have concentrated on taxonomy and information organization. Roussos [1], Hightower and Borriello [2] have used modest taxonomy for the survey of location systems. Their surveys have been limited to indoor location systems only. Since these survey papers were published before 2002, quite a long time ago from now, much of the collected informations has currently been out-of-date. H. Liu et al. [3], Gu, Lo and Niemegeers [4] have used a large taxonomy for the survey of location systems, but their taxonomy has not been rigorous enough. Moreover, all these informations have not been presented in well-organized way. Manesis and Avouris [5] have done a survey on location detection techniques rather than location systems.

3. LOCATION DETECTION TECHNIQUES

The system, which detects positions of objects within a definite space, is called a location detection system or a location system. There are mainly four types of location detection techniques. They are triangulation, scene analysis, proximity and stochastic. A location system can deploy them individually or in combination. Each technique has its own advantages and disadvantages. Figure 1 shows different location detection techniques.

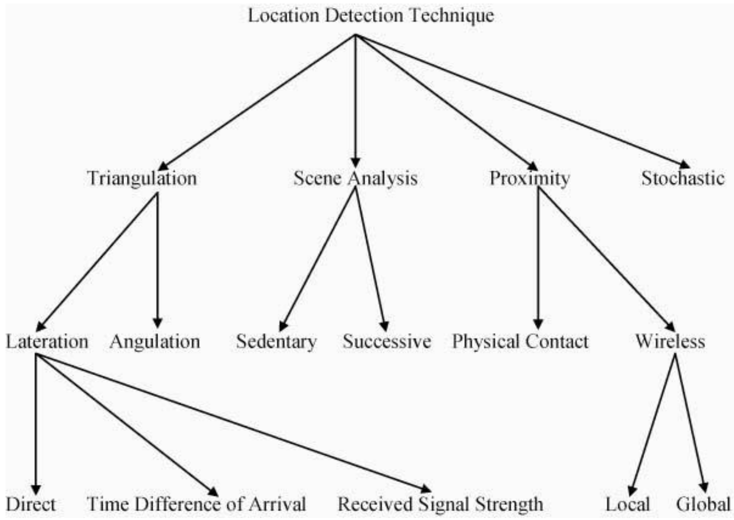

Figure 1: Location detection techniques

3.1. Triangulation

Triangulation is the most established and pure mathematical technique for detecting location. It uses the geometric properties of triangles to estimate location. In this method, measurement is made from multiple reference points. Then location is computed using the measurements along with some additional measurements if they are required. There exist many location systems, which use triangulation method, e.g. GPS (Global Positioning System), Bat, VOR (VHF Omnidirectional Ranging), 3D-iD, E911, SpotON, Asset, and SafePoint [2], [6-12]. Triangulation is divided into two types. They are lateration, which uses distance measurements, and angulation, which uses angle measurement.

3.1.1. Lateration

Lateration uses straight-line distance measurement from multiple reference points to calculate the position of an object. Objects' positions can be obtained either in two-dimensional space or in three-dimensional space. In two dimensions, computing an object's position requires distance measurements from 3 non-collinear reference points as shown in Figure 2a. Distance measurements from 4 non-collinear reference points are required in three dimensions as shown in Figure 2b. Actually, the logic behind the distance measurements requirements is that it needs $n+1$ point to find the coordinate of a point in n dimensions. Active Badge Location System uses only 3 reference points to compute the location of an object [6-8]. Lateration can again be divided into three divisions. They are direct, time-difference of arrival and received signal strength (RSS) [13].

3.1.1.1. Direct

Direct method is based on some events. An event can be a physical action or movement. This method is used in robotics. EDAR (Event Driven Assembler Robot) is a movable robot which uses direct method. The concept of direct method is easy to understand but the problem with this method is to implement it [14].

3.1.1.2. Time Difference of Arrival

Time difference of arrival method uses the time taken to reach a point (end point) from a point (start point) at a uniform velocity. If the points of time at which travel starts and ends are gotten, the distance between the points can be calculated by using the uniform velocity. The end point is always immobile. The start point can be mobile or immobile. GPS, Asset, SafePoint, Bat etc. are the notable location systems, which uses the technique of time difference of arrival [2, 4, 8, 15, 16].

3.1.1.3. Received Signal Strength (RSS)

The strength of a transmitted signal diminishes as the signal goes apart from its source. This decrement in signal strength is called attenuation. In the RSS technique, the attenuation is taken into account. Many kinds of signals namely, Radio Frequency (RF), ultrasound and infrared, can be used in the RSS technique. RSS is applied by many location systems, namely, 3D-iD, E911, SpotON [1], [9-11].

3.1.2. Angulation

Angulation is the triangulation location detection technique, which uses angular distance measurement from a reference vector (***R***) to calculate the position of an object. Objects' positions can be obtained either in two-dimensional space or in three-dimensional space. In two dimensions, computing an object's position requires two angular-distance measurements (θ_1, θ_2) and one straight-line-distance measurement (*K*) as shown in Figure 2. Along with these measurements, one azimuth measurement is required in three dimensions to calculate an object's position. VOR is a remarkable location system, which uses angulation technique [1, 2, 7].

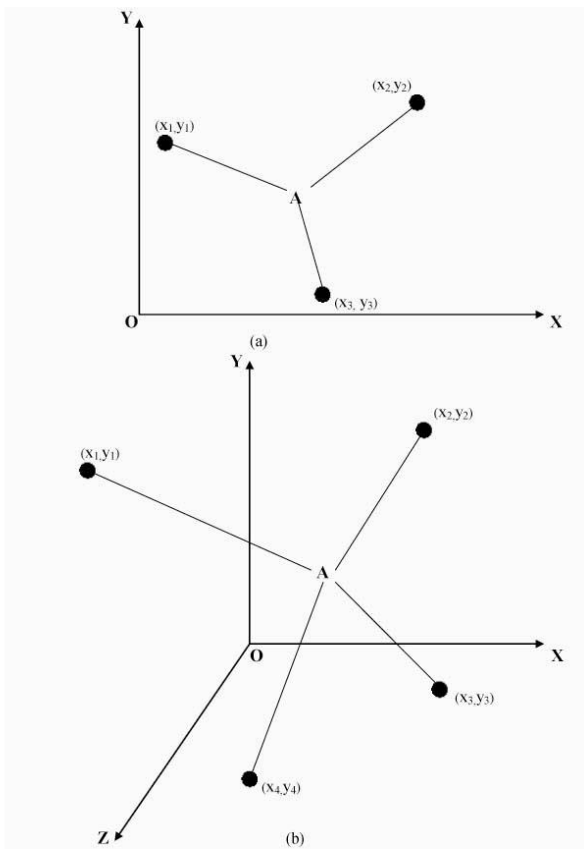

Figure 2: Determining the position of object "A" in a) 2 dimensions and (b) 3 dimensions.

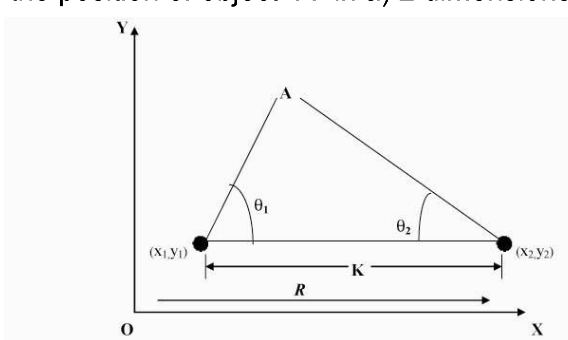

Figure 3: Determining the position of object "A" in 2 dimensions.

3.2. Scene Analysis

The scene analysis location detection technique uses a scene from a specific vantage point, called view point, along with an acceptable representation of a space under observation, to identify features of the scene so that inferences about the location of the observer or of objects within the space can be made. Image processing techniques are applied, along with the deployment of geometric representation of the space, obtained through vision systems. Thus, performance and accuracy are improved [1, 2]. There are two types of scene analysis. They are sedentary and successive. In sedentary scene analysis, a dataset is build for various locations in a space which is used to look up observed features in order to map them to the location of an object. In successive scene analysis, the deviations between consecutive scenes are traced to calculate location. MotionStar Wireless 2 and MSR RADAR are the location systems which use scene analysis [1, 2].

3.3. Proximity

Proximity involves in determining the location of an object close to a known reference point. A limited range of physical phenomenon is used to detect the presence of an object [1, 2, 13]. Proximity location detection technique entails two types of fashion for detecting proximity. In the first fashion, physical contact is the determining factor for proximity. In the second fashion, proximity is determined wirelessly. This fashion has two approaches. In the first approach, a space is covered by the power of the wireless access mode and the proximity of an object to the reference point is detected as containment within the space. The second approach comes into play when the information of proximity is disseminated by the reader at regular intervals. Then devices get location aware services using this information. Active Badge, Avalanche Transceivers, Automatic ID Systems, Wireless Andrew use the proximity location detection technique [1, 2].

3.4. Stochastic

Stochastic uses statistical concepts (e. g., probability theory, probability distribution, central tendency and dispersion) to detect the location of an object. In this technique, the space is divided into subspaces. Each of the subspaces has at least one point, called training point, at which the signal strength is measured from some certain points of reference. Thus, a database of signal strength information is constructed. The signal strength at an object's position from some certain points of reference is used as test data for the database constructed to infer the position of the objects. Ekahau and NIST are instances of the location detection system, which uses stochastic location detection technique [1, 17, 18].

4. TAXONOMY OF LOCATION SYSTEMS

Taxonomy of location systems can be established by characterizing features of location systems. By comparing different features of location systems, one can set priority of a location system over another. This section identifies and discusses different features of location system. Along with these, examples of location systems, which apply the techniques, are given.

4.1. Information Provided

The information provided by a location system can be divided into two types. They are physical and contextual position. Physical position is a certain point or space in a physical coordinate system. GPS, Bat, MotionStar Wireless 2, VOR, MSR RADAR etc. provide physical position information. On the other hand, contextual position is a position relative to a certain context. Active Badge, Wireless Andrew, RFID etc. provide contextual position information. It is possible for many applications to transform physical position to contextual position and vice versa [1, 2], [6-8], [19].

4.2. Frame of Reference

Physical position or contextual position – whatever information provided by a location system is considered with respect to one or more frame of reference. If all located objects' information is provided with respect to the same frame of reference, the location system is absolute. GPS, Bat, MotionStar, VOR, MSR RADAR, Active Badges, Wireless Andrew etc. are absolute location systems. On the other hand, a relative location system can provide an object's location information with respect to the object's own frame of reference. Cricket, Automatic ID System etc. is relative location systems [1, 2], [6-8], [19].

4.3. Calculation Responsibility

Using available information, location calculation can be done in three ways. Firstly, location calculation is done locally, i.e. is done by the object using available information. In this approach, an object's location remains unknown to all other object. Thus, the privacy of the object is ensured. GPS, VOR and Cricket follow this approach. Secondly, location calculation is done centrally, i.e. an infrastructure calculates the location of an object using the information sent out by the object. In this case, location information of a certain object is maintained by the infrastructure. As a result, the privacy of an object is not secured enough. Bat, MotionStar, MSR RADAR, Active Badges and Wireless Andrew follow this approach. Thirdly, a hybrid approach is formed combining the previous two approaches i. e., location calculation is collaboratively performed by the device and the infrastructure in order to achieve better performance. Assisted Global Positioning System (AGPS) is a location system that follows this approach [1, 2], [6-8], [19].

4.4. Recognition

A location system may have provision of recognizing located objects. Recognition is performed through some attribute (color, shape etc.) checking. Location system cannot differentiate objects other than the attributes. Bat, MotionStar Wireless 2, MSR RADAR, Active Badge, E911, SpotON, PinPoint 3D-iD, Wireless Andrew etc. is the location systems with recognition capability [2, 8, 9].

4.5. Accuracy and Precision

Accuracy and precision are the measure of effectiveness of a location system. The minimum distance at which a location system can distinguish two positions, is called the accuracy of the location system. The less the minimum distance, the more accurate the system is. Precision is how often it can be anticipated to achieve the stated accuracy, that is, the number of times, that the stated accuracy is achieved, is called the precision of the location system. Precision is expressed in terms of percentage. The more the number of times, the more precise the system is. In order to compare two location systems, both accuracy and precision have to be considered concurrently. GPS's accuracy is 1-5 meters in 95-99% of time [2, 6].

4.6. Scale

A location system has definiteness in its purview and the number of locatable objects. There must be a definite space within which a location system can locate objects. Likewise, there must be a definite number up to which objects can be located by a location system. This definiteness is the scale of a location system. In this regard, scale can be divided into two components. The first component is the coverage area per unit of infrastructure in which a location system can locate objects. The second component is the number of objects a location system can locate per unit of infrastructure. The scale of GPS is any number of objects throughout the world by 27 satellites including 3 redundant ones [1, 2, 6].

4.7. Update Rate

Update rate of a location system is the number of times that a position of an object is calculated per unit time. The more the response time, the better the location system is. GPS Receivers have at least an update rate of 1-20Hz. The update rate of VOR is 30Hz [13, 19].

4.8. Availability

The availability of a location system is the degree of usability and deployment of the system. It is related to precision, update rate, and the geometric shape and physical characteristics of a specific environment. If a location system is precise enough, its update rate is high, and the geometric shape and physical characteristics of a specific environment is favorable enough to locate an object anywhere within the coverage area, the system is said to be continuous in that specific environment, otherwise it is called discontinuous in that specific environment. GPS, VOR, Bat, MotionStar, Wireless 2, 3D-iD are examples of continuous location systems and Active Badge, SpotON, and Cooltown are examples of discontinuous location systems [2, 8, 19].

4.9. Cost

Cost is an important feature of location systems which determines the suitability of a location system for a particular application. Cost of a location system can be estimated from many points of view. An important one is time cost, which is comprised of the duration of installation process and the administration needs of the system. Another important estimation is space cost, which includes degree of infrastructure, hardware and form factor. For example, VOR costs a lot for infrastructure and less for aircraft receivers. Bat costs high for administration, medium for sensors and a bit for tags [2, 7, 8, 19].

4.10. Limitations

Limitations are an important issue for location systems. A system may not work in certain situation or in certain environment. These limitations should be taken into account while choosing a location system for a particular application. In general, a location system's limitations can be detected by taking the traits of the technologies, followed by the system, into account [1, 2, 20].

5. A SURVEY OF LOCATION SYSTEMS

In the previous two sections, different location detection techniques and features of location systems are discussed. This section describes some location systems with respect to these techniques and features.

5.1. Global Positioning System (GPS)

The Global Positioning System (GPS), founded by the US Department of Defense (DoD), is a worldwide navigation system. A group of satellites and their ground stations form the system. GPS provides satellite signals which are specially coded. A GPS receiver processes the signals in order to calculate position, velocity and time. GPS is split into three segments. They are the space segment, the control segment and the user equipment segment. The Space Segment of the system comprises of the GPS satellites. The GPS Control Segment comprises of a system of monitoring stations. It contains five monitoring stations and four dedicated ground antennas with uplink capabilities. The GPS User Segment comprises of persons or organizations and GPS receivers. A GPS receiver converts the satellite signals into information of position, velocity, and time. By receiving at least four satellite signals, mobile or immobile users computes their three-dimensional position, their three-dimensional velocities, and time, using the method of triangulation [6, 19, 20].

5.2. VHF Omnidirectional Range (VOR)

The VHF Omnidirectional Range (VOR) is a navigation system for aircraft. It was developed from Visual-Aural Range (VAR) system by Amalgamated Wireless Australasia Limited (AWA) in the 1960s. It helps landing, terminal, and en route guidance. It is also useful for weather broadcast, special instructions of flight, and identification of voice and code station. The VOR system provides information of the direction. The pilot flies in relation to the VOR station and magnetic north [7, 17]. The VOR stations broadcast VHF (very high frequency) radio signals. They are assigned radio channels ranging from 108.0 MHz to 117.95 MHz with 50-KHz channel width. The carrier signal is omnidirectional and frequency modulated. It carries station Morse code or voice identifier. The accuracy of the VOR is good, but VOR transmitters cost a lot.

5.3. Active Badge

The Active Badge location system was developed from 1989 to 1992 at AT&T Laboratories. It is an indoor location system, which locates an individual within a building at any given time. It sends a unique pulse IR signal every 10 seconds. The building contains many networked sensors. The signals, sent by the Badges, are received by the sensors. The IR signals can not move through walls. So, the sensors have to be set in every room of the building. The network contains a master station to compute the location of the Badge, i.e., the individual who carries it, using the information supplied by the sensors. It is an absolute location system with acceptable accuracy [2, 21].

5.4. Bat

Although Active Badge was an inexpensive and accurate location system, it could not provide precise 3D location information. This led researchers at AT&T Laboratories to develop a new 3D location system named Bat. It is also an indoor location system, which locates an individual within a building at any given time. It is a small device carried by an individual, which deploys ultrasonic technology to send data. Each Bat features a unique identification code by which they are recognized [3, 8]. It has issues with network, e.g., specialized cabling. It needs many networked sensors above the ceilings of the rooms of the building and their exact and accurate placement. Cost of network is high but that of devices, e.g. Bats and sensors, is low for Bat system. The ease of deployment and maintainability are the main disadvantages of the Bat system [2, 8].

5.5. Enhanced 911 (E911)

In the United States (US), the caller is connected to a Public Safety Answering Point (PSAP) dispatcher when he dials 911, the official national emergency number. The PSAP dispatcher is taught to route the call to the desired destination. Thus, the 911 network plays a significant role in the US. So, the Federal Communications Commission (FCC) of US needs upgrades, made by the wireless phone providers, in this network in order to supply emergency service more effectively and efficiently. That is, FCC needs that the wireless phone providers make a technique so that any phone calling 911 can be located exactly and quickly. This initiative, taken by FCC in 1996, is called Enhanced 911 (E911). Though E911 is not a location system, many vendors are developing location systems due to E911 so that the location of a wireless phone can be detected exactly and quickly [2, 9]. E911 needs carriers in order to determine location information, which is far more accurate and precise. The accuracy and precision required by the FCC are 50-300 meters and 95%, respectively.

5.6. SpotON

SpotON was developed by Palo Alto Research Center (PARC), formerly Xerox PARC, and the Portolano research group at the University of Washington in the late 1990s. It is an indoor location system for small-scale environments such as offices with floor space less than $16m^2$. Received radio signal strength information (RRSSI) is employed by SpotON tags as a distance measurement so that ad-hoc lateration can be accomplished. Concepts of object location tracking and the theories of ad-hoc networking forms ad-hoc location sensing [10].

5.7. MotionStar Wireless 2

The MotionStar Wireless 2, a magnetic tracker, was developed by Ascension Technology Corporation in the early 2000s. It can capture the movements of maximum six performers. It performs very well in sessions of motion capture, which include complex movements like twisting, flipping and spinning. It is very fast and its accuracy is very good. Source code is also provided to develop the customer’s own software. MotionStar Wireless 2 can be used for 3D character animation for TV, movies and games, live performance animation, CAD simulation of human motions, virtual prototyping, sports & medical analysis, biomechanical analysis, human performance assessment, interactive game playing, and rehabilitative assessment/feedback. It costs high and needs precise installation [2, 22].

5.8. 3D-iD

The 3D-iD location system was developed by PinPoint Corporation (Massachusetts, USA) in the late 1990s. It is a location system that allows hospitals and other facilities to precisely monitor the movement and location of people and equipment. 3D-iD is an indoor location system, which locates an individual or equipment within a building at any given time. It is based on operating techniques originally employed by global positioning system (GPS), wireless local area networks (LANs) and radio frequency identification (RFID), and is targeted at applications requiring a high degree of tracking accuracy. The 3D-iD location system provides physical information of location. The accuracy of the 3D-iD is 1-3m, which is good, but it is costly to deploy and maintain 3D-iD system.

6. COMPARATIVE ANALYSIS OF LOCATION SYSTEMS

Three tables of comparison of location systems discussed above have been formed taking the features of location systems into account. Table 1 has been formed based on the theoretical concept. It depicts the theoretical aspects of the location systems. Table 2 has been formed based on performance. It describes how effective and efficient the location systems are. Finally, Table 3 has been formed based on deployment. It depicts the research, commercial and historical aspects of the location systems.

Table 1: Location system features regarding theory

Location System	Technique	Information Provided	Frame of Reference	Calculation Responsibility	Recognition
GPS	Radio Time-Difference of Arrival Lateration	Physical	Absolute	Local	×
VOR	Radio Angulation	Physical	Absolute	Local	×
Active Badge	Infrared Wireless Proximity	Contextual	Absolute	Central	√
Bat	Ultrasound Time Difference of Arrival Lateration	Physical	Absolute	Central	√
E911	Triangulation	Physical	Absolute	Central	√
SpotON	Ad hoc RF RSS Lateration	Physical	Relative	Central	√
MotionStar Wireless 2	Scene Analysis	Physical	Absolute	Central	√
3D-iD	RF RSS Lateration	Physical	Absolute	Central	√

Table 2: Location system features regarding performance

Location System	Accuracy	Precision	Update Rate	Availability	Scale
GPS	1-5m	95%	1-20Hz	√	Unlimited number of receivers all over the world by 24 satellites
VOR	1° radial	100%	30Hz	√	Unlimited number of aircrafts per VOR station and several VOR stations per metropolitan area
Active Badge	Room size	100%	0.1Hz	×	Room in which at least one sensor required for an object to detect
Bat	3cm	95%	15Hz	√	Room in which al least three sensor required for an object to detect
E911	50-300m	95%	N/A	√	One base station per cell
SpotON	Cluster-size dependant	N/A	Random	×	At least two tags per cluster
MotionStar Wireless 2	1mm, 0.1°	100%	100Hz	√	120 sensors per scene and 20 sensors per performer
3D-iD	1-3m	N/A	N/A	√	Several base stations per building

Table 3: Location system features regarding deployment

Location System	Developing Organization	Time of Development	Commercialism	Purview	Cost	Limitation
GPS	U.S. Department of Defense (DoD)	1978 – 1994	√	Outdoor	Medium	Constraints on time difference of arrival method and accuracy degradation by DoD
VOR	Amalgamated Wireless Australasia Limited (AWA)	1960s	√	Outdoor	High	Reliant on line of sight which is a maximum of 25– 130 nautical miles (46–240 Km)
Active Badge	AT&T Laboratories	1989 - 1992	×	Indoor	Medium	Requirement for IR confining volume in the building
Bat	AT&T Laboratories	N/A	×	Indoor	High	Ease of deployment and maintainability
E911	Federal Communications Commission (FCC)	1996	√	Outdoor	High	Necessity of dense cellular infrastructure and coverage of network
SpotON	Dept. of CSE of University of Washington	1999 – 2000	×	Indoor	Low	Environmental threat, e.g. reflection, to accuracy
MotionStar Wireless 2	Ascension Technology Corporation	N/A	√	Indoor	High	Metal and noise interference change performance adversely
3D-iD	PinPoint Corporation	Late 1990s	√	Indoor	High	Proprietary interference

CONCLUSION

Ubiquitous computing is considered as the next generation of mobile system. It is going to have profound effect on technology and society in the twenty-first century. In this regard, location detection is of huge importance. We have discussed the basic location detection techniques, and then identified the features of location systems in order to build a basis on which to compare different location systems. We then have surveyed research and commercial location systems. Finally, we have compared these location systems using the identified features of location systems [1]. Features of location systems, identified in this paper, are not the only ones. We have identified the major features, which are applicable to almost all systems. We hope that this paper will benefit every newcomer to the area of location detection.

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