

Towards Smart Surroundings: Enabling Techniques and Technologies for Localization

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Abstract. In this paper we identify the common techniques and technologies that are enabling location identification in a ubiquitous computing environment. We also address the important parameters for evaluating such systems. Through this survey, we explore the current trends in commercial products and research in the area of localization. Although localization is an old concept, further research is needed to make it really usable for ubiquitous computing. Therefore, we indicate future research directions and address localization in the framework of our Smart Surroundings project.

1 Introduction

Recent advances in wireless communication devices, sensors, hardware (MEMS) technology make it possible to envision large scale dense ad-hoc networks acting as high resolution eyes and ears of the surrounding physical space, making the vision of Mark Weiser [36] into a reality. This calm technology promises various applications and spans a wide range of fields ranging from medical and fitness, security and safety, work, learning and leisure. Ad-hoc networks play a vital role in modeling these future pervasive networks.

As we approach the level of ubiquitous network connectivity and pervasive mobile devices, the enticing new category of *context-aware applications* has been proposed. By definition [5] ‘context’ is any information that can be used to characterize the situation of an entity. An entity is a person, place or object that is considered relevant to the interaction between a user and an application, including the user and applications themselves. A system is ‘context-aware’ if it uses contexts to provide relevant information and services to the user, where relevancy depends on the user’s tasks. One of the important dimensions of context is *location*. The proliferation of wireless technology, mobile computing devices and Internet has fostered a growing interest in location-aware systems and services. It is useful for accomplishing emergency services, E911, follow me services, finding the nearest resources such as printer, habitat monitoring, patient tracking, asset monitoring, buddy finder or a product finder, etc. *Localization* acts as a bridge between the virtual and physical world [8].

A mobile or a static node could answer the question ‘Where am I?’ in several ways. It might be relative to a map or relative to another node, or global coordinate system. This is referred to as *localization* or *location identification*.

Networked applications are often implemented in a layered architecture or protocol stack, and several layers of the protocol stack can benefit from localization [2]. Knowing the objects location not only promote context awareness at the application level, but also bumps up low level functionalities such as routing, service discovery and resource management.

Localization is by nature an interdisciplinary problem involving research in several areas of computer science and many kind of engineering. Consequently, research has proceeded in both the systems and the algorithmic fronts. In this paper we discuss the basic principles of localization, and the developments and advances made in the field. Finally, we show why localization is a corner stone in the future of pervasive computing.

1.1 Performance parametric measures of localization

The key metric for evaluating a localization technique is the *accuracy* defined as, how much is the estimated position deviated from the true position. The accuracy is denoted by an accuracy value and *precision* value (e.g. 15 cm accuracy over 95% of the time). The precision indicates how often we expect to get at least the given accuracy. The accuracy of a location sensing system is often used to determine whether the chosen system is applicable for certain applications.

Calibration also plays a very important role. The uncalibrated ranging readings are always greater than the true distance and are highly erroneous due to transmit and receive delays [37]. Device calibration is the process of forcing a device to conform to a given input/output mapping.

Responsiveness is defined as how quickly the location system outputs the location information. It is an important parameter, especially when dealing with mobility. However, this parameter is mostly ignored in the description of the existing systems.

Scalability is also significant, as the proposed design should be scalable for large networks. Also of great importance is *self-organization* as it is infeasible to manually configure the location determination processes for a large number of mobile devices in random configurations with random environmental characteristics.

Cost, which includes the cost of installation, deployment, infrastructure and maintenance, is also a crucial parameter. An important cost factor when running the system in a real environment is *power consumption*. When scaling to thousands or millions of autonomous small devices it is clearly not feasible to change or recharge batteries very often, thus *energy efficiency* should be a goal of any localization mechanism meant for a large scale system.

In our view *privacy* is an important parameter of localization systems and it should form part of the architecture since its conception. Using localization it is very easy to create a Big Brother infrastructure that track users movements and allow to deduce patterns of behavior. However, this issue is being generally

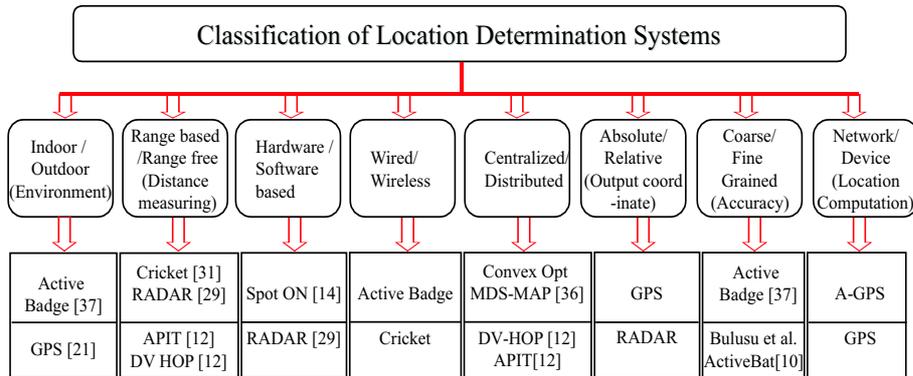


Fig. 1. Taxonomy of the existing location systems

overlooked in the design of systems and considered as an after thought only. Centralized systems are particularly weak with regard to privacy.

2 Taxonomy of existing Location systems

Though localization is not a new field of research, it has gained additional credit due to the advent of ubiquitous computing research and it is still an evolving research area. Figure 1 shows a taxonomy of localization technology.

3 Enabling techniques and technologies for Localization in Wireless Ad-hoc Networks

Localization is defined as a mechanism to find the spatial relationship between objects [2]. An assumption in most of the localization system is the availability of *anchor nodes* or *landmarks* [29], while some other uses beacon nodes. Langendoen et al [19] differentiates anchor nodes and *beacon nodes*. They define anchor nodes as nodes having a priori knowledge of their own position with respect to some global coordinate system, while beacons (access points) are nodes based on external infrastructure (e.g. GPS-less, Cricket). Beacons have the same capabilities (processing, communication, energy consumption) as other nodes in the network. Fundamentally speaking, location systems needs some kind of input, for example it can be sensor reading originating from a sensor, or information from an access point as signal strength, for getting a symbolic representation. This information is then combined using a given technique to derive the location, either absolute or relative, of an object or set of objects. An absolute location system may use a shared reference grid for all located objects. For example, all GPS receivers use latitude, longitude and altitude for reporting the location, where as a relative location system has its own frame of reference. The following

subsections give an overview about the existing technologies and techniques that enable localization.

3.1 Signal technologies

Technology	Merits	Remarks
Infrared	Inexpensive (due to ubiquitous deployment) Compact Low power	Typical range is upto 5m Restriction to line of sight conditions Unusable in direct sunlight
Ultrasound	Relatively slow propagation (speed of sound) Allows for precise measurement at low clock rates, making the system simpler and inexpensive	Typical range is 3- 10m have been reported Environmental factors have substantial effects
Radio Frequency	Better than IR in terms of bandwidth, cost and speed	No proper propagation model exists Affected by multipath Typical range of bluetooth is 10-15m Typical range of WLAN is 50-100m Typical range of RFID is 1-10m Typical range of cellular systems is 100 -150m
DC Electromagnetic	High precision High signal propagation speed	Typical range is 1-3m Signals are sensitive to environments Precision calibration required,hence expensive Difficult to install
Optical	High precision Compact Low power	Typical range is upto 5m Restriction to line of sight conditions Unusable in direct sunlight
Inertial		Errors accumulate over time Calibration
UWB radio	High precision and accuracy Less affected by multipath than the traditional RF systems	Expensive Higher receiver density than the conventional RF systems nevertheless its easier to install

Table 1. Enabling signal technologies

The different types of signal technologies are tabulated in Table 1. Depending on the required range, propagation speed, cost, precision, bandwidth, etc. one can choose the required technology for a specific application. As you can see from Table 1, there are infrared based, ultrasonic based, electromagnetic based, inertial based, optical based, and radio frequency based systems. Depending on the type of frequency range used, Radio Frequency can be categorized into RFID (Radio Frequency IDentification), WLAN (IEEE 802.11b), Bluetooth (IEEE 802.15), wide area cellular and UWB. UWB is based on sending ultra short pulses (typically $< 1ns$). For location identification, UWB uses Time of Arrival measurement. The very short pulses lead to high accuracy and low power consumption.

3.2 Distance Measuring Techniques

The *ranging technology* forms the heart of any range based localization system. There are several range-based techniques such as Time-of-arrival (TOA), Time difference of Arrival (TDOA), Angle-of-arrival (AOA), and Received Signal Strength Indication (RSSI). The TOA and TDOA make use of signal propagation time for finding the range of distance. To augment and complement TOA and TDOA, AOA was proposed. AOA allows nodes to estimate and map relative angles between the neighbors. However, this approach requires costly antenna

arrays on each node [30]. RSSI makes either theoretical or empirical calculations to convert the signal strength measurements to distance estimates. There are also other ranging techniques like E-OTD(Enhanced Observed Time Difference) and A-GPS(Assisted GPS)which are typically used in cellular location determination.

On the other hand range free schemes make use of some algorithm that calculates the distance in terms of hop count to anchor nodes [12]. Some algorithms that use range free schemes are Centroid algorithm, DV-Hop, Amorphous, Point-In-Test (PIT) and Approximate Point-In-Test (APIT) [12]. In the DV-hop method, the anchor nodes are placed at known position and they transmit broadcast messages that are flooded throughout the network containing the location of the anchor node, and the distance between the anchors is obtained by using hop count as a metric. Later, any of the below discussed position estimation method is used to estimate the node location. The other range free schemes are explained in Section 4.2.

3.3 Location Estimation Techniques

The next step after the determination of the distance is the *location estimation*. There are different methods for estimating the location. *Triangulation* uses the geometric properties of triangles to compute object locations. It is a positioning procedure that relies on angle measurements with respect to the known landmarks. Triangulation is subcategorized into *lateration*—using distance measurements— and *angulation*—using angle or bearing measurements [13]. *Trilateration* uses ranges to at least three known node position to find the coordinates of unknown nodes. The trilateration [24] procedure starts with an a priori estimated position that is later corrected towards the true position. There are many other types of lateration such as Atomic multilateration and Collaborative multilateration, which are addressed in detail in [31].

Proximity measures the nearness to a known set of points. The objects presence is sensed using the physical phenomenon with limited range. Scene analysis examines a view from a particular vantage point to draw conclusions about the observer's location [13][17]. The scene itself can contain visual images, such as frames captured by a wearable camera or any other measurable physical phenomena, such as electromagnetic characteristics that occur when an object is at a particular position and orientation.

When the localization problem is addressed in wireless sensor networks, there is yet another type of location estimation method called *min-max* algorithm [19]. The main idea is to construct a bounding box for each anchor using its position and distance estimate, and then to determine the intersection of these boxes. The intersection of the bounding boxes is computed by taking the maximum of all coordinate minimums and the minimum of all maximums. Hence it is named as min-max. The estimated position by min-max is found to match closely with the true position computed through lateration.

The least square algorithm [30] [9]is also used to derive position estimation from collection of reference points and their associated ranges.

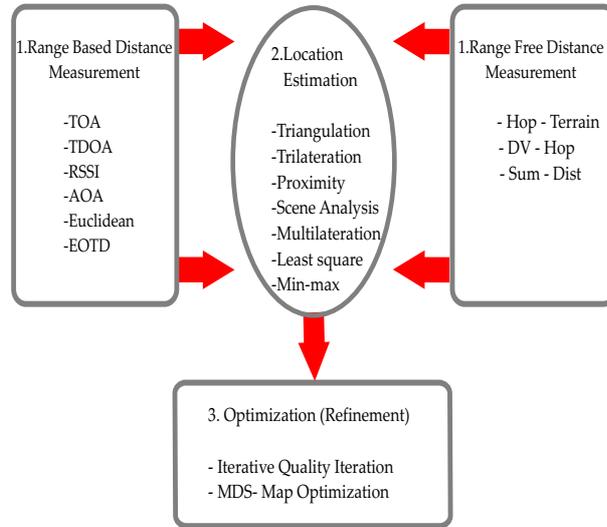


Fig. 2. Steps in localization

Figure 2 shows that there are 3 steps involved in any localization system namely, distance measurement to anchors or beacons, position estimation and position refinement, which is an optional step [19]. The choice of the techniques and technology affects the granularity and accuracy of the location information.

4 State of the Art

4.1 Implemented Systems

Loran was the first navigation system, launched before the World War II to employ time difference of arrival of radio signals, developed by MIT radiation lab [26]. It was also the first true all weather position finding system, but it is only 2 dimensional. Transit was the first operational satellite based navigational system launched in the year 1959. Transit users determine their position on earth by measuring the Doppler shift of signals transmitted by the satellites. Global Positioning Systems (GPS) [26] is one of the oldest location technologies that provided the location of the users in 3D. GPS works well in urban outdoor environments, but it is quirky, unreliable and its accuracy degrades when the device is indoors and has limited line-of-sights to the satellites. It is not ubiquitously available and hence not suitable for under water and cluttered urban environments [2]. Additionally, it cannot be used for the future calm technology, as it is not practically implementable on low power devices and also size and the cost pose harsh limitations. Table 2 shows the comparison of various outdoor geo-location systems.

System	Method	Coverage	Dimensions	Accuracy
Loran	Hyperbolic	Cont	2D	250m
Transit	Doppler shift	Global	2D	25m
Omega	Hyperbolic	Global/cont	2D	2-4km
GPS	Spherical	GLobal/Cont	3D	5-10m

Table 2. A comparison of several radio navigation methods

Bulusu has designed a *GPS-less system* for outdoor locations suited for very small, low cost devices [4]. The system uses a RF-based signal technology and proximity based position estimation and got satisfying results. In principle the system can be used indoors, but in this case the accuracy is bad.

The *active badge* [35] is the one of the early centralized indoor personal location system making use of IR technology. Each person in the office wears a badge, which emits a unique IR signal that is then gathered by the network of sensors and collected by a master server. The information is then relayed, to the visual display location manager. This was mainly used as an aid for the telephone receptionists to direct the phone calls to appropriate persons during working time. However its range was limited and obstacles such as walls and windows made it difficult for the IR signal to propagate. Nevertheless it works well for the intended application of routing telephone calls.

However, the Active Badge is not able to provide fine-grained 3D location information, which is needed by many applications. So the *Active Bat* [10] system was developed, with a primary focus on low power, low cost and accuracy. The bat is attached to the objects or persons whose location has to be determined. These bat transmitters emit ultrasound pulse, which are received by the receiver that is mounted on the ceiling. A central controller coordinates the transmitters and receivers. To locate a particular bat, the controller sends the unique ID over the radio channel. When a bat detects its ID, it sends an ultrasound pulse, which is picked by receivers in the ceiling. From the time-of-flight measurements, the system can calculate the 3D position of a bat to an accuracy of 3cm. Figure 3 shows the Active Bat System.¹

Cricket location [28] support systems make use of proximity based lateration techniques for providing location information. Many beacons installed at known locations advertise the identity of that space with the use of some character string and every device in the network has a listener attached to it. The Listeners use some inference algorithm to determine the space in which they are currently located by listening to the beacon announcements. Each beacon sends two signals, an RF signal carrying the location data and an ultrasound carrying a narrow pulse. Based on the difference of arrival times, the device finds the absolute distance between the beacon and the listener.

¹ Graphics copied from [10].

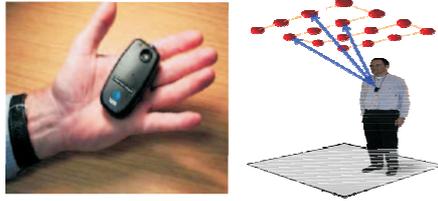


Fig. 3. Active Bat System, developed by AT&T and Cambridge University.

RADAR [1] makes use of RF signal for finding the user location indoors. A centralized system gathers signal strength information from multiple receivers and performs triangulation to compute the location of the user.

Pinpoint 3D-iD [27] is similar to RADAR, but expensive. Proprietary base stations and tag hardware are used to measure radio time of flight. It uses an installed array of antennas at known positions to perform multilateration. Pinpoint's accuracy is roughly 1 to 3 meters.

In the *SpotOn system* [14], special tags use radio signal attenuation to estimate the distance between tags. The aim in SpotOn is to localize a wireless device relative to one another, rather than to fixed base stations, allowing for ad-hoc localization.

HP Labs *SmartLOCUS* [16] uses synchronized RF and ultrasound differential time-of-flight measurements to determine the inter-nodal range between any two nodes. It yields an accuracy of 2-15 cm.

Georgia Institute of Technology's *Smart floor* [25] identifies people based on their footsteps. The goal of the system is to create an accurate system for recognizing a user's identity. However, this technology's negative side is the huge installation cost and infrastructure cost.

UBISENSE [34] uses UWB technology to locate people and objects to an accuracy of 15cm. Sensors are mounted in the area to be monitored. Ubitags attached to objects or carried by people are then automatically tracked to provide accuracy and reliability.

There are also systems that make use of *Radio Frequency Identification (RFID)* technology, for locating objects inside buildings. RFID is a radical means of enhancing the supply chain, especially for Returnable Transport Items [20]. RFID includes RFID readers, RFID tags and communication between them. One example is the *LANDMARC* systems [22].

Computer vision has also been used in localization. Microsoft's *Easy Living* [17] uses Digiclops real-time 3D cameras to provide stereovision-positioning capability in a home environment. However the dependence on infrastructural processing power, can limit the scalability of such systems for many applications.

Ekahau Positioning system is a software based positioning solution that can continuously pinpoint and track the location of mobile computing devices with an accuracy of 1-2 meters in indoor and campus environments. Unlike the com-

peting solutions, Ekahau technology does not require any additional wireless infrastructure on top of the standard Wi-Fi network [7].

All the systems described above are already implemented. However, there are many other theoretical methods available to solve the location identification problem. We describe these methods in the next section.

4.2 Theoretical Methods

An often ignored issue in ongoing research is the impact of beacon density and the placement of the beacons. Self-configuring localization systems consider beacon density as an important parameter in characterizing the localization quality. Two algorithms were developed HEAP and STROBE [2] depending on the density of beacons in the network.

In the *convex optimization* [6] approach, the positional information is inferred from connectivity imposed proximity constraints. Few nodes have known locations, called the anchor nodes, and the remaining nodes infer their position from the knowledge about communication links.

MDS-MAP [32] is a method that makes use of connectivity information to provide locations in a network with or without beacons (known co-ordinates). The advantage of MDS-MAP is that it has a wide range of applicability, having the ability to work with both simple connectivity and range measurements to provide both absolute and relative positioning [32] [23]. Both convex optimization and MDS-MAP require centralized computation.

Whilst lot of research was initially based on range-based schemes, many developments in range free schemes also came in. Range free schemes make no assumption about validity of distance or angle information like the range based schemes. Some examples to quote are *Centroid algorithm*, *APIT*, *amorphous localization* and *DV-Hop algorithm*. In the centroid method [4], each node estimates its location by calculating the center of the locations of all seeds (or anchors) it hears. If seeds are well positioned, the location error can be reduced [3], but this is not possible in ad-hoc deployments. The APIT method [12] isolates the environment into triangular regions between beaconing nodes, and uses a grid algorithm to calculate the maximum area in which a node will likely reside. DV-based positioning algorithms are localized, distributed, hop by hop positioning algorithms [23] [24]. They work as an extension of both distance vector routing and GPS positioning in order to provide approximate positions for all nodes in a network where only a limited fraction of nodes have self positioning capabilities. They use the same principle of GPS, with the difference that the landmarks are contacted by hop-by-hop fashion rather than a direct connection and similar to distance vector each node at any time can communicate only with its neighbors. The amorphous method [21] is similar to DV-hop as the coordinates of the seeds are flooded throughout the network so each node can maintain a hop count to that seed. Nodes calculate their position based on the received seed locations and corresponding hop count. From an extensive study on range free schemes and on benchmarking various range free schemes, Tian He et al. [12] concluded that range free schemes offers cost effective solutions.

Table 3 lists the comparison between various range free schemes. Tian He et al. experiment with several parameters such as node density (ND), anchors heard (AH), anchor to node range ratio (ANR), anchor percentage (AP), degree of irregularity (DOI), GPS error and placement of node and anchors.

Recently research on localization is focused on incorporating the mobility model. Although mobility makes the analysis more difficult, more accuracy is obtained. In [15], Lingxuan Hu et al. use a *sequential Monte Carlo Localization* method and argues that they exploited mobility to improve accuracy and precision of localization. Probabilistic techniques, such as *Markov modeling*, *Kalman filtering* and *Bayesian analysis* can also be used to determine the absolute location of a mobile node [18].

	Centroid	DV Hop	Amorphous	APIT
Accuracy	Fair	Good	Good	Good
Node Density	>10	>8	>8	>6
Anchors Heard	>10	>8	>8	>10
ANR	>0	>0	>0	>3
DOI	Good	Good	Fair	Good
GPSError	Good	Good	Fair	Good
Overhead	Smallest	Largest	Large	Small

Table 3. Comparison of range free schemes

Table 4 gives a global view of localization techniques classified by achievable accuracy and the type of location estimation used for various technologies.

Technology	Accuracy	Location Estimation	Example
Infrared based	5-10m	Proximity	Active Badge
Ultrasound based	1-10cm	TOF-lateration	Active Bat
Vision based	1cm-1m	Scene Analysis	Easy Living
RF-UWB based	6-10cm	TOF-triangulation	Ubisense
RF-Bluetooth based	2-10m	Proximity, Triangulation	
RF-WLAN based	2-100m	Triangu.,Proximity,Scene An.	Radar
Satellite based	5-10m	Triangulation	GPS
RF cellular based	50-10m	Triangulation,Proximity	GSM localization
RFID based	5cm-5m	Proximity	Landmarc

Table 4. Summary of existing localization systems. Accuracy as reported in [11].

5 Conclusions and Future work

Designing a location system for a particular environment presents difficulties when the system is applied to other environments. Despite the plethora of established location technology, there is no single location technology that may be relied upon in all environments to provide accurate location information. Clearly “*No one size fits all*”, there may not be a single best technology. However each of the techniques has its own pros and cons.

Ubiquitous computing is the *wave of the future*. Recent advancement in the various related technologies are paving way for the design and implementation of the future ubiquitous computing. *Location identification* is an important research area that had gained additional credit since the epoch of pervasive computing. This paper provided an overview of the existing location systems/algorithms and also highlighted the limitations of the existing technologies. In order to improve the existing techniques in future, we would focus on developing new distributed localization algorithms for resource poor ambient systems. They need to address specific issues like ease of deployment, scalability, and automatic configuration. Additionally, they need to provide easy adaptability to different types of environment, self-calibration, responsiveness, accuracy, be tolerant to node failures and range errors. Also of great importance is self-organization as it is infeasible to manually configure the location determination processes for a large number of mobile devices in random configurations with random environmental characteristics. Last but not least, we need to keep an eye on the cost factor—computational power, resources needed and money.

While there is plenty of research going on in developing new systems or algorithms, yet another available solution on hand is to make use of the existing systems/algorithms and choose the best in each case and fuse the location information reported by several technologies to get more meaningful results. It is not just sufficient to have technology development, also of foremost importance is to use the existing systems and have a means to have them integrated so that seamless transition between the available systems is achieved. Ideally the localization system should provide a framework to integrate location reading from all these sensor types into one seamless environment. The future research in the project Smart Surroundings [33] addresses all these issues and will provide an open platform for supporting new architectures and frameworks for the future ambient systems.

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