A SURVEY ON 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 thesis, we discuss the basic techniques used for location detection, describe taxonomy of location system features, present a survey on 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.

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Chapter I: INTRODUCTION

Computing is needed any time in any place. This requirement poses a new field in the area of computing. This area is known as ubiquitous computing. Mark Weiser, in 1988 at Xerox Palo Alto Research Center (PARC), first introduced the concept of ubiquitous computing. Ubiquitous computing is also called pervasive computing. The attributes of pervasive computing include that of mobile computing, but goes much further, i.e., pervasive computing incorporates some additional features. The computer is made live with human in the physical world by pervasive computing. Instead of having computers, computation is embedded in the environment by pervasive computing. It is a complex integration of human, engineering, computing, and sociology [1, 2].

Pervasive computing is an evolving field of computer science and engineering. Its purview is expanding in the world. The worldwide penetration of the handheld mobile devices (PDA, smart phone, cell phone, etc.) through 2005 is more than 500 million. This is a substantial increase compared to 1999 while it was around 200 million! Table 1 shows these statistics in detail. To continue the pace of pervasive computing, huge research is going on. Many research thrusts in pervasive computing have been posed. One of the major thrusts is location detection. In fact, location detection is a primitive task in pervasive computing. In a pervasive computing environment, any service cannot be provided to users unless their locations are computed. Again, location detection is essential for recognizing intrusion [3, 4].

Table 1: Worldwide penetration of handheld devices through 2005.

Country/Continent	**1999**	**2005**	**% Increase**
Asia	125	310	148
Germany	22	62	181.82
UK	21	45	114.29
France	17	45	164.71
Netherlands	7	12	71.43
Belgium	3	7	133.33
Austria	3	6	100
US	1.7	24	1311.76
Total	199.7	511	2225.34

A pervasive computing environment is such an environment which has devices and users along with high computing and communication capability. It has to be dynamic. It expands automatically as its resources or capability increases like “plug and play”. The environment expands in terms of resources when new devices to the system that the system can use them whenever it needs. For example, if some CRTs are incorporated to a classroom, the system should automatically start using them. When devices are added, the environment not only expands in terms of resources but also in terms of capability. For example, if some microphones are incorporated to a hall room, the system’s resources not only increase but also the system’s physical coverage. A pervasive computing environment is embedded on a definite space which has to be smart. A space becomes smart when computing infrastructure is embedded in it, i.e., a smart space is a seamless integration of computation, and physical reality. Location is determined within the space. The infrastructure includes cost, devices, privacy, security, software components, deployment, and user interfaces. To convey the magic of pervasive computing to users, it is very important to detect the location of users or devices within the space. Other issues of pervasive computing, like security, privacy, service discovery etc., also depend on location sensing. There have emerged many applications on pervasive computing nowadays. In order to properly serve, the applications require knowing the current location of objects to take necessary actions. So, they are vastly using the favor of location detection. For example, let us assume a museum with the provision of pervasive computing. When a visitor come to a specific object, all the information of the object is displayed on the screen of his hand-held device. We may consider another example of a super market with provision of pervasive computing where an email is sent to a customer visiting the market. In both of the cases, the visitor or the customer will not get the facility of pervasive computing unless their location is detected. Thus location detection plays an important role in pervasive computing applications. One of the magical attributes of pervasive computing is invisibility or implicitness. The concept of invisibility or implicitness, expressed by Weiser, is full disappearance of pervasive computing technology from a user’s awareness. In a non-pervasive computing environment, people perform their explicit tasks on the computer—reading or sending e-mail, browsing web pages, editing documents, and so on. When the invisibility of pervasive computing technology comes into play, this obsolete explicitness will disappear. A plausible approximation in implementation to this invisibility is the minimal user distraction. If a pervasive computing environment fulfills users’ anticipations continuously and seldom surprises him, it will let him behave nearly at a subconscious level. People will do what they commonly do: use things, roam, see and talk to each other. It will be possible that the computation in the environment benefits these actions, and users will anticipate certain services, but they will be performing things at a subconscious level rather than a conscious level [3, 5, 6, and 7].

Many location detection techniques have been conceived. They are classified in different ways. Jeffrey Hightower and Gaetano Borriello have classified the location detection techniques in [11]. Again, a classification has been given in [14] by George Roussos. Location systems have been addressing the problem of automatic location detection for many years. 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. Some will fit one application where some will fit other. Again, how a location system's applicability is measured is a matter of question. Location systems have some features, e.g., technique, accuracy, precision, cost etc. By measuring these features, one location system is placed over another. Many researchers have tried to solve the problem of determining the location of a mobile device which is communicating through a wireless local area network (WLAN). All of them have designed a mathematical model and made one or more experiments on real infrastructures or tested with a simulator. Their deployment also varies with respect to applications.

This thesis describes different location detection techniques, location systems with taxonomy and some location detection models based on signal strength. Any newcomer in the world of pervasive computing can find this thesis handy to have an introduction to location detection techniques. He will be able to know about many old and new location systems and their technology. Moreover, he can be able to compare different location systems. This thesis 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.

The paper is structured as follows. Chapter 2 presents our assumptions and introduces terms used throughout the paper. Chapter 3 describes different location detection techniques. Next, Chapter 4 depicts taxonomy of location systems. Chapter 5 discusses different location systems and compares them. Then Chapter 6 presents three location detection models and compares them. Chapter 7 makes some improvement on one of the models. Finally, Chapter 8 concludes the paper and depicts future research.

Chapter II: BACKGROUND

Pervasive computing is a new idea. It comes into play when certain level of technological capability is achieved. Capability is required in terms of environment, infrastructure and space. So, the purview of this thesis should be presumed. Again, many terms will be used throughout this thesis. It will be handy for the readers if these terms are introduced in the beginning. This chapter discusses the assumptions and terms. Section 2.1 discusses the assumptions made for this thesis. Section 2.2 gives definitions of the terms used throughout the thesis.

2.1. Assumptions

The location detection techniques, location systems and location detection models depend on environment, infrastructure and space. The assumptions of this thesis on the pervasive computing are centered on an infrastructure consisting of devices, users, software components and user interfaces, cost, privacy, security, deployment. Software components are programming units that are dynamically comprised to build complete applications. User interfaces are logical entities that manipulate the interaction with the user and which may be distributed over multiple software components and devices. So, the environment is full of computing capability. The concern of this thesis in pervasive computing is location detection. Our discussion covers both indoor and outdoor location [8, 7].

2.2. Nomenclature

Location is determined as position over a definite space. A space may be an enclosed area such as a meeting room or a hall-room or corridor, or it may be an open area such as a stadium or a parade ground or a park. Generally, a place is a human-readable labeling of positions. A more rigorous definition is a set of both shared and personal labels for potentially overlapping geometric volumes. If an object is found in the volume, it is informed that the object is in that place [3, 9].

Chapter III: LOCATION DETECTION TECHNIQUES

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. For each of the techniques, this chapter describes the principles behind it, provide some implementation technologies and list the advantages and disadvantages. Along with these, examples of location systems which apply the techniques are given.

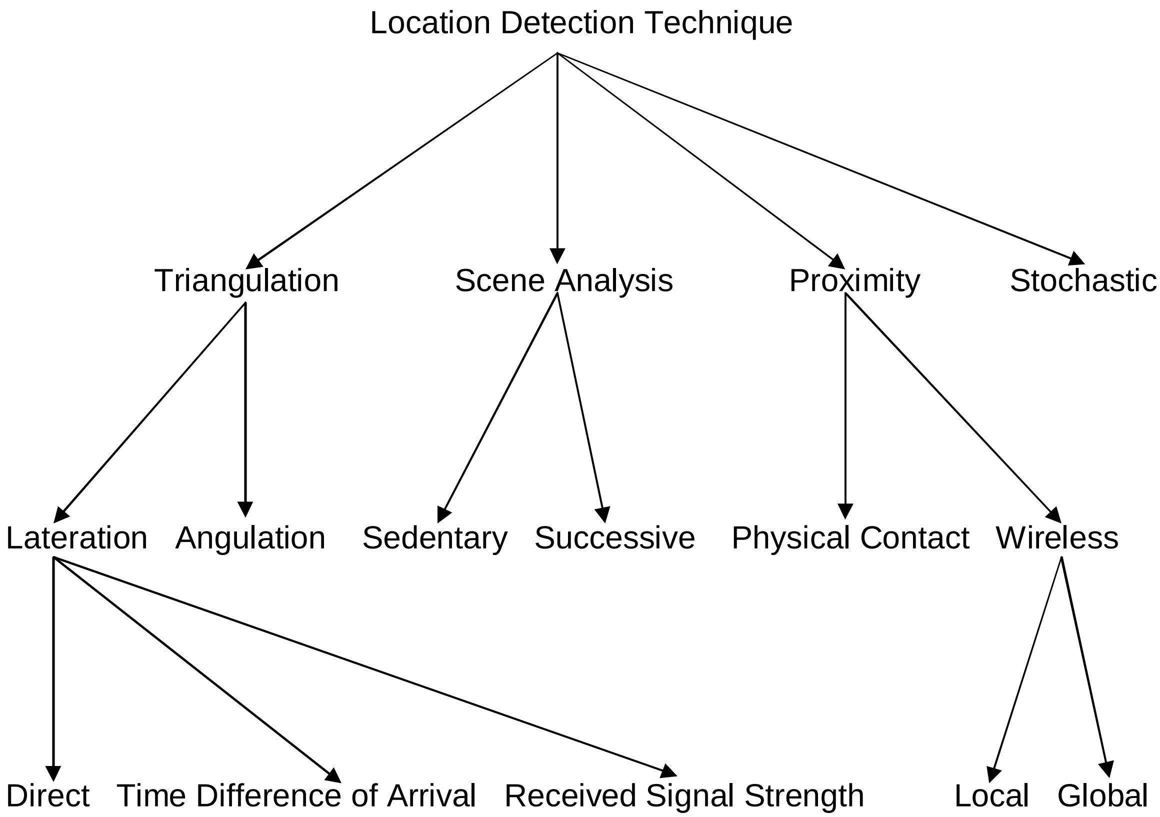


Figure 1: Location detection techniques.

3.1. Triangulation

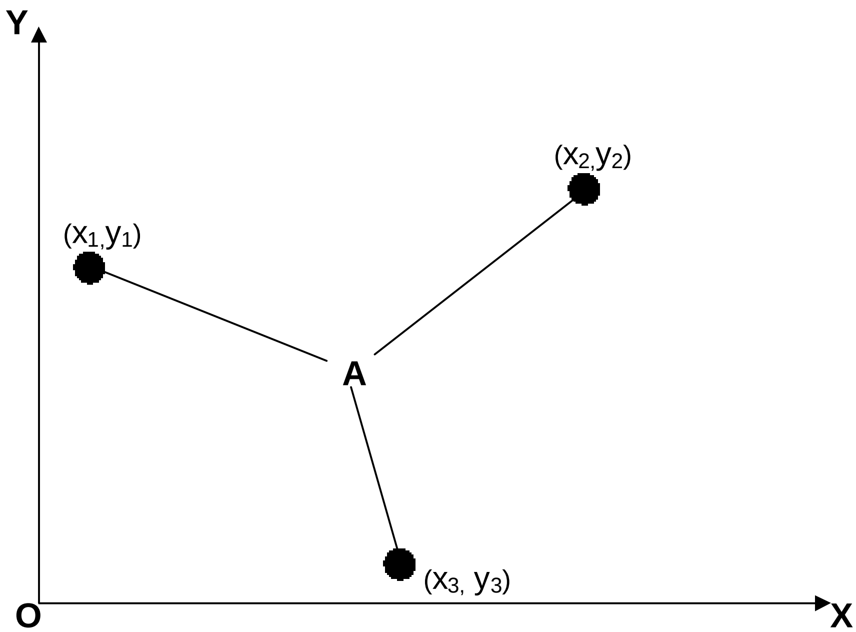
Triangulation is pure mathematical technique for detecting location. It is the most established method, too. It uses the geometric properties of triangles to estimate location. In this method, measurement is made from multiple reference points.

Then location is computed using the measurements along with some additional measurements if they are required. Applying triangulation in countryside, containing towers along a line which causes the geometry awkward, is difficult. Also, some areas remain uncovered due to scarcity of cell sites. There exist many location systems which use triangulation method. Some of them are GPS (Global Positioning System), TRSR (Turbo Rogue Space Receiver), Skyhook Wireless WiFi, Asset Location System, Active Bat, VOR (VHF Omnidirectional Ranging), 3D-iD, E911, and SpotON [10, 11].

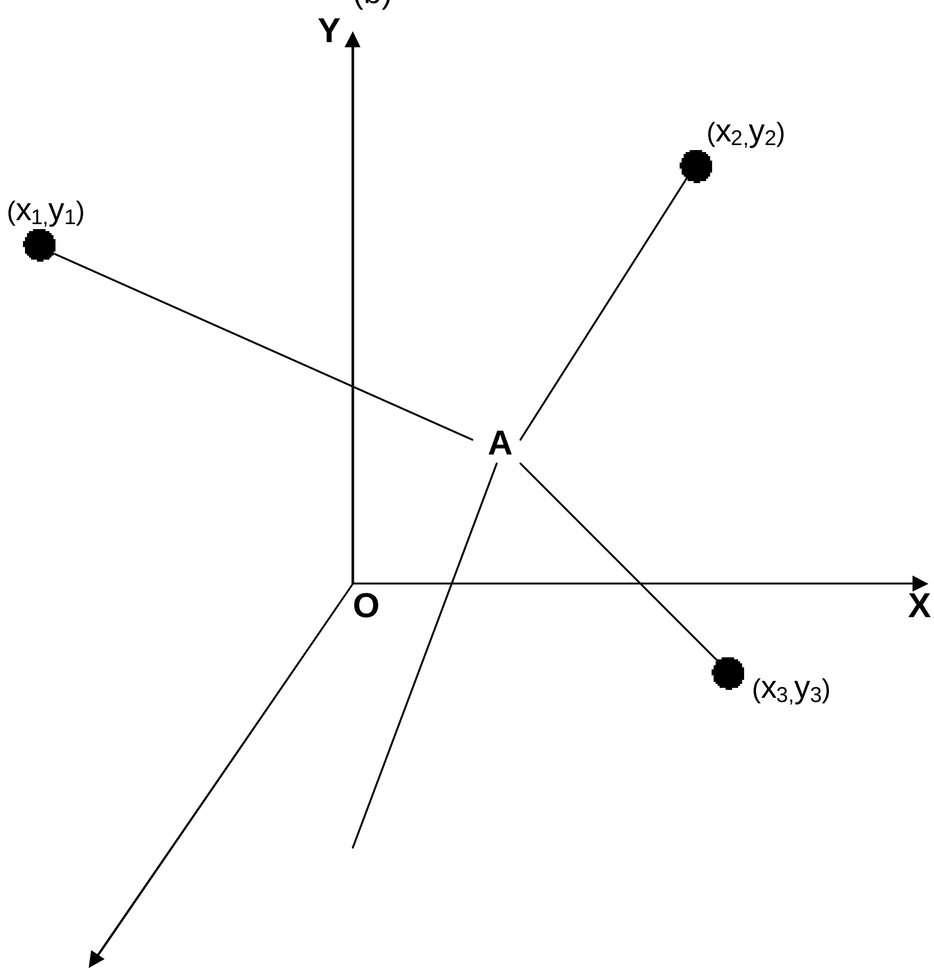
Triangulation is divided into two types. They are lateration, which uses distance measurement, and angulation, which uses angle measurement.

3.1.1. Lateration

Lateration is the triangulation location detection technique which uses straight-line distance measurement from multiple reference points to calculate the position of an object. Objects' positions can be obtained in either in two-dimensional space or 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) points to find the coordinate of a point in n dimensions.



(b)



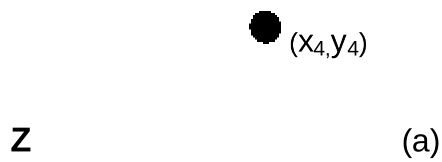


Figure 2: Determining the position of object “A” in **(a)** 2 dimensions and **(b)** 3 dimensions.

If information about the domain is gotten, number of reference points can be reduced. As an example, in three-dimensional space, if the point of observation (receiver) is always set above the object (transmitter), measuring distance from three reference points will suffice instead of four reference points. Active Bat Location System uses only 3 reference point to compute the location of an object.

Lateration can again be divided into three divisions. They are direct, time-difference of arrival, and received signal strength (RSS) [10, 11, and 12].

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 [11, 13].

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 is can be mobile or immobile. The specific velocity is can be of light, sound, radio etc. Sound wave has a velocity of 332 ms^{-1} in standard temperature and pressure. If a sound pulse sent by an object at the start point reaches the end point t seconds later, the distance between the start and end points will simply be 332t meters. GPS, TRSR, Asset Location System, Active Bat are the notable location systems which uses the technique of time difference of arrival [14, 11].

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, generated when a signal travels from a transmitter to a receiver, is taken into account. Say, we have a function of attenuation and distance for a type of signal. If we can measure the signal strength at the source of transmission and any point P, we can calculate the distance between the source and P using the function. Many kinds of signals can be used, namely, Radio Frequency (RF), ultrasound and infrared, in the technique of RSS. RSS is applied by the many location systems, namely, Skyhook Wireless WiFi, 3D-iD, E911, SpotON [14, 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 in either in two-dimensional space or 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 3a. 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 [14, 11].

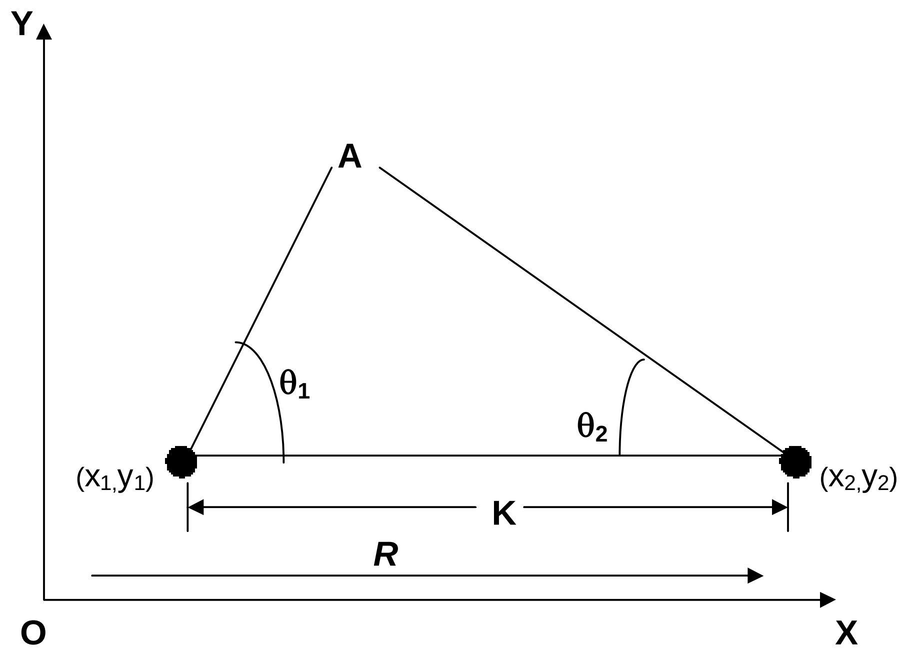


Figure 3: Determining the position of object "A" in 2 dimensions.

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. Usually, the simplification is made on the observed scenes to extract features. Image processing techniques are applied, along with the deployment of geometric representation of the space, for simplification and feature extraction from images, obtained through vision systems. It is easy to represent and compare features. Thus, performance and accuracy are improved [14, 11].

Scene representation can be of three types. In first type, geometric models are used for representing scenes. Scene representation is made in second type by visual images. Third type uses signal strength to form a model. In this case, signal strength profiles are estimated from different reference points and then are combined associating specific locations of the space taking certain features of the profiles into account in order to form a model [14, 11].

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. This predetermined dataset are 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.

Many location systems use scene analysis technique. Scene analysis is widely used in robotics. MotionStar, MSR RADAR are the location systems which use scene analysis [14, 11].

3.3. Proximity

Proximity is the location detection technique which involves determining the location of an object when it is close to a known reference point. A limited range of physical phenomenon is used to detect the presence of an object [14, 11, and 12].

Proximity location detection technique entails two types of fashion for detecting proximity. In the first fashion, physical contact is the determining factor for proximity. Various types of sensors, e.g., pressure sensor and touch sensor, are generally used to sense physical contact. 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. The location systems Active badges, Cricket, Avalanche Transceivers, Smart Floor, Automatic ID Systems, Wireless Andrew use the proximity location detection technique [14, 11].

3.4. Stochastic

Stochastic location detection is a data driven approach. It uses statistics 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. In this calculation many statistical concepts come into play, such as, probability theory, probability distribution, central tendency and dispersion. As stochastic location detection technique make approximations on many things, some errors are incurred during calculations. So, errors have to distributed and handled properly. Many kinds of signals can be used, namely, RF, ultrasound and infrared, in the stochastic technique. Ekahau is an instance of the location detection system which uses stochastic location detection technique [14, 15].

Chapter IV: TAXONOMY OF LOCATION SYSTEMS

Problems arise when location systems are considered for a particular application. We fall in confusion of setting priority of a location system over another. Thus, some classification criteria are required to be established in order to choose the best one among various alternative 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 chapter identifies and discusses different features of location system. For each of the features, this chapter gives its definition and provides some explanation and instances. 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. For example, BRAC University is situated at 51^{o}31’ 17’’ N by 0^{o}7’46’’ W at 4.5m elevation. Here, 51^{o}31’ 17’’ N by 0^{o}7’46’’ W at 4.5m elevation, is the physical position of BRAC University. GPS, Active Bats, MotionStar, VOR, MSR RADAR etc. are the location systems which provide physical position information. On the other hand, contextual position is a position relative to a certain context. A context may be a hotel, a bus, a school, a rail-station etc. For example, the visitor is now inside the room no.123. This is telling visitor’s contextual position where the room no.123 is the context. Active Badges, Cricket, Easy Living, Wireless Andrew, BBK Beacons, RFID etc. are location systems which provide contextual position information. It is possible for many applications to transform physical position to contextual position and vice versa [8, 14].

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. In this case, the location information provided by the location system for all objects situated in the same place will be indifferent and conversely, the indifferent location information of all objects always indicate the same place. GPS, Active Bats, MotionStar, VOR, MSR

RADAR, Active Badges, Cricket, Easy Living, 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. In this case, the location information provided by the location system for all objects situated in the same place will be reference-frame-dependent. Cricket, Automatic ID System etc. is relative location systems [14, 11].

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. If the object wants, it can let other objects know its location. As the calculation is done by the object, power consumption of the object becomes high which cause additional expense on many applications. GPS, VOR and Cricket are examples of location systems which 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. As the calculation is done by the infrastructure, power consumption of the object becomes low which lead to low expense on applications. Active Bats, MotionStar, MSR RADAR, Active Badges, Easy Living and Wireless Andrew are examples of location systems which follow this approach. Thirdly, a hybrid approach is formed combining the previous two approaches. That is, 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 which follows this approach. In this system, the object sends out information, provided by the GPS satellites, to the infrastructure. The infrastructure then supplies additional computational power and cell ID information so as to make calculation effective and efficient [14, 11].

4.4. Recognition

A location system may have provision of recognizing located objects. Recognition is required in order to take necessary action. Recognition is performed through some attribute checking. Attribute may be color, shape etc. Location system cannot differentiate objects other than these attributes. For example, a location system can recognize footballs in a basket but cannot differentiate a certain football from others. One obvious necessary condition for a location system to have recognition capability is to follow second approach in Section 4.3. Active Bats, MotionStar, MSR RADAR, Active Badges, Easy Living, E911, SpotON, PinPoint 3D-iD, Wireless Andrew, Smart Floor etc. are the location systems with recognition capability [11].

4.5. Accuracy and Precision

Accuracy and precision are the measure of effectiveness of a location system. Accuracy is the grain size of the information of position in a location system. The minimum distance at which level 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. There is a trade-off between accuracy and precision. So, 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 [11].

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. If the two components are combined, scale becomes the number of objects a location system can locate within the coverage area per unit of infrastructure. Infrastructure can be base station, sensor, emitter etc. The scale of GPS is any number of objects throughout the world by 27 satellites including 3 redundant ones [11, 14].

4.7. Update Rate

Time is an important consideration in the regard of features of location systems. In this case, update rate comes into play. 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. The update rate of GPS is good. GPS Receivers have at least an update rate of 1-20Hz. The update rate of VOR is 30Hz [16, 12, and 17].

4.8. Availability

The availability of a location system is the degree of usability and deployment of the system. It indicates that a location system is how capable to provide usable service in a specific environment. Thus, 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 [17].

4.9. Cost

Cost is an important feature of location systems. It is a very important factor 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. Active Bats costs high for administration, medium for sensors and a bit for tags [11].

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. For example GPS has some limitations. In some situations, GPS receivers do not function properly. When GPS receivers are situated in an urban deep valley with very steep sides created by very high buildings or in indoors with very weak signals, they do not work properly. In general, a location system's limitations can be detected by taking, the traits of the technologies, followed by the system, into account [11, 14].

Chapter V: A SURVEY OF LOCATION SYSTEMS

In the previous two chapters, different location detection techniques and features of location systems are described. In this chapter, we discuss many location systems with respect to these techniques and features. At the last of this chapter, three tables (Table 2, 3 & 4) are formed using the taxonomy established in the previous chapter so as to compare different location systems discussed in this chapter. Table 2 compares location systems in regard to technical issues; Table 3 compares location systems in regard to issues of performance and Table 4 compares location systems in regard to commercial issues.

5.1. Global Positioning System (GPS)

The Global Positioning System (GPS), founded by the US Department of Defense (DoD), is a precise worldwide radio-navigation system. It consists of a constellation of satellites (Figure 4) and their ground stations, operated and maintained by DoD. The first GPS satellite was launched in 1978. The first 10 satellites were development satellites, called Block I. From 1989 to 1993, 23 production satellites, called Block II were launched. The launch of the 24th satellite in 1994 completed the system. The DoD keeps 4 satellites in reserve to replace any destroyed or defective satellites. GPS provides specially coded satellite signals that can be processed in a GPS receiver, enabling the receiver to compute position, velocity and time. Four GPS satellite signals are used to compute positions in three dimensions and the time offset in the receiver clock [18, 19, and 20].

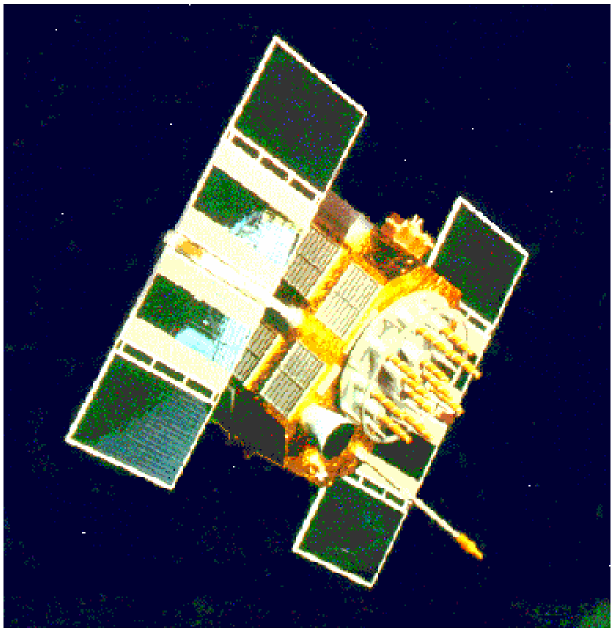


Figure 4: A GPS Satellite [44].

The navigation system is divided into three segments: the space segment, the control segment and the user equipment segment. The Space Segment of the system consists of the GPS satellites. These space vehicles (SVs) send radio signals from space. All of the GPS satellites orbit the earth in 12 hours. The satellite orbits repeat almost the same ground track (as the earth turns beneath them) once each day. The orbit altitude is such that the satellites repeat the same track and configuration over any point approximately each 24 hours (4 minutes earlier each day). There are six orbital planes (with nominally four SVs in each), equally spaced (60° apart), and inclined at about 55° with respect to the equatorial plane (Figure 5). This constellation provides the user with between five and eight SVs visible from any point on the earth. The GPS Control Segment consists of a system of monitoring stations located around the world. It has five monitoring stations and four dedicated ground antennas with uplink capabilities. The monitoring stations use GPS receivers to passively track all satellites in view and accumulate ranging data from the satellite signals. The information from the monitoring stations is processed at the Master Control Station (MCS) to determine satellite clock and orbit states and to update the navigation message of each satellite. This updated information is transmitted to the satellites via the ground antennas, which are also used for transmitting and receiving satellite health and control information. The GPS User Segment is any person or agency equipped with a GPS receiver, which converts the satellite signals into useful navigation information. By receiving signals from at least four satellites, users, whether stationary or moving, can calculate their time, three-dimensional position and their three-dimensional velocities (if moving) using the method of triangulation [17, 18, and 19].

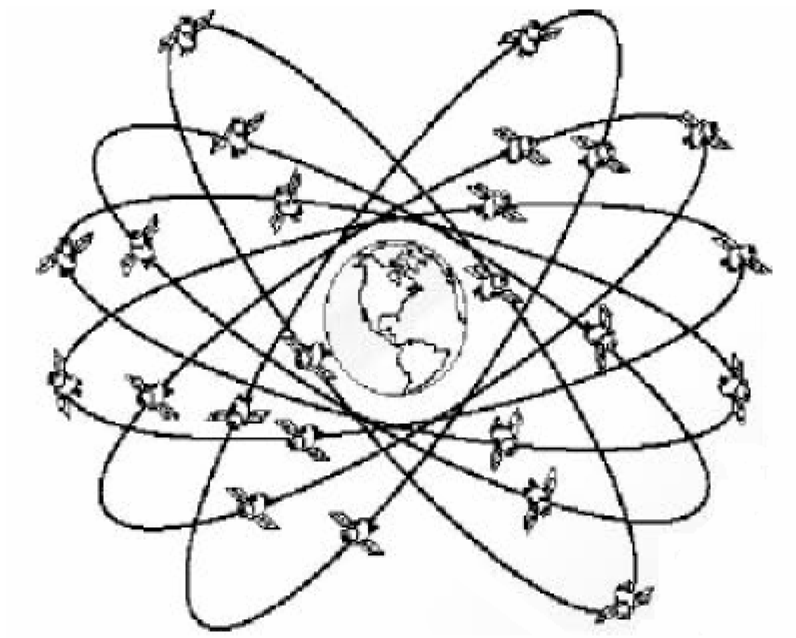


Figure 5: GPS Satellite Configuration [44].

GPS is a space-based dual use radio-navigation system that is operated for the Government of the United States by the U.S. military. The U.S. Government provides two levels of GPS service. The Precise Positioning Service (PPS) provides full system accuracy to designated users. Authorized users with cryptographic equipment and keys and specially equipped receivers use the Precise Positioning System. U. S. and Allied military, certain U. S. Government agencies, and selected civil users specifically approved by the U. S. Government, can use the PPS. PPS provides an amazing accuracy of an order of millimeter. The Standard Positioning Service (SPS) provides an accuracy of 1-5 meters to all users. Civil users worldwide use the SPS without charge or restrictions. Most receivers are capable of receiving and using the SPS signal. The SPS accuracy is intentionally degraded by the DoD [17, 18].

Many factors can affect the accuracy of GPS data. They are ephemeris errors, receiver errors, atmospheric effects, satellite geometry, occupation time, multipath errors. Most of the errors listed above can be corrected by collecting more positions at each point, configuring the GPS receiver correctly, and applying the Differential GPS (DGPS) technique. The idea behind all differential positioning is to correct bias errors at one location with measured bias errors at a known position. A reference receiver, or base station, computes corrections for each satellite signal [18, 19].

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. A pilot can easily and properly navigate from one point to another point using the VOR system. The VOR system provides information of the direction the pilot flies in relation to the VOR station and magnetic north [21, 22, 23, 24 and 25].

The VOR stations broadcast VHF (very high frequency) radio signals. They are assigned radio channels ranging from 108.0 MHz (megahertz) to 117.95 MHz with 50-KHz channel width. This is in the VHF range. The reason behind choosing VHF is its characteristic of moving only in straight lines. So, atmospheric effects cannot bend its line of flight. This makes measurements of angle correct. Each VOR station sends out two radio signals concurrently. The VOR system employs the phase relationship between two radio signals in order to encode direction. The carrier signal is omnidirectional and frequency modulated. It carries station Morse code or voice identifier. The reference signal is frequency modulated on a 9960-Hz sub-carrier and is found from the electronic rotation of a cardioid pattern around the station. The number of rotation is 30 per second. Although older antennas physically rotated, present antennas do not do so. In fact, the VOR system electronically scans them as if they rotated. As the signals are received in the aircraft, the frequency is extracted from the frequency modulated signal. Then the phase difference between the two 30-Hz signals is calculated comparing them. The phase difference is the angle in degrees made by the direction from the station to the aircraft with magnetic north. This angle is called the radial. Figure 6 shows a VOR display indicating 345° radial [21, 26 and 22].

Figure 6: A mechanical VOR display indicating 345° radial [21].

The VOR system provides physical information of location. It is an absolute location system. The responsibility for computing location of the aircraft is on the receiver in the aircraft. A VOR station can handle an unlimited number of aircrafts. The accuracy of the VOR is good. But VOR transmitters cost a lot. Moreover, it is costly to deploy and maintain VOR transmitters and receivers.

Another problem is with the VOR system is its reliance on line of sight. The radio signal sent by the transmitter will not be caught by the receiver if the day is not so clear that the transmitting antenna cannot be seen. Again, the VOR system may face trouble in hilly and mountainous region. Moreover, the maximum range of a VOR station is 25– 130 nautical miles (46–240 kilometers). So, an extensive network of stations is required to solve these problems which cost a lot [26, 22 and 17].

5.3. Active Badge

The Active Badge location system was developed from between 1989 and 1992 at AT&T Laboratories. It is an indoor location system which locates an individual within a building at any given time. It locates an individual by detecting the location of their Active Badges (Figure 7). An Active Badge is a small device carried by an individual which deploys infrared (IR) technology to send data. It has four generations. The volume of its first version was only 55mm x 55mm x 7mm and had a weight of only 40g [27, 28].

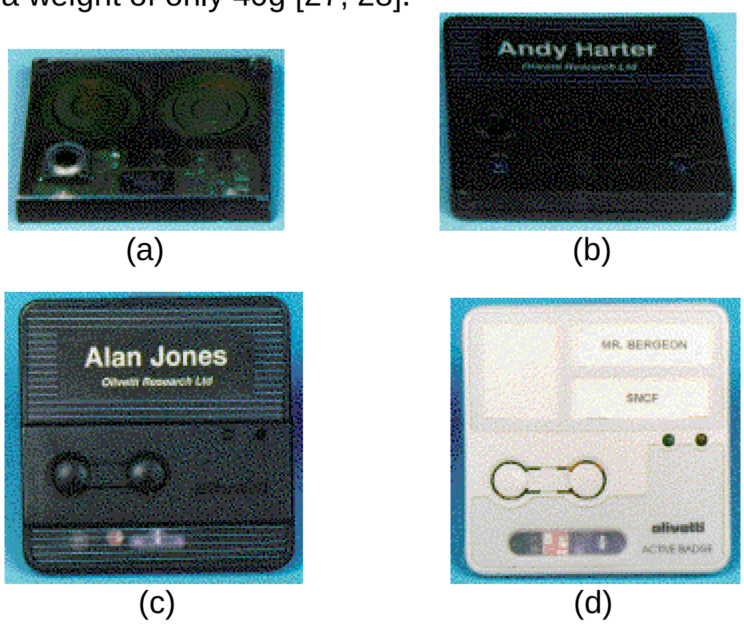


Figure 7: Four generations of the Active Badge. **(a)** The first version. **(b)** The second version. **(c)** The third version. **(d)** The current version [42].

An Active Badge sends a unique pulse IR signal every 10 seconds. The building contains many networked sensors (Figure 8). 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 which computes the location of the Badge, i.e., the individual who carries it, using the information supplied by the sensors. The reason behind using IR signals for signaling between the Badge and sensor is the fact that IR solid-state emitters and detectors can be yielded very small at a very cheap cost [27, 29 and 28].

Figure 8: The Active Badge sensor [43].

The information provided by the Active Badge location system is contextual. The context is a volume confining IR. For example, the context may be a room. The Active Badge system is an absolute location system. Its accuracy is acceptable [11, 29, and 28].

Active Badge location system costs high for network but low for devices, e.g. Badges and sensors. It works very well in many buildings but it falls into troubles if the building has no IR confining volume. For example, Active Badge system is not applicable to a factory or a hall or a theatre or an office covered with cubicles [27, 29 and 28].

5.4. Bat

Though 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 locates an individual by detecting the location of their Bats (Figure 9). A Bat is a small device carried by an individual which deploys ultrasonic technology to send data. Its volume is only 7.5cm x 3.5cm x 1.5 cm. Power consumed by a Bat is supplied by a long-lasting battery, 3.6V Lithium Thionyl Chloride cell. Each Bat features a unique identification code by which they are recognized [28, 30 and 31].

Figure 9: A Bat [30].

A Bat sends a short ultrasound pulse at a specified time interval. The building contains many networked sensors above the ceiling (Figure 10). The sensors are set in a square grid at a distance of 1.2m. The pulses, sent by the Bats, are detected by the sensors. The time of flight of the pulse from the Bat to the sensor is computed using an accurate clock. The distance from the Bat to the receiver can be computed as the speed of ultrasound in air is known. Finding at least three such distances, the location of the Bat, i.e., the individual who carries it, in 3D space, is computed. The network contains a master station which performs the task of computing location. If an individual carries two or more Bats, his orientation can be computed using the relative locations of the Bats [30, 31].

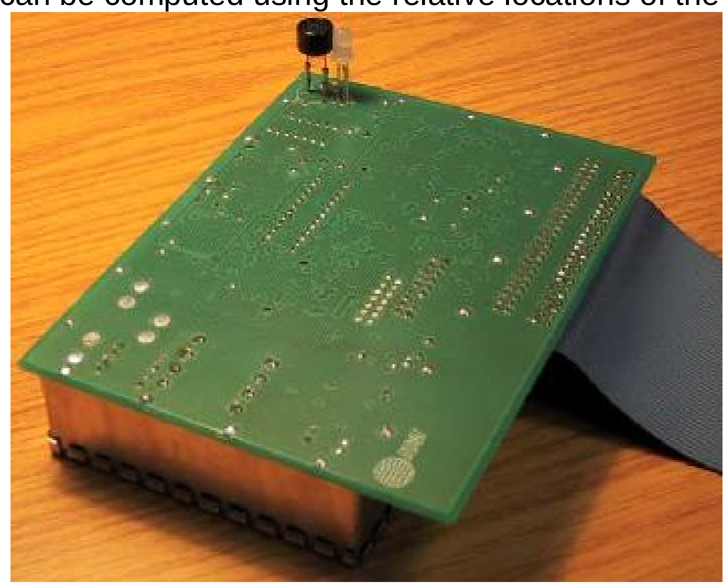


Figure 10: A Bat sensor [30].

The information provided by the Bat location system is physical. Making natural conclusions about individuals can be a great future work on the Bat system. The Bat system is an absolute location system. Its accuracy is acceptable. 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 [11, 30, and 31].

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 [11, 32 and 33].

E911 is split into parts. The first one is Phase I which needs carriers. When valid request is made by a local PSAP, carriers are used in order to report the number of the wireless phone calling 911 and the location of the call-receiving antenna. The Phase II also needs carriers in order to determine location information which is far more accurate and precise. Many companies are exercising many location techniques in order to obey E911. Triangulation is the one which is mostly used. The companies have to achieve certain level of accuracy and precision specified by the FCC. The accuracy and precision required by the FCC are 50-300 meters and 95%, respectively. RedSky Technologies, Inc. is a vendor which helps large organizations with 911 emergency responses. RedSky's E911 Manager captures, manages and delivers all the required location information in order to serve the customers [34, 35].

5.6. SpotON

SpotON is 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. SpotON tags (Figure 11) use received radio signal strength information (RRSSI) as a distance estimator to perform ad-hoc lateration. Ad-hoc location sensing is a fusion of concepts from object location tracking and the theories of ad-hoc networking [36, 37].

Figure 11: A SpotON ad-hoc location sensing tag [37].

SpotON hardware tags were created to study ad-hoc location sensing and evaluate the use of RRSSI as a measurement tool. The choice of measurement technology was motivated by the target scenario: flexible or temporary sensor deployments in small scale environments such as offices with floor space less than $16m^2$. A strategy room can be “SpotON enabled" simply by attaching one or more SpotON tags to the walls and interior. Tagged people and objects inside the room can then be located relative to one another (or absolutely if the fixed tags are configured to know their absolute location). Both infrastructural and wearable applications in the room can leverage the location data. The SpotON hardware is considered as nodes in an ad-hoc location sensing network. Tags beacon radio packets of a calibrated power at randomized intervals.
In this context, calibration means the creation of tag specific information such that any given tag can transmit at the same power as the others and can accurately map its RRSSI measurements to an estimated distance from a transmitter. The randomization, along with a simple listen and back-off technique allows clusters of tags to use the shared 916.5MHz radio spectrum efficiently. An alternative approach is to beacon periodically with random phase difference back-off relative to other beacons. This approach converges to a tag-specific beacon time slot. In both cases, packet collisions are reduced, and fairness and aggregated throughput are maximized. Any tags hearing a radio beacon measure the RRSSI subject to their receiver specific calibration model. RRSSI is used to estimate the distance from a transmitter. Beacon packets may also contain a measurement history payload. This payload distributes measurements around the cluster allowing any node to quickly aggregate a global snapshot needed to perform location calculations. Both infrastructure-centric and wearable application models are supported. For example, emulation of infrastructure-centric location systems can be achieved by simply attaching an application server to one of the fixed nodes. Wearable applications attached to a tag can

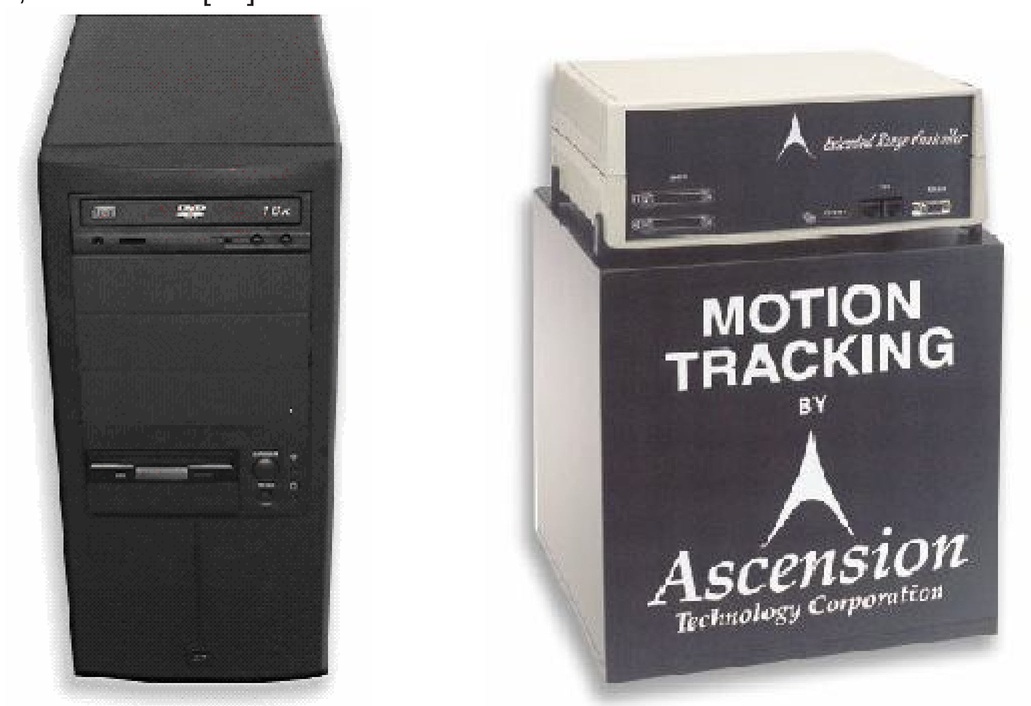
participate however they wish using the measurement information available to all cluster participants [37].

The SpotON project has completed. SpotON hardware is no longer available but all available information regarding the SpotON project is on [36]. This research is continued in the Location Stack project [36].

5.7. MotionStar Wireless 2

The MotionStar Wireless 2 location system was developed by Ascension Technology Corporation in the early 2000s. It is a magnetic tracker for capturing the motions of up to six performers. It is perfect for motion capture sessions that require complex movements such as twisting, flipping and spinning (fighting sequences in computer games, for example.). MotionStar precisely replicates human movement. Fully integrated with animation software and host computer, MotionStar makes an in-house motion capture system reliable [38, 39].

Data is instantaneously available in MotionStar Wireless 2 deployed environment. Each sensor calculates both position (x, y, z) and orientation (azimuth, elevation, and roll) for full 360° coverage. Data is never lost. 6 data points per sensor (i.e. 20 sensors yield 120 actual data points) is acquired. Data is sent via a wireless communications link to the base-station. Thus, MotionStar Wireless 2 instantly captures and records the motions of up to six performers at once, in real-time [39].



(a) (b)

(c)

Figure 12: Hardware of MotionStar Wireless 2. **(a)** Base-station. **(b)** Extended-range transmitter. **(c)** Controller [38].

The information provided by the MotionStar Wireless 2 location system is physical. It is an absolute location system. 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 & 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. Moreover, it needs precise installation [11, 38, and 39].

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.
It locates an object by detecting the location of their radio tags which is a small device. Its core technology is a Tag Tracking Network composed of cell controllers and antennas which continuously monitor thousands of tags as they move through a facility. Asset Tracking Network software, built on an open client/server model, collects and processes the information in a form compatible with existing computer systems. Location data for individual assets is presented to the end-user over the corporate Intranet through an intuitive user interface [40, 41].

The 3D-iD location system provides physical information of location. It is an absolute location system. The accuracy of the 3D-iD is 1-3m which is good.

But 3D-iD costs a lot. It is costly to deploy and maintain 3D-iD system. Another problem is with the 3D-iD system is its proprietary solution. Unfortunately, the 3D-iD location system does not currently exist. Either it has stopped operating or it has merged with another system [11].

5.9. Tables of Comparison

Table 2: 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 3: 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 al 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 4: 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	High	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

Chapter VI: CONCLUSION

Pervasive 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. The world is waiting to watch and enjoy the magical power of pervasive computing. In this regard, location detection is of huge importance. It is going to play a major role in the future of pervasive computing. In this thesis, 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 [14].

In this thesis, we have attempted to design everything from the scratch in well order. Theory is explained. To make explanation clear, diagrams are provided where they are necessary. Pictures of hardware are inserted in the thesis in order to make the readers' concepts robust. The information provided is latest. Relevant references are given so that interested readers can explore the subjects thoroughly. We hope that this thesis will benefit every newcomer to the area of location detection.

Features of location systems, identified in this thesis, are not the only ones. We have identified the major features, which are applicable to almost all systems. There are many features else. These features are given in appendix for interested readers.

REFERENCES

[1] Ubiquitous Computing, Available at http://en.wikipedia.org/wiki/Ubiquitous_computing

[2] Ubiquitous Computing, Available at http://sandbox.xerox.com/ubicomp

[3] M. Satyanarayanan, "Pervasive Computing: Vision and Challenges," *IEEE Personal Communications*, vol. 8, no. 4, August 2001, pp. 10-17.

[4] Statistics for Mobile Commerce, Available at http://www.epaynews.com/statistics/mcommstats.html

[5] Barry Brumitt, John Krumm, Brian Meyers, and Steven Shafer, "Ubiquitous Computing and the Role of Geometry", In Special Issues on Smart Spaces and Environments, vol. 7-5, pages 41-43, *IEEE Personal Communications,* October 2000.

[6] W. Mark, "Turning Pervasive Computing into Mediated Spaces", *IBM SYSTEMS JOURNAL*, vol. 38, no. 4, 1999.

[7] A. Huang, and L. Rudolph, “An Infrastructure for Location Aware Computing”, *Student Oxygen Workshop,* 2004, Available at http://sow.lcs.mit.edu/2004/proceedings/Huang.pdf

[8] K. Henricksen, J. Indulska and A. Rakotonirainy “Infrastructure for Pervasive Computing: Challenges,” *Workshop on Pervasive Computing and Information Logistics at Informatik* 2001, Vienna, September 25-28, 2001.

[9] J. Hightower, “From position to place”. In Proc. Workshop on Location-Aware Computing, 2003.

[10] It's Time For GPS, Available at http://www.fonefinder.com/rescue.html

[11] J. Hightower, and G. Borriello, “A Survey and Taxonomy of Location Systems for Ubiquitous Computing,” *Extended paper from Computer*, 34(8) p57-66, August 2001.

[12] M. Rodriguez, J. P. Pece, C. J. Escudero, “In-building location using Bluetooth”, Available at http://www.ctr.kcl.ac.uk/IWWAN2005/papers/65.pdf

[13] EDAR - Event Driven Assembler Robot, Available at http://www.isl.ee.boun.edu.tr/projects/edar/EDAR.html

[14] George Roussos, “Location Sensing Technologies and Applications”, November 2002, Available at http://www.jisc.ac.uk/uploaded_documents/tsw_02-08.pdf

[15] Ekahau Corporation, Website 2007. http://www.ekahau.com/

[16] Definitions of Update Rate on the Web, Available at http://www.google.com.bd/search?hl=en&lr=&defl=en&q=define:Update+Rate&sa=X&oi=glossary_definition&ct=title

[17] “Federal Radionavigation Systems”, Department of Transportation and Department of Defense (March 25, 2002). 2001. Available at http://www.navcen.uscg.gov/pubs/frp2001/FRS2001.pdf

[18] P. H. Dana, “Global Positioning System Overview”, The Geographer's Craft Project, Department of Geography, The University of Colorado at Boulder.

[19] “Introduction to GPS”, GeoXT Training Information, Drinking Water Source Assessment Protection Program, January 20, 2004.

[20] GPS Overview Part 1 – Introduction, Available at http://www.palowireless.com/gps/tutorial1.asp

[21] VOR Navigation Part I, Available at http://www.navfltsm.addr.com/vor-nav.htm

[22] VHF Omnidirectional Range, Available at http://experts.about.com/e/v/vh/vhf_omnidirectional_range.htm#hd1

[23] VOR (VHF Omnidirectional Range), Available at http://www.answers.com/VOR

[24] VHF Omnidirectional Range WikiFeed Preview, Available at http://www.blinkbits.com/en_wikifeeds/VHF_Omnidirectional_Range

[25] Amalgamated Wireless Australasia Limited, Available at http://en.wikipedia.org/wiki/Amalgamated_Wireless_Australasia_Limited

[26] VHF Omnidirectional Range, Available at http://en.wikipedia.org/wiki/VHF_omnidirectional_range

[27] The Active Badge System, Available at http://www.cl.cam.ac.uk/research/dtg/attarchive/ab.html

[28] M. T. Shiraji, S. Yamamoto, "Human Tracking Devices: the Active Badge/Bat and Digital Angel / Verichip systems", Project paper #1, ECE 399, Fall Term 2003, Oregon State University, USA.

[29] R. Want, A. Hopper, V. Falcao, and J. Gibbons, "The Active Badge Location System", *ACM Transactions on Information Systems,* vol. 10, no. 1, January 1992, pp. 91-102.

[30] The Bat Ultrasonic Location System, Available at http://www.cl.cam.ac.uk/research/dtg/attarchive/bat/

[31] The Bat System, Available at http://www.cl.cam.ac.uk/research/dtg/research/wiki/BatSystem

[32] 911 Services, Available at http://www.fcc.gov/911

[33] Federal Communications Commission, Washington, D.C., Available at http://www.fcc.gov/Bureaus/Common_Carrier/Orders/1997/fcc97402.txt

[34] Enhanced 911 - Wireless Services, Available at http://www.fcc.gov/911/enhanced

[35] E911 MANAGER, Available at http://www.redskytech.com/documents/E911_Manager_Overview.pdf

[36] SpotON Location System, Available at http://portolano.cs.washington.edu/projects/spoton/

[37] J. Hightower, C. Vakili, G. Borriello, and R. Want, "Design and Calibration of the SpotON Ad-Hoc Location Sensing System", *Research Report*, University of Washington, Seattle, WA, August 2001.

[38] MotionStar Wireless 2, Available at http://www.ascension-tech.com/products/motionstarwireless.php

[39] MotionStar Real-Time Motion Capture, *Product Brochure*, Available at http://www.ascension-tech.com/products/motionstar_10_04.pdf

[40] "Product briefs: PinPoint to unveil new locator system", *The BBI Newsletter*,

October 1, 1998, Available at
http://www.findarticles.com/p/articles/mi_m3570/is_10_21/ai_50331627

[41] "PinPoint Enhances Local Positioning System Technology; Incorporates Features Specifically Designed for Healthcare", Business Wire, April 10, 2000, Available at
http://www.findarticles.com/p/articles/mi_m0EIN/is_2000_April_10/ai_61396134

[42] The Active Badge, Available at
http://www.cl.cam.ac.uk/research/dtg/attarchive/thebadge.html

[43] The Active Badge Network Sensor, Available at
http://www.cl.cam.ac.uk/research/dtg/attarchive/thesensor.html

[44] Global Positioning System Overview, Available at
http://www.colorado.edu/geography/gcraft/notes/gps/gif/sv3.gif