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Localization in Cooperative Wireless Sensor Networks: A Review

Mert Bal [1, 2], Min Liu[1, 3], Weiming Shen [1, 2], Hamada Ghenniwa [2]
[1] *Centre for Computer-assisted Construction Technologies, National Research Council, Canada*
[2] *Dept. of Electrical and Computer Engineering, University of Western Ontario, Canada*
[3] *School of Electronic and Information Engineering, Tongji University, Shanghai, China*

Abstract

Localization in Wireless Sensor Networks has become a significant research challenge, attracting many researchers in the past decade. This paper provides a review of basic techniques and the state-of-the-art approaches for wireless sensors localization. The challenges and future research opportunities are discussed in relation to the design of the collaborative workspaces based on cooperative wireless sensor networks.

Keywords: Wireless Sensor Networks, Localization Algorithms, Cooperation, Collaborative Workspaces.

1. Introduction

Recent developments in wireless communication and MEMS IC technology have made possible the use of large networks of wireless sensors for a variety of new monitoring and control applications [1]. A micro-sensor is a small sized and low powered electronic device with limited computational and communication capabilities. A Wireless Sensor Network (WSN) is a network containing some ten of millions of such micro-sensors. These sensors could be measuring a variety of properties, including temperature, acoustics, light, and pollution.

The WSNs can be developed at a relatively low-cost and can be deployed in a variety of different settings. A WSN is typically formed by deploying many sensor nodes to sense the physical characteristics of the world.

The automatic location detection of sensors, namely localization is an important issue for WSN applications, especially in cases, when the sensors are deployed randomly, or when they move about after deployment. One reason is that a sensor's location must be known for its data to be meaningful. In most cases, the location itself is often the main data that needs to be sensed. Position information is essential to many location-aware sensor network communication protocols such as packet routing and sensing coverage [2].

The localization in WSN is a significant, key enabling technology, attracting considerable research interest. With the constrained resources of network sensors, as well as their high failure rate, many challenges exist in the automatic determination of the sensor's location. Various application requirements such as; scalability, energy efficiency, cost, accuracy, responsiveness and privacy influence the research and development of sensor localization systems [3].

As shown in [4], the processor power consumption is an important factor that directly affects the lifetime of a WSN and therefore, it must not be overlooked. Moreover, the small amount of code space available in WSN nodes make the implementation of both the data service logic and the localization algorithm on a single node a problematic issue, which forces the researchers to reduce the complexity of the localization techniques.

So far, in this domain, a number of state-of-the-art systems and technologies have been developed addressing the problem of automatic location sensing for various application scenarios. The effectiveness of the existing localization systems vary, depending on the parameters, such as: the physical phenomena used for location determination, the form factor of the sensing apparatus, power requirements, infrastructure versus portable elements, and resolution in time and space, etc. [5].

It should be noted that the performance and effectiveness of any given localization system is completely application-dependent. This means that each localization approach solves a slightly different problem or supports different applications; therefore, there is no 'one size fits all' solution for localization of the WSNs.

The objective of this paper is to summarize and review the literature of localization systems proposed particularly for localizing sensor nodes in WSN in order to provide a guideline for low-level application developers. We describe and clarify the current research issues in this field in relation to the real-time indoor tracking applications of the WSN localization schemes.

The remainder of the paper is organized as follows: Section 2 briefly describes the background of the WSN in general; Section 3 presents a classification of the WSN localization systems; Section 4 outlines the major localization systems and discusses the current state-of-the-art; Section 5 identifies the challenges and future research opportunities and finally Section 6 provides some brief concluding remarks.

2. Background: Wireless Sensor Networks

In the last few years, technological progress has been taking the spread of the embedded control steps further. Through the integration of ubiquitous computing [6] in daily life, the computation will eventually surround the living spaces, realizing the vision of ambient intelligence, where many different devices will gather and process information from many different sources to both control physical processes and to interact with human users.

In order to realize this vision, communication has been recognized as a crucial aspect in addition to computation and control. All these sources of information have to be able to transfer the information to the place where it is needed – an actuator or a user – and they should collaborate in providing as precise a picture of the real world as required. For some application scenarios, the existing wired networking technologies are sufficient for building such networks of sensors and actuators. For many other application types, however, the need to wire together all these entities constitutes a considerable obstacle to success: wiring is expensive, in particular, given the large number of devices that is imaginable in our environment, wires constitute a maintenance problem; wires prevent entities from being mobile; and wires can prevent sensors or actuators from being close to the phenomenon that they are supposed to control. Hence wireless communication between such devices is, in many application scenarios, an inevitable requirement.

The WSN is a new class of network, evolved in the past few years as a consequence of the developments in the MEMS technology to satisfy the growing requirements of computing.

The WSNs consist of individual nodes that are able to interact with their environment by sensing or controlling physical parameters. The nodes often have to cooperate to fulfill their tasks as, usually a single node is incapable of doing so, and they use wireless communication to enable this collaboration. The WSNs are powerful in that they are amenable to support a variety of real world applications; they are also a challenging research and engineering problem because of their flexibility [7].

In most of the applications requiring long operation time, energy efficiency is an important consideration, due to the fact that the sensor nodes are dependant on limited run time power, usually provided by on-board batteries. Numerous sensors that are close to the phenomenon can make the architecture of a system both simpler and more energy efficient due to distributed computation.

Apart from the need to build cheap, simple to program, simple to network and potentially long-lasting sensor nodes, a crucial and primary ingredient for developing actual applications is the sensing facility with which a sensor node can be endowed. For many physical parameters, appropriate sensor technology exists that can be integrated in a node of a WSN. Some of the popular ones are temperature, humidity, visual and infrared light, acoustic, vibration, acceleration, pressure, chemical sensors, mechanical stress and magnetic field.

On the basis of nodes that have sensing and actuation capabilities, many different application scenarios can be constructed. The major application scenarios include; disaster relief applications (i.e. detection of wildfire or forest fire) [8]; environment control (i.e. detection of chemical pollution earth movement, habitat monitoring); intelligent buildings (i.e. HVAC systems control [9] for energy consumption optimization, monitoring mechanical stress levels in structures); facility management (tracking people and assets, monitoring leaking chemicals in chemical plants); preventive maintenance of machines, medicine and health care (monitoring patient or elderly health conditions) [10].

In many circumstances, it is necessary for a sensor node in a WSN to be aware of its location in the physical world in which it resides. In other words, the node's location must be known in order to collect meaningful data from a physical phenomenon. Due to the fact that the sensor nodes are usually deployed in high quantities and their position is often subject to changes, each node has to be equipped with an onboard positioning system such as: GPS that tells the location. However, the GPS is often impractical to use in WSNs due to cost and deployment limitations [11]. The WSNs are often facilitated with localization systems that use various special techniques for automatically detecting the position of nodes.

Sensor network localization techniques usually consist of the algorithms that estimate the locations of sensors with initially unknown location information by using knowledge of the absolute positions of a few sensors and inter-sensor measurements, such as distance and bearing measurements. Sensors with known location information are called beacons or anchors. The anchors define the local coordinate system to which all other sensors are referred. The coordinates of the sensors with unknown location information, also called blind or non-anchor nodes, will be estimated by various sensor network localization techniques.

3. Classification of WSN Localization Techniques

The researchers, focusing on research on several aspects of WSN localization, have ended up with a variety of different localization approaches according to the nature of the given problem. Hence, the existing WSN localization techniques can be classified into many categories. However, in general, almost all the sensor network localization algorithms share three main phases; i) distance estimation, ii) position computation and iii) localization algorithm. In order to summarize the existing state-of-the-art, in this paper, we classify the WSN localization algorithms under these three phases.

The distance estimation phase involves measurement techniques to estimate the relative distance between the nodes. Position computation consists of algorithms to calculate the coordinates of the unknown node with respect to the known anchor nodes or other neighboring nodes. The localization algorithm, in general, determines how the information, concerning distances and positions, is manipulated in order to allow most or all of the nodes of a WSN to estimate their positions. Optionally, the localization algorithm may involve algorithms to reduce the errors and refine the node positions.

3.1 Measurement Techniques for Distance Estimation

The distance estimation process highly influences the accuracy and precision. The communication between two nodes allows extracting information about connectivity/proximity and their geometric relationship.

Various measurement techniques are employed for measuring the range between nodes in a network. The four common methods of measuring range are angle of arrival, time of arrival, time difference of arrival and received signal strength indicator.

The Angle of Arrival (AoA) methods allows each sensor to evaluate the relative angles between received radio signals [12]. The advantage of this method is the high accuracy, and the main disadvantage is the additional hardware they employ. Various approaches developed for AoA can be found in [13], [14] and [15].

The Time of Arrival (ToA) and Time Difference of Arrival (TDoA) methods try to estimate distances between two nodes using time based measures [16]. The distance between two nodes is directly proportional to the time the signal takes to propagate from one point to another. This type of estimation requires specific hardware and precisely synchronized nodes and the time at which the signal leaves the node must be in the packet that is sent. Therefore, the cost is generally high.

The Received Signal Strength Indicator (RSSI) is based on the physical fact of wireless communication that: theoretically, the signal strength is inversely proportional to the squared distance between the transmitter and receiver. A known radio propagation model is used to convert the received signal strength into distance. In RSSI techniques, either theoretical or empirical models are used to translate signal strength into distance. The RSSI technique is the simplest and cheapest method amongst the range-based measurement techniques, since it does not require additional, dedicated hardware. However, in real-world environments, this indicator is highly influenced by noises, obstacles, and the type of antenna, which makes it hard to model mathematically [16], [17].

Several efforts have been spent on developing distance-based measurement techniques. For example, the lighthouse approach derives the distance between an optical receiver and a transmitter of a parallel rotating optical beam by measuring the time duration that the receiver dwells in the beam [18].

In addition to these common approaches, there are a number of other localization algorithms based on the data fusion of hybrid measurements [19]. Fundamentally, localization based on hybrid measurements, can achieve a performance improvement over that based on a single measurement type because measurement noise for different types of measurements comes from different sources. Various hybrid approaches have been discussed in [20-23].

Recently, the use of ultra wide band (UWB) signals for propagation time measurements has become popular in accurate distance estimation. UWB can achieve higher accuracy because its bandwidth is very large and therefore its pulse has a very short duration [24, 25].

In the domain of WSN localization, the distance estimation process is not limited to the range measurements but is based on connectivity information between the nodes. These approaches are called range-free localization techniques, which will be discussed later in this paper.

3.2 Position Computation Techniques

In the literature, several methods have been widely used for calculating the coordinates of the blind node based on range/connectivity information. The well-known techniques are lateration, multilateration, and angulation.

Lateration is a technique of computing the location of a blind node, based on the precise measurements to three noncolinear anchors. The extension to a three dimensional space is trivial and it requires four anchors. Lateration, which is performed using the three anchors, is called trilateration and more than three anchors is called multilateration. Multilateration is a core solution technique for positioning applied to WSNs and serves as a building block for many other localization approaches.

Angulation or triangulation is recognized as a common method for position computation, based on the information about angles**,** instead of distances. In WSNs, triangulation computation is done by the blind node itself. The blind node estimates its angles from at least three anchor nodes and computes its own position using simple trigonometrical relationships. This technique is similar to trilateration. In fact, based on the AoAs, it is possible to derive the distances to the reference nodes.

The uncertainty in distance/angle estimations has motivated researchers to develop some alternative techniques for computing a node's position.

S. Simic and S. Sastry [26] have proposed the bounding box method, which uses squares instead of circles, as in trilateration, to bind the possible positions of a node. A bounding box is defined using the intersecting squares derived from the radio range of the anchor nodes. The center of the square points to the position of the blind node. The intersection of all bounding boxes can be easily computed without any need for floating point operations by taking the maximum of the low coordinates and the minimum of the high coordinates of all bounding boxes. This technique is also known as the Min-Max method [27].

V. Ramadurai and M. L. Sichitiu [28] have proposed a Probabilistic Approach, where the errors in distance estimations are modeled as normal random variables for finding the probable location of the blind node, based on statistical methods which use the collective information received from the neighbouring nodes.

In addition, the fingerprinting technique handles the localization problem more like a pattern matching or data mining problem rather than calculating a localization parameter (angle or distance) [29]. Briefly, the technique consists of creating a (preferably) huge database of pre-measured RSS values coupled with respective locations, then trying to match RSS values taken from blind-nodes with the values in that database.

3.3. The Localization Algorithm

According to the ways of their implementation, we classify the current WSN localization algorithms into several categories such as: node connectivity and topology (i.e. single-hop or multi-hop localization); dependency of the range measurements (i.e. range-based vs. range-free); distributed or centralized position computation- with or without an infrastructure (anchor-based or anchor-free).

3.3.1. Single-Hop vs. Multi-Hop Algorithms

In a typical WSN, a direct link between two neighbor nodes is called a *hop*. Localization algorithms that only make use of single-hop radio information are called the one-hop or 'single-hop'. Single-hop localization is possible when a sufficient number of beacon nodes is comprised of one hop neighbors of a blind-node. A GPS system is a good example. It uses satellites as beacons and performs multilateration to position a mobile target on the earth's surface [30].

When the distance between two nodes is larger than the radio range but there are other nodes that create a continuous path between them, the path is called a multi-hop path. In WSNs that cover a wide area, such as a forest, there are many node pairs that can only communicate over a multi-hop path. The structure of such a WSN is called a multi-hop topology. Multi-hop localization algorithms seek a scalable solution to the localization problem. For a multi-hop algorithm, input is a symmetric, square matrix of inter node distances constructed with shortest paths along the topology.

The most challenging issue here is to overcome the problem of shortest-path/Euclidean distance deviation. The ambiguity of a single-hop distance, with the varying radio ranges of sensor nodes, generates a cumulative effect on estimation errors in multi-hop networks.

The single-hop algorithms are lighter and simpler than multi-hop solutions but they have severe scalability problems. Multi-hop localization schemes, on the other hand, are much more scalable because of their distributed nature.

3.3.2. Range-Based vs. Range –Free localization

With regard to the mechanisms used for distance estimation, the existing localization algorithms can be classified according to distance estimation into two categories; 'range-based' and 'range-free'. The range-based approaches exploit range information (distance or angle estimates) for calculating location. The range-free methods do not need absolute range information for distance estimation but they use the number of hops between a node pair as a distance metric. The accuracy of range-free methods is less than the range-based ones but they satisfy the requirements for many applications. Because of the hardware limitations of WSN devices, solutions in range-free localization are being pursued as a simple and cost-effective alternative to more expensive range-based approaches. The most obvious disadvantage of this scheme is the fact that it performs poorly for irregular topologies.

3.3.3. Centralized vs. Distributed localization

In certain types of WSNs, the architecture is already centralized due to the nature of the problem the network is dealing with. Most of the networks, designed for monitoring and control purposes, are centralized because the data gathered is accumulated in one or more servers to be processed. In such environments, centralized solutions to the localization problem are most appropriate. The advantage of centralized approaches is the accuracy they provide.

Distributed algorithms differ from centralized algorithms since the information about a node (RSSI, AOA...) stays within the proximity of that node. Centralized approaches collect such information in a single server for processing.

In distributed algorithms, the general trend is to execute the localization algorithm on each node so that they can locate themselves relative to their neighbors. After this relative localization phase, and erecting a local map in each node, a global map has to be created. This is usually achieved by merging local maps and transforming coordinate systems with respect to known beacon positions. Distributed solutions tend to distribute and increase the error, cumulatively. This is because in multi-hop execution, there are a considerable number of blind nodes that cannot directly communicate with any beacon nodes.

3.3.4. Anchor-Based vs. Anchor-Free Localization Algorithms

In the context of the existence of nodes with known positions, also called *beacon* or *anchor* nodes, localization algorithms can be further classified into two groups: *anchor-free* and *anchor-based* algorithms.

Anchor-based algorithms, rely on anchor nodes and assume that a certain minimum number or fraction of the nodes know their position, e.g., by manual configuration or using some other location mechanism (i.e. GPS). The final coordinate assignment of individual nodes will therefore be valid with respect to another, possibly global, coordinate system.

Any positioning scheme, built around such algorithms, has the limitation that it needs another positioning scheme to bootstrap the anchor node positions, and cannot be easily applied to any context in which another location system is unavailable (e.g., strictly interior to a building). It turns out that, in practice, a large number of anchor nodes are needed for the resulting position errors to be acceptable [6]. In anchor-based algorithms, the percentage of anchor nodes over blind nodes is generally very small. Most of the studies (including [31], [5]) using anchor-nodes suggest that even a small number of anchor nodes significantly increases the performance of a localization algorithm.

Anchor-free algorithms use local distance information to attempt to determine node coordinates when no nodes have pre-configured positions. Of course, any such coordinate system will not be unique and can be embedded into another global coordinate space in infinitely many ways, depending on global translation, rotation, and possibly, flipping. This limitation is fundamental to the problem specification, and is not a limitation of the algorithm.

If the coordinates assignments must conform to another coordinate system such as GPS, any algorithm that does not use anchor nodes can easily be converted to one that uses a small number of anchor nodes by adding a final transformation where all the node coordinates are transformed using three (in 2-D) or four (in 3-D) anchor nodes.

Priyantha *et al.* [32] have proposed a decentralized anchor-free localization algorithm, where nodes start from a random initial coordinate assignment and converge to a consistent solution using only local node interactions.

There are two classes of anchor-free algorithms, namely, the incremental algorithms and concurrent algorithms.

The incremental algorithms usually start with a core of three or four nodes with assigned coordinates. Then they repeatedly add appropriate nodes to this set by calculating the node's coordinates, using the measured distances to previous nodes, with already computed coordinates. These coordinate calculations are based on either simple trigonometric equations or some local optimization scheme. A drawback of incremental algorithms is that they propagate measurement errors, resulting in poor overall coordinate assignments. Some incremental approaches apply a later global optimization phase to balance such an error, but it remains difficult to jump out of local minima introduced by the local optimization in the incremental phase.

In the case of concurrent algorithms, all the nodes calculate and refine their coordinate system in parallel. Some of these algorithms use an iterative optimization scheme that reduces the difference between measured distances and the calculated distances, based on current coordinate estimates. In these algorithms, the network is divided into small overlapping sub-regions, each of which creates a local map. Then, the local maps are stitched together to form a single global map.

The concurrent approach works much better for topologies in which the shortest path distance between two nodes does not correspond well to their Euclidean distance [33].

Recently, this class of algorithms received a great deal of attention. Several researchers have developed well-known methods, for example MDS-MAP, which uses connectivity information to roughly estimate the distance between each possible pair of nodes. The method uses the multidimensional scaling (MDS), a technique from mathematical psychology, to derive node locations for those estimated distances and normalize the resulting coordinates to take into account any nodes whose positions are known [34].

Oh-Heum Kwon, and Ha-Joo Song [35] have introduced a map stitching localization algorithm based on a technique for map-to-map stitching that exploits every available distance between two maps.

4. Review of WSN Localization Systems

4.1 Systems based-on single-hop localization

Werb and Lanzl [36] have designed and developed the Pinpoint's 3D-iD system for positioning of the small devices and assets indoors. This positioning system is one of the first single-hop local positioning solutions that covers an entire three-dimensional indoor space and is capable of determining the 3-D location of items within that space. The system subdivides the interior of the building into cell areas that vary in size with the desired level of coverage. The main drawback of this system is that it is centralized, and requires significant infrastructural set up.

Harter *et al.* [37] have developed the Active Bat location system, which consists of a collection of fixed nodes arranged on a grid. The fixed nodes receive ultrasonic chirps from the mobile device and compute distance estimates to the mobile using the time-of-flight of the ultrasonic signals. The Bat system employs a centralized architecture in which both mobile transmissions and mobile position estimations are handled by a central computer. As a successor of the Active Badge project [38], the Bat system, as described, is expensive to implement in that it requires large installations, has a centralized structure, and does not preserve user privacy.

Hightower *et al.* have developed the SpotON tags for indoor location sensing, based on signal strength measurements. The system uses radio signal attenuation to estimate the distance between tags. It localizes the wireless devices relative to each other [39].

Bahl and Padmanabhan [40] have designed and tested the RADAR system for indoor localization which uses a kind of fingerprinting algorithm to perform extensive RF signal strength measurements offline in order to design signal strength maps. These maps are used during localization to estimate the distance from signal strength measurements.

Priyanta *et al.* [41] have developed the Cricket localization system for indoor environments, fixed beacons, broadcasting local geographical information to the listener nodes to increase the accuracy of distance estimation from ultrasound signals. The Cricket considers the blind nodes as listeners, which receive consecutive radio frequency signals and ultrasound pulses from anchors in order to determine the distances in a decentralized manner. Although the overall system has been reported as possessing high accuracy, it is a decentralized, anchor-based localization system and requires complex hardware and costly installation of anchor nodes.

Bulusu *et al.* describe a single-hop, range-free scheme that uses the radio connectivity of a node to a set of anchor nodes to determine its coordinates [42]. The coordinates of non-anchor nodes are obtained by calculating the centroid of all the anchors in the nodes radio-range. Nodes localize themselves to the centroid of their proximate reference points. The accuracy of localization depends on the distance separating two-adjacent reference points and the transmission range of these reference points.

He *et al.* [5] has developed the APIT algorithm, which employs an *area-based* approach to perform location estimation of a sensor node by isolating the environment into triangular regions and which allows a node to narrow the area in which it can potentially reside.

Baggoi and Langendoen [43] have presented a range-free, anchor-based localization algorithm for mobile wireless sensor networks that builds upon the Monte Carlo localization algorithm with the aim of improving the localization accuracy.

4.2 Multi-hop localization algorithms

Niculescu *et al.* [44] proposed a well-known algorithm of DV(Distance Vector)-Hop Localization, which collects the neighborhood information from the network and calculates shortest-paths between non-neighboring nodes. The DV-Hop algorithm uses known locations of beacon nodes to estimate a hop size, and then guesses distances from beacon nodes to blind nodes using the shortest-path hop distances.

The Amorphous Positioning algorithm, described in [45] uses offline hop-distance estimations, like the DV Hop, improving location estimates through a neighbor information exchange. Each sensor produces a locally propagating *gradient* that allows other sensors to estimate their distance using a multilateration procedure to combine the distance estimates from all the neighbor sensors to produce its own position [46].

Savvides *et al.* [47] have introduced N-Hop multilateration, which uses the bounding box approach for distributed position computation for avoiding the error accumulation in the sensor network and improving accuracy.

Heurtefeux and Valois [27] introduced a coarse grained localized algorithm which classified the proximity of the neighborhood for a node. Each node builds a Qualitative Distance Table according to the hop neighborhood information. Thus, the algorithm allows for a coarse determination of the location of the neighbors, which are classified as very close, close or far.

Capkun *et al.* [48] have proposed a Self-Positioning Algorithm (SPA) for positioning of the nodes in a multi-hop, ad-hoc network. The algorithm uses the distances between the nodes to build a relative coordinate system in which the node positions are computed in two dimensions. The nodes in the network will then compute their positions in the coordinate system of the n-hop neighborhood of the node with a highest density factor. This procedure is expensive in terms of the number of messages to be exchanged since each node individually re-orients its coordinates to the reference node's coordinates.

5. Challenges and Opportunities

The existing algorithms and state-of-the-art systems for WSN localization vary in many parameters, such as the physical phenomena used for location determination, the form factor of the sensing apparatus, power requirements, infrastructure versus portable elements, and resolution in time and space [49].

The cost and limitations of the hardware on sensing nodes prevent the use of some of the localization schemes in real-world tracking applications. In addition, accuracy, calibration, fault tolerance, scalability and energy efficiency are major issues that must be addressed in the area of automatic location determination of a sensor's location. Hence, there is already extensive research potential for optimizing the cost and energy consumption, while improving the accuracy, scalability and fault tolerance of the WSN localization techniques.

The accuracy and precision of a location sensing system is often used to determine whether the chosen system is applicable for certain applications [31]. The accuracy of the measurements plays a very important role in range-based WSN localization and it depends often on the implementation measurement techniques, device calibration noise and environmental conditions. The uncalibrated ranging readings are always greater than the true distance and are highly erroneous due to transmit and receive delays [50].

The scalability is a significant attribute of WSN localization, as the proposed localization approach should be scalable for large networks. Also of great importance is self-organization, as it isn't feasible to manually configure the location determination processes for a large number of mobile devices in random configurations with random environmental characteristics. These issues are often underestimated by researchers working in the field of localization.

As noted earlier, the performance of any localization technique depends completely on the application, in which the wireless sensors are intended to be deployed, meaning that each localization approach solves a slightly different problem or supports different applications. In the context of the implementation of WSNs into real systems for tracking or location-aware monitoring purposes, the challenge is to find out the most suitable localization algorithm for any application domain.

The WSN application developers intend to focus on range-based localization techniques for achieving stability. The majority of developed multi-hop localization techniques, such as range-free schemes, is not implemented and remains at the theory level. Most of the development efforts of this type of technique, as also reviewed in this paper, have been carried out in simulated environments. The design requirements and specifications of ad-hoc localization techniques should be studied deeper in consideration of the application scenarios.

In the domain of the localization for WSN, for simplicity, the position computation problems are mostly formulated and solved in two dimensional planes.. Several techniques developed address the 2-D solutions of location determination and only a few researchers provide detailed analysis and the benefits of the 3-D aspects of these solutions [51, 52]. In addition, most of the software applications and tools, so far developed for WSN visualization, include 2-D presentation of the spaces.

Nevertheless, a three-dimensional representation definitely improves the usability of spatial information and most significantly, the visualization of reality compares to a simple and flat 2-D representation. Of all of the drawbacks of 2-D graphics, the most vital is the lack of capability to offer users a life-like representation of real environments [50]. The WSN localization algorithms, supported with the corresponding 3-D visualization systems will have considerable potential, especially in developing Virtual Reality based workspaces

Virtual Reality, (VR) is an emerging technology, which puts the user and the information support elements in direct relation to the operation of the system in a three dimensional realistic environment to provide a sense of reality and an impression of 'being there'. Understandable 3-D animation models of VR will help in building and controlling the real world applications of WSNs.

In some instances the actual simulation could be carried on concurrently as the WSN application is being built. Such an approach will enable the developer to speed up the time to market by integrating systems design and construction so that the overall system is tested in real time on a computer at the same time. The visualization of sensor nodes in 3-D, allowing the establishment of cooperative and collaborative real-time workspaces, could yield essential tools for deployment or monitoring of the sensors in real life applications.

In addition, collaborative VR could offer benefits for cooperative design and monitoring of the facilities with the support of the WSNs. The facility managers and plant supervisors can 'collaboratively' evaluate multiple plants and buildings, remotely, in distant geographic locations using the sensor information provided by the deployed sensor nodes.

The current research in this direction generally focuses on modelling the collaborative behaviour of WSNs [53]. However, deeper research and focus on the WSN localization algorithms and corresponding measurement techniques is necessary for developing applications in 3-D collaborative environments.

6. Concluding Remarks

Wireless sensor network localization has attracted significant research interest. This interest is likely to grow further with the increase in wireless sensor network applications. This paper has provided a review of the techniques in WSN localization and the corresponding state-of-the-art. The localization algorithms were classified according to the measurement, computation, optimization and communication mechanisms they use. Despite significant research developments in the area, there are still many unsolved problems in wireless sensor network localization. A discussion on some challenges and opportunities for extending WSN localization in 3-D were presented in the direction of possible application areas in VR-based collaborative workspaces.

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