2011

Indoor Localization Based on Wireless Sensor Networks

Fujun Yang

Indoor Localization Based on Wireless Sensor Networks

(Thesis Format: Monograph)

by

Fujun Yang

Department of Electrical and Computer Engineering

Submitted in partial fulfillment
of the requirements for the degree of
Master of Engineering Science

School of Graduate and Postdoctoral Studies
The University of Western Ontario
London, Ontario
October 2011

THE UNIVERSITY OF WESTERN ONTARIO
SCHOOL OF GRADUATE AND POSTDOCTORAL STUDIES

CERTIFICATE OF EXAMINATION

Supervisor	Examiners
______________________	______________________
Dr. Weiming Shen	Dr. Evgueni Bordatchev
Co-Supervisor	______________________
	Dr. Abdallah Shami
______________________	
Dr. Hamada H. Ghenniwa	______________________
	Dr. Xianbin Wang

The thesis by

Fujun Yang

entitled:

Indoor Localization Based on Wireless Sensor Networks

is accepted in partial fulfillment of the
requirements for the degree of
Master of Engineering Science

Date______________________	______________________
	Dr. Gerry Moschopoulos Chair of Examining Board

Abstract

Indoor localization techniques based on wireless sensor networks (WSNs) have been increasingly used in various applications such as factory automation, intelligent building, facility management, security, and health care. However, existing localization techniques cannot meet the accuracy requirement of many applications. Meanwhile, some localization algorithms are affected by environmental conditions and cannot be directly used in an indoor environment. Cost is another limitation of the existing localization algorithms. This thesis is to address those issues of indoor localization through a new Sensing Displacement (SD) approach. It consists of four major parts: platform design, SD algorithm development, SD algorithm improvement, and evaluation.

Platform design includes hardware design and software design. Hardware design is the foundation for the system, which consists of the motion sensors embedded on mobile nodes and WSN design. Motion sensors are used to collect motion information for the localizing objects. A WSN is designed according to the characteristics of an indoor scenario. A Cloud Computing based system architecture is developed to support the software design of the proposed system.

In order to address the special issues in an indoor environment, a new Sensing Displacement algorithm is developed, which estimates displacement of a node based on the motion information from the sensors embedded on the node. The sensor assembly consists of acceleration sensors and gyroscope sensors, separately sensing the acceleration and angular velocity of the localizing object. The first SD algorithm is designed in a way to be used in a 2-D localization demo to validate the proposal.

A detailed analysis of the results of 2-D SD algorithm reveals that there are two critical issues (sensor's noise and cumulative error) affecting the measurement results. Therefore a low-pass filter and a modified Kalman filter are introduced to solve the issue

of sensor's noises. An inertia tensor factor is introduced to address the cumulative error in a 3-D SD algorithm.

Finally, the proposed SD algorithm is evaluated against the commercial AeroScout (WiFi-RFID) system and the ZigBee based Fingerprint algorithm.

Acknowledgements

I would like to express my most sincere gratitude to Dr. Weiming Shen, my supervisor. He introduced to me the existing research area of localization based on wireless sensor networks. During the past two years, he offered great help to me in all stages of the work, from defining the research scope, designing the algorithms to writing the thesis. His academic advising has always been inspiring; and his patience and encouragement have all been indispensable for the success of the research. Meanwhile, he also has created many academic exchanging chances for me to extend my vision. That is also very helpful for my research.

I would also like to thank my co-supervisor Hamada H. Ghenniwa for weekly group meetings, teaching and advising, which are all very helpful for me to further my study. His comments and suggestions are appreciated and have stimulated much subsequent thought. Thank him for prompting me to see the project from new perspectives.

My thanks also go to my colleagues of EK3 laboratory and NRC for their always being so caring and supportive. Specially, thanks to Mert Bal, Henry Xue, Mickey Hao, and Jay Xue for their supports and contributions to this research.

Tables of Contents

List of Tables

List of Figures

Chapter 1

Introduction

1.1 Wireless Sensor Networks

1.1.1 Promotive Factors of WSNs

A Wireless Sensor Network (WSN) is a wireless network of spatially distributed autonomous devices using sensors to cooperatively monitor physical or environmental conditions [1] [2].

Micro-electro-mechanism system (MEMS), system-on-chip (SOC), wireless communications, and low-power embedded technologies, rapidly promote the development of wireless sensor networks. Their low-power, low cost, and the characteristics of distributed and self-organization of nodes have brought a revolution in information perception. Wireless sensor networks are deployed in monitoring areas with a large number of low-cost micro sensor nodes through protocol of multi-hop ad hoc networks [3] [4].

1.1.2 Background of WSNs

In the past two decades, the development of WSNs can be divided into three stages: smart sensors, wireless smart sensors, and wireless sensor networks [5]. Smart sensors embedded computing power to the sensors, in the sensor nodes. Such sensors have not only the data collection capacity, but also the capabilities of filtering and information processing. Wireless intelligent sensors based on smart sensors increased wireless communications capabilities, greatly extended the perception range of the sensor sensitivity area, and reduced the cost of the implementation. In a wireless sensor network (WSN), wireless network technologies are introduced into the wireless smart sensors, and each sensor is no longer a single perception unit, but can exchange information, coordinate control, so as to achieve the interaction of objects. WSNs are becoming an important part of the next generation Internet of Things.

In 1996, William Kaiser and his colleagues submitted a report titled “Low Power Systems for Wireless Micro-sensors” to the Defense Advanced Research Projects Agency (DARPA) in USA, which opened the curtain of modern WSNs [6]. In 1998, Gregory Pottie researched the scientific significance of WSNs in the perspective of networks [7]. With the increasing of monitoring needs, in the subsequent decade, WSN technologies have attracted wide attention of academia, industry and even government communities, and become one of the most competitive technologies used in national defense, environmental monitoring and forecasting, health care, intelligent building, smart home, complex machinery monitoring, and so on.

WSN technologies have widely spread as a research area. From 1998 to 2003, WSN was already a hot topic in various international conferences related to wireless communications, Ad Hoc networks, and distributed systems. In 2001, the first specialized academic conference for the sensor network technology, International Conference on Information Processing in Sensor Network (IPSN), supports a new stage for the WSN technologies [8]. From 2003 to 2004, several other conferences on sensor network technologies were organized. In 2005, ACM launched a new journal "ACM Transaction on Sensor Network" to publish the best results of sensor network technologies.

In 2004, Boston University and BP, Honeywell, Inetco Systems, Invensys, Millennial Net, Radianse, Sensicast Systems, and other companies co-founded the Association of sensor networks to promote the development of WSN technologies.

The first facing problem of WSNs application is which kind of network model should be adopted. Network model is used to model the support of infrastructure, the mobile terminal, data transport frequency, and delay network.

According to the different application scenarios, various network models have been proposed and developed (as shown in Figure 1.2):

(1) Flat Network Model: All nodes working as the same roles cooperate the completion of the exchange and aggregation of data. [9]
(2) Hierarchical Clustering Model: Nodes are divided into general data nodes and cluster head nodes, data notes collect and send data to the nearest cluster head node, and then transport data by the cluster head node to the background. [10]
(3) Mesh Model: Mesh model adds a fixed wireless communication notes layer in the sensor network to collect data from sensors, support the communication of nodes, and networks fuse. Akyildiz L.F. [11] summarized the application of Mesh Model in WSNs.

(4) Mobile Convergence Model: Mobile convergence model uses mobile devices to collect sensor data in the target area, and forwards the data to a server. Mobile convergence can improve network capacity, but the data transfer delay impacted by the path of mobile nodes. The typical applications can be seen in [12] [13] [14].

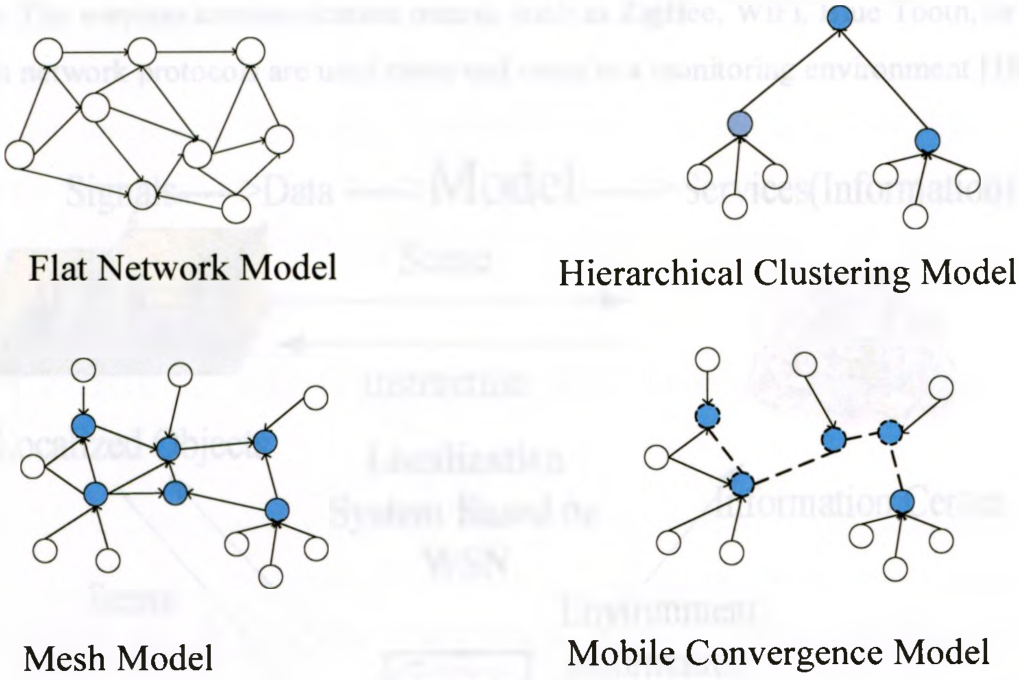

Figure 1.2 Four Types of WSN

In most practical applications, several of these network models are combined to achieve better performance.

1.2 WSN-based Localization

An ideal localization system based on wireless sensor networks can be described as a series of wirelessly interconnected nodes in two-dimensional or three-dimensional space, where there are some reference nodes with known locations. Node localization is thought using certain measurement characteristics and reference node location information to solve all the unknown node coordinates.

In a WSN-based localization system, the data come from sensors are transferred by radio or wire. The wireless communication means, such as ZigBee, WiFi, Blue Tooth, or other wireless network protocols are used more and more in a monitoring environment [18].

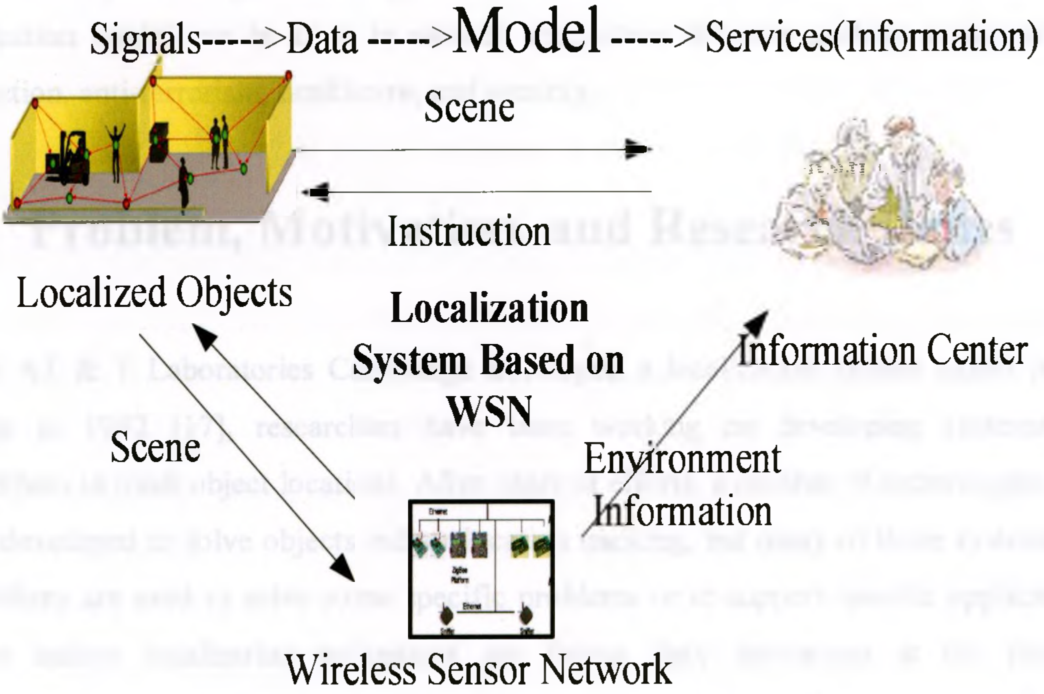

Figure 1.3: Typical Localization Application Model Based on WSN

A typical WSN-based localization application model is shown in Figure 1.3, which also indicates the interaction between sensors and localized objects.

The localized objects are within a localization-scenario which can be a waterfall, a battlefield, a department store, a fire scene, a factory, a health care facility, or an infrastructure. Wireless sensor networks consist of a large number of battery-powered nodes (also called motes), which use functional sensors to collect the localizing information from the localized objects. In some smart wireless sensor networks, the nodes have some information processing capability, such as signal analysis, raw data processing, and even data mining. The information center focuses on the localizing information processing, reasoning, and interaction with the localized objects. This application model can be used in various application domains such as environmental protection, anti-terrorism, healthcare, and security.

1.3 Problem, Motivation, and Research Issues

Since AT & T Laboratories Cambridge developed a localization system called Active Badge in 1992 [17], researchers have been working on developing systems and algorithms to track object locations. After years of efforts, a number of technologies have been developed to solve objects indoor location tracking, but many of those systems and algorithms are used to solve some specific problems or to support specific applications. Those indoor localization techniques are facing their limitations at the physical phenomena, sensor devices composition, energy consumption, infrastructures and space complexity. There are some common challenges as communication overhead, the need for additional hardware and other issues, and so on.

The automatic localization based on WSNs is playing an increasingly important role in industries. However, existing indoor localization techniques still have many problems when used in practical environments. For example, Using Global Positioning System (GPS) [16] is a way to obtain location information. But GPS is only suitable for outdoor environment. For many application scenarios, environments are indoor spaces without GPS signals. Sensors are battery powered, but the battery power is very limited and it is not convenient to replace or recharge batteries.

In addition, wireless sensor nodes are widely varied in the function, communication characteristics, and physical characteristics, because they are produced by different manufacturers. Mostly, smart sensor nodes already have some capabilities of information collection, data transmission, data processing, data storage, and decision making. However, in some distributed applications, the nodes have to cooperate with others to meet the requirements of some collaborative tasks in order to fulfill the requirement of localization applications. It is a new challenge for indoor localization techniques.

In summary, the key challenges on WSN-based indoor localization are to improve the localization accuracy, decrease the nodes power consumption, and enhance collaboration among nodes and sensors. This thesis is to address the localization accuracy challenge.

Various localization techniques and algorithms have been proposed and developed in literatures. However, existing algorithms still have some issues as follows:

- Unknown nodes must be directly adjacent to the reference node
- No distance / angle measurement error suppression
- Low accuracy
- Prone to be interference
- Cost and power consumption

Therefore, more efficient indoor localization techniques are algorithms need to be developed, which should consider the following points:

- Low hardware cost: nodes should be low power consumption, less weight, and cheaper.
- Low computation and communication overhead
- Easy implementation
- High accuracy: to meet the requirement of the indoor application.
- Anti-jamming and indoor environment suitable

1.4 Thesis Overview and Organization

The research work of this thesis consists of the following three aspects:

1. According to the characteristics of a typical indoor environment, a sensing displacement (SD) localization algorithm is proposed to estimate the location of indoor objects. The algorithm is based on the sensing motion information of the monitored object to estimate the object location. The motion information is collected by the accelerometers and gyroscopes embedded on moving nodes.
2. Two virtual spaces are designed to validate the performance of the proposed SD algorithm. Based on the particular scenario of the indoor environment, first step designs the whole architecture of the indoor localization system which adopts the typical web service structure. The challenge of the SD algorithm is analyzed with the testing of a demo system. Meanwhile, a hardware filter (low-pass filter) and software filter (a modified Kalman filter) are used to address the sensors' noise and the cumulative error. The SD localization algorithm achieved a higher localization accuracy (get to 10 cm level). In addition, this algorithm solves the environment noise interference and the affect of the irregular distribution of nodes and mobility obstacles in the environment.

3. Additionally, the proposed SD algorithm is compared against other localization algorithms in a physical testbed.

The remaining chapters of the thesis are organized as follows:

Chapter 2 first gives the mathematical definition of a localization problem, and then reviews several common algorithms of localization based WSNs. Then the chapter introduces the some typical localization systems which are now used different application areas. Finally, Challenges and Opportunities of localization based on WSNs are analyzed in the end of this chapter.

Chapter 3 discusses the difference between indoor and outdoor localization systems, which describes the special characteristics of localization system in an indoor environment. An indoor scenario is defined which include all the typical characteristics of an indoor environment to be used as the demo system testing environment. After the list of the basic techniques, a new SD localization algorithm is designed used in the 2-D localization system with 4 degrees of freedom (DoF). Finally, the implementation of the 2-D localization system is produced to validate the SD algorithm.

Chapter 4 analyzes the estimated results of the 2-D SD localization system. There are two issues in the estimated results. One issue is the location accuracy, which is mainly affected by the noises within the sensors and the cumulative error, where cumulative error is caused by multiple integrations within SD algorithm. Another issue is instability of the system, which is mainly caused by the cumulative error.

Chapter 5 focuses on the improved 2-D SD indoor localization algorithm used into a 3-D virtual space. Based on the analysis in Chapter 4, Chapter 5 adopts three improving points: low-pass filter (hardware filter) and modified Kalman filter (software filter) to decrease the effect of sensor's noises, and inertia tensor factor I to decrease the effect of cumulative error. Lastly, 3-D SD localization algorithm is designed with 6 DoF. Meanwhile, the implementation of the 3-D localization algorithm is produced to validate the feasibility of the proposal.

Chapter 6 summaries the contribution of this thesis and proposes some ideas for future work.

Chapter 2

Literature Review

Currently, many researchers are engaged in the research of indoor localization based on WSNs. In this chapter, firstly the definition of Localization based on WSNs introduced. Then the existing indoor localization algorithms are analyzed and compared. Finally, the issues of indoor localization area are summarized.

2.1 Localization Principles

In the research of wireless sensor networks, node localization has been an active research topic. The a large number of wireless sensor network applications is widely used in many areas, such as battlefield surveillance, environment monitoring, earthquake monitoring, coal main, flood and fires, and other field applications, which mostly can be divided into the two types of principles. Of course, some applications combine several techniques at the same time.

2.1.1 Triangulation Localization Algorithm

Triangulation localization is a basic method of the target localization algorithm. It is also the foundation for many WSN localization systems which use the distance from multiple points to target to coordinately calculate the target localization [19]. In a two-dimensional coordinate system, at least three reference points' distances are needed to uniquely determine target localization in the coordinate system. The target node X coordinate (x, y) are unknown, and the distances from reference point A, B, and C's coordinates (x_1, y_1), (x_2, y_2), and (x_3, y_3) to the unknown node-X are known, as: d_1, d_2, and d_3. Through d_1 which is the distance from A to X, the localization will be able to derive that X certainly is on the circle with A as the center, and d_1 as the radius. As same idea, other two circles can be introduced: one is with B as the center and d_2 as the radius; another one is with C as the center and d_3 as the radius. The three circles intersect at exactly the certain point X (x, y). The unique coordinates (x, y) of X can be calculated based on the three circles. This positioning method can be extended to the three-dimensional case. This method is similar to the localization technology of Global Positioning System (GPS), as shown in Figure 2.1.

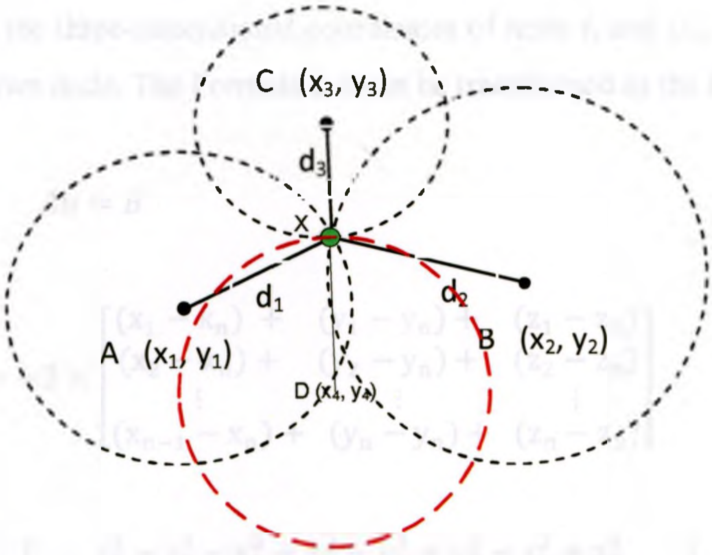

Figure 2.1: Principle of Triangulation Localization

The coordinate value of the unknown point can be calculated using the following functions:

$$\begin{bmatrix} x \\ y \end{bmatrix} = \begin{bmatrix} 2(x_1 - x_3) & 2(y_1 - y_3) \\ 2(x_2 - x_3) & 2(y_b - y_3) \end{bmatrix}^{-1} \begin{bmatrix} x_1^2 - x_3^2 + y_1^2 - y_3^2 + d_3^2 - d_1^2 \\ x_2^2 - x_3^2 + y_2^2 - y_3^2 + d_3^2 - d_2^2 \end{bmatrix} \tag{2-4}$$

For the general situation in WSNs, it needs to extend triangulation algorithm using in the case of multiple reference nodes to get a high tracking precision. Namely, through given n reference nodes (x_i, y_i, z_i), and the measured distance r_i from them to the unknown node (u_x, u_y, u_z), where $1 \leqslant i \leqslant n$, i representatives the number of the reference nodes, unknown the values of u_x , u_y, and u_z can be computed. The problem can be solved with the following steps [19]:

$$\begin{bmatrix} (x_1 - u_x)^2 + & (y_1 - u_y)^2 + & (z_1 - u_z)^2 \\ (x_2 - u_x)^2 + & (y_2 - u_x)^2 + & (z_2 - u_z)^2 \\ \vdots & \vdots & \vdots \\ (x_n - u_x)^2 + & (y_n - u_x)^2 + & (z_n - u_x)^2 \end{bmatrix} = \begin{bmatrix} r_1^2 \\ r_2^2 \\ \vdots \\ r_n^2 \end{bmatrix} \tag{2-5}$$

where (x_i, y_i, z_i) are the three-dimensional coordinates of node i, and (u_x, u_y, u_z) are the coordinates of unknown node. The Formula 2-4 can be transformed as the follows:

$$Au = B \tag{2-6}$$

$$A = -2 \times \begin{bmatrix} (x_1 - x_n) + & (y_1 - y_n) + & (z_1 - z_n) \\ (x_2 - x_n) + & (y_2 - y_n) + & (z_2 - z_n) \\ \vdots & \vdots & \vdots \\ (x_{n-1} - x_n) + & (y_n - y_n) + & (z_n - z_n) \end{bmatrix} \tag{2-7}$$

$$B = \begin{bmatrix} r_1^2 - r_n^2 - x_1^2 + x_n^2 - y_1^2 + y_n^2 - z_1^2 + z_n^2 \\ r_2^2 - r_n^2 - x_2^2 + x_n^2 - y_2^2 + y_n^2 - z_2^2 + z_n^2 \\ \vdots \\ r_{n-1}^2 - r_n^2 - x_{n-1}^2 + x_n^2 - y_{n-1}^2 + y_n^2 - z_{n-1}^2 + z_n^2 \end{bmatrix} \tag{2-8}$$

Using least squares method, the localization of the unknown node can be calculated as following [19]:

$$u = (A^{'}kA)^{-1}A^{'}kB \tag{2-9}$$

where, k is the weighted diagonal matrix, and the diagonal elements p_{ii} are the error weighting factors.

2.1.2 Matching Localization Algorithm

Matching algorithm [20] is a typical algorithm which estimates the localization through matching the eigenvalue with the map data of the previous database, which is based on the following steps: initialization and localization. The details can be seen in Figure 2.2.

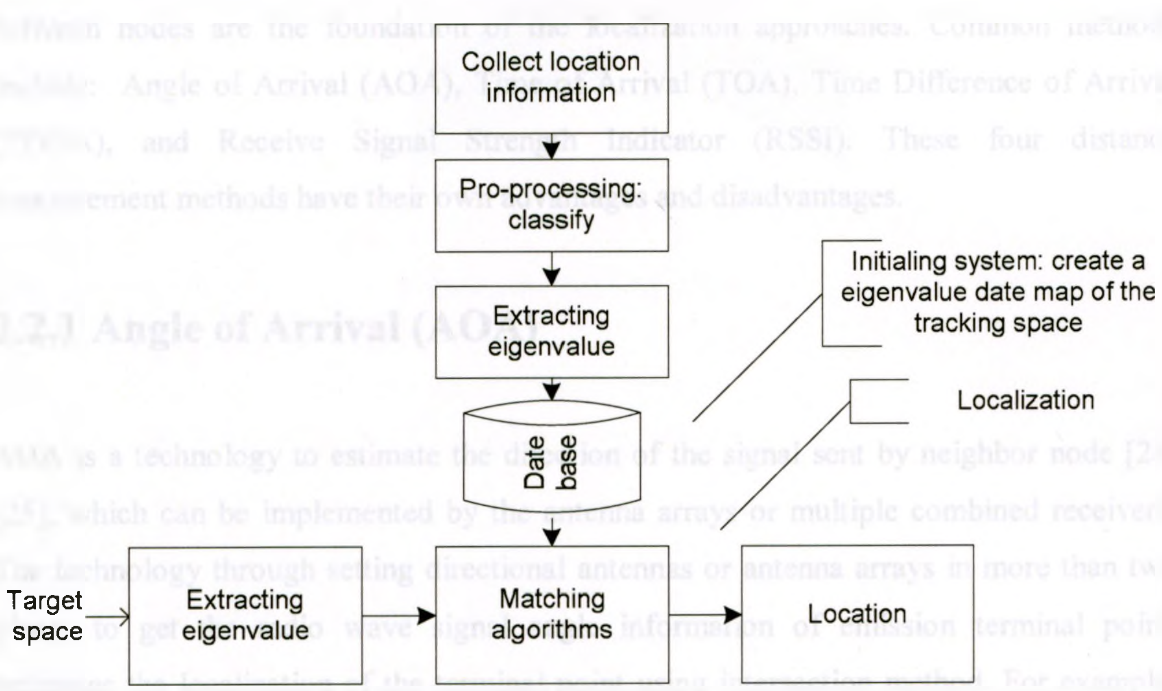

Figure 2.2: Processing Steps of Matching Algorithm Localization

In the initial process, a location tracking space is divided into many cells which have unique identifying characteristics that can be collected by the nodes. All of the unique characteristics are named eignevalue of the cell to be saved into database with the corresponding cells. The essentials of the localization process are the matching algorithms which will decide the results of location estimate. Usually, this algorithm are based on RSSI [21], Audio [22], and image [23] to extract the eigenvalue.

2.2 Measurement Techniques for Distance Estimation

In WSNs localization domain, the measurement techniques of the distance or angle between nodes are the foundation of the localization approaches. Common methods include: Angle of Arrival (AOA), Time of Arrival (TOA), Time Difference of Arrival (TDOA), and Receive Signal Strength Indicator (RSSI). These four distance measurement methods have their own advantages and disadvantages.

2.2.1 Angle of Arrival (AOA)

AOA is a technology to estimate the direction of the signal sent by neighbor node [24] [25], which can be implemented by the antenna arrays or multiple combined receivers. The technology through setting directional antennas or antenna arrays in more than two places to get the radio wave signal angle information of emission terminal point, estimates the localization of the terminal point using intersection method. For example, after two reference nodes known own localizations as A (x_1, y_1) and B (x_2, y_2) receive the RF signals from an unknown node C, through the antenna array technology to get the directions of the signal from node C arriving the reference node A and node B, as θ_1 and θ_2, they can estimate node C (x, y) according to the intersection algorithm as show in Formulation 2.10 and Formulation 2.11. Figure 2.3 is an example of AOA.

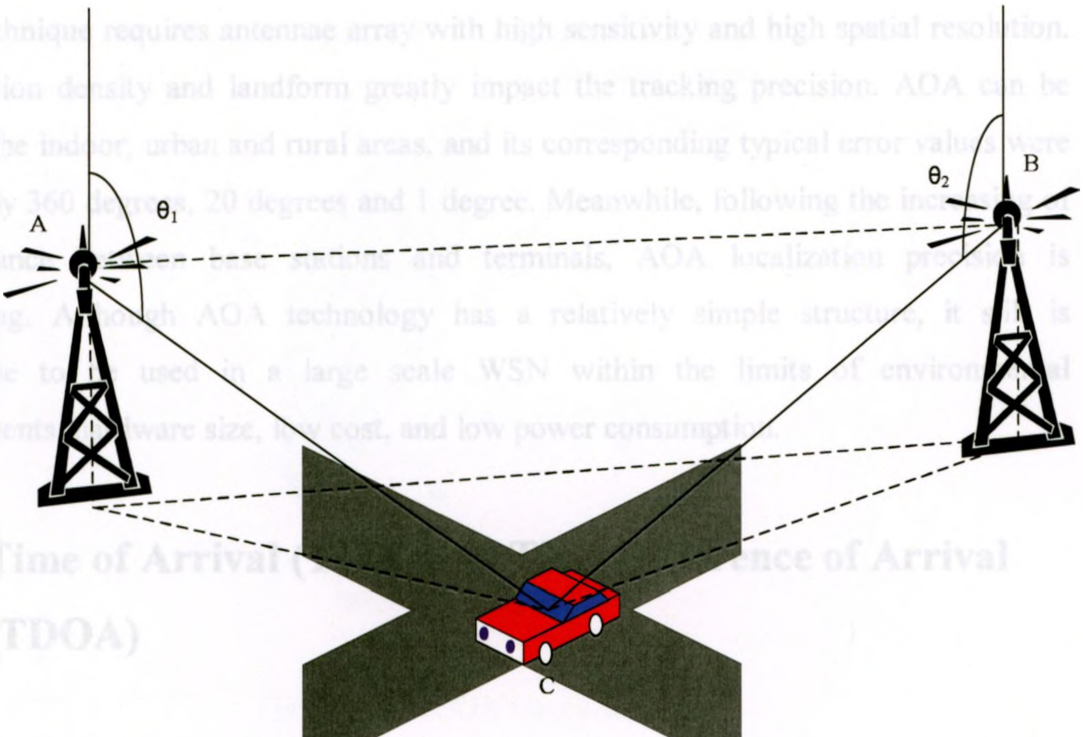

Figure 2.3 Principle of AOA

$$(x_1 - x)^2 + (y_1 - y)^2 + l_1^2 = \left(\frac{l_1}{\cos(180^\circ - \theta_1)}\right)^2 \qquad (2\text{-}10)$$

$$(x_2 - x)^2 + (y_2 - y)^2 + l_2^2 = \left(\frac{l_2}{\cos(180^\circ - \theta_2)}\right)^2 \qquad (2\text{-}11)$$

where l_1 is the height of the switch tower of the reference point A, and l_2 is the height of the switch tower of the reference point B.

AOA technique requires antennae array with high sensitivity and high spatial resolution. Distribution density and landform greatly impact the tracking precision. AOA can be used in the indoor, urban and rural areas, and its corresponding typical error values were separately 360 degrees, 20 degrees and 1 degree. Meanwhile, following the increasing of the distance between base stations and terminals, AOA localization precision is decreasing. Although AOA technology has a relatively simple structure, it still is unsuitable to be used in a large scale WSN within the limits of environmental requirements, hardware size, low cost, and low power consumption.

2.2.2 Time of Arrival (TOA) and Time Difference of Arrival (TDOA)

TDOA technique is a modified TOA. TOA by measuring the signal propagation time to measure the distance can be described as shown in Figure 2.4. The basic principle of TOA is that the node to be located obtains the RF signal propagation times: t_1, t_2, t_3 separately from the three reference nodes to the unknown node. Meanwhile, propagation time difference can also be used to calculate the distance difference. The three times are used to estimate three distance d_1, d_2, and d_3 from the reference nodes to the unknown node, and then using the triangulation method to get the localization of unknown node.

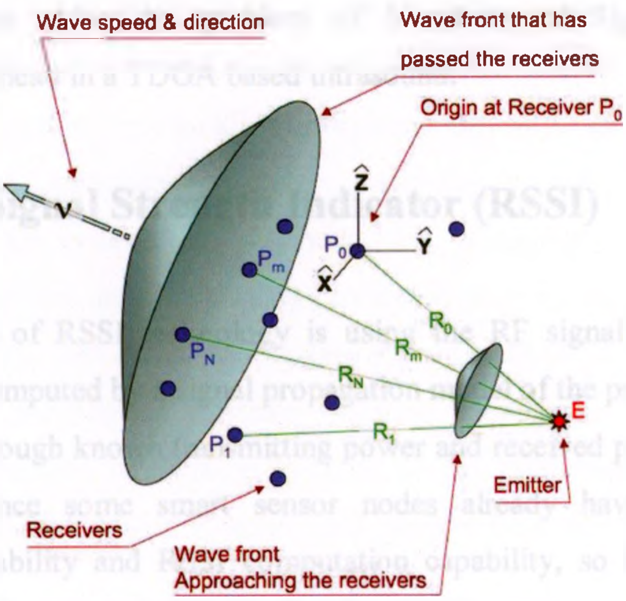

Figure 2.4: TDOA Geometry [26]

TOA technology is mainly used in the GPS positioning system, which requires expensive, high-energy consumption equipment to accurately synchronize the satellite clock. TOA is facing a greatest challenge in its high requirement of the clock synchronization on the RF signal propagation time measurement. Since the limits in the hardware size, price and power consumption constraints sensor nodes, GPS and other RF-based signal propagation time technology is not feasible for an indoor application.

In order to solve the RF time synchronization problem and the cost, some localization system in WSNs adopts the ultrasound technique in TDOA [27] [28]. Namely, recorded the reaching-time differences of two different signals (ultrasonic signals) multiply the speed of sound wave propagation to get the distance. Since the ultrasonic propagation velocity is much lower than the speed of light, so the requirement of node time synchronization is lower to decrease the cost. However, since this kind of TDOA is limited in the ultrasonic propagation distance (usually a few meters), it requires intensive network deployment. Also the problem of Non-Line of Sight also effects the communication overhead in a TDOA based ultrasound.

2.2.3 Receive Signal Strength Indicator (RSSI)

The basic principle of RSSI technology is using the RF signal strength to estimate distance, which is computed by a signal propagation model of the propagation power lose that is calculated through known transmitting power and received power measured at the receiving node. Since some smart sensor nodes already have powerful wireless communication capability and RSSI computation capability, so RSSI technology has been developed as a low-power, low-cost localization technology, which is being used in many existed localization projects [29] [30] [31]. The main error sources of RSSI technology come from the environmental impact which causes the signal propagation model modeling complexity: reflection, multipath propagation, non line of sight, antenna gain, consistency, and other issues. All of those issues will produce the significantly difference of the propagation power loss. Usually RSSI can be seen as a rough distance measuring technology, which has a greater distance error.

2.3 Typical Localization Approaches Based on WSNs

The localization technology in WSNs is an interdisciplinary research focusing point, including large range of the localization systems, and different classification methods [32]. Depending on the difference of the application goals, localization systems can be divided into single-targeting localization, multi-targeting localization, and localization between nodes. According to the difference of the application environments, localization systems can be divided into indoor and outdoor localization systems. Based on coordinates of a different nature, localization systems can be divided into the relative and absolute coordinate localization systems. According to the different positioning algorithms, localization systems can be divided into triangulation localization systems, scene localization systems and neighboring law localization systems. Meanwhile, using a different wireless signal can divide localization systems into radio frequency localization systems, ultrasonic localization systems, infrared localization systems, positioning systems, and mixed-signal localization systems. In the following subsections, we will discuss a few typical localization systems, and analyze their characteristics, advantages and disadvantages.

2.3.1 RADAR Localization System

RADAR (A radio-frequency (RF)-based system for locating and tracking users inside buildings) [33] localization system is an indoor localization system developed by Microsoft based on radio scene information. RADAR localization system is divided into two parts: one part is the localization information named scene database, another part is the localization module named match module. Correspondingly, the localization process have two steps: First step is that an offline database is created to record all the scene of various parameters of a node, usually implemented by a node roaming in the localization range in order to record received signal strength or angle from the fixed nodes. The second step is to match the localization online. When the system receives a signal from the node to be positioned, it will use the signal and the database to match some scene parameters, and select the scene whose argument tuples are closest as the current position of the node. Under the premise of the scene database in small enough position, this algorithm can get a higher precision, so it can be easily applied to indoor localization. However, since this algorithm requires a strong computing capability, and the pre-acquisition scene database, it is not suitable to some large-scale WSN applications.

2.3.2 Centroid Localization Algorithm

Centroid location algorithm, proposed by Bulusu and his colleagues at University of Southern California, is an outdoor localization algorithm based on network connectivity factors [34]. The core idea of the algorithm is that reference nodes frequently broadcast a beacon signal to their neighbor nodes, and the signal contains their own node IDs and localization information. When the number of the beacon signals received by an unknown node from different reference nodes exceeds a certain presetting threshold or after certain received time, the unknown node should determine its own localization as the centroid of the polygon consisted by these reference nodes. The simulation presented in [34] shows that precision of about 90% of the unknown nodes localization is less than the 1/3 of the distance between the reference nodes. Obviously, the algorithm is a kind of coarse-grained localization, and needs a high reference-node density. The advantage of the algorithm is very simple and completely based on network connectivity factors, without the coordination between reference nodes and unknown nodes.

2.3.3 Convex Program Localization Algorithm

Convex program localization algorithm is developed by Doherty et al. at University of California Berkeley [35]. In the algorithm, point-to-point communication link between nodes is seen as the geometric constraints of the node location and the entire network model into a convex set, thus the localization problem of the nodes are converted into a convex constrained optimization problem. And then semi-definite programming and linear programming method are used to get a global optimization solution, to determine the node location.

Convex program is a centralized localization algorithm, whose localization error is about equal to the node's wireless range (compared to 10% of the reference nodes). In order to achieve an effective result, the reference nodes need to be deployed at the edge of the WSN; otherwise the perimeter nodes estimation location will shift to the network center.

2.3.4 DV-hop Localization Algorithm

DV-hop localization algorithm is developed by Dragos Niculescu of Rutgers University [36] [65], which proposed several measures to estimate unknown location using the known location, such as: DV-hop, DV-distance, Euclidian, DV-coordinate, DV-Bearing and DV-Radial. As an example, DV-hop algorithm is described as follows:

First step, the Distance Vector (DV) is exchanged in the WSN, so that each node knows its hop number between the node and the reference nodes. Each node maintains a table as $\{X_i, Y_i, h_i\}$, where $\{X_i, Y_i\}$ is the localization coordinates of a reference node, and h_i is the hop number from the node to the reference node.

Second step, when a reference node $\{X_i, Y_i\}$ learned the hop number through the exchange, it can calculate the average distance c_i of each hop.

$$c_i = \frac{\sqrt{(X_i-X_j)^2+(Y_i-Y_i)^2}}{\sum h_i}, i \neq j \tag{2-12}$$

where, $\{X_i, Y_j\}$ are all the reference nodes detected by node $\{X_i, Y_j\}$.

Third step, when the unknown node learned the hop number of more than 3 reference nodes, it can calculate its location by Triangulation localization algorithm.

2.4 Challenges and Opportunities

The existing algorithms and state-of-art systems for WSN's localization vary in many parameters, such as the physical size, power consumption, infrastructure versus portable elements, and limited in time and space [37].

Table 2.1 summaries the key characteristics of those typical localization systems.

Table 2.1: Comparison of Some Typical Localization Systems

Characteristic	RADAR RADAR Localization System	Centroid Localization Algorithm	Convex program localization algorithm	DV-hop localization algorithm
Distributed/Centralized	Centralized	Distributed	Centralized	Distributed
If or not need measurement distance	Not	Not	Not	Yes
Distance estimate algorithm	N/A	Communication range	Communication range	One hop
Localization algorithm	Scene Matching	Centroid algorithm	Optimization algorithm	Triangulation algorithm
Application scenarios	Indoor	Outdoor	Outdoor/Indoor	Outdoor

The area of WSN techniques is still a new research domain, therefore, there are still many issues waiting to be solved. Some issues are about the hardware of networks; some issues arc arisen by assistances; and some issues come from signals of sensors. So many limitations obstruct the development of WSNs' localization techniques. Several sorts of the issues are summarized as follows:

- **Power consumption:** Sensor notes are usually tiny and carrying power supply. Therefore, the power consumption is always a limit under a longtime using situation.
- **Range limit:** The distributed notes transmit data by radio in air. Especially, in some noisy environment, the communication range is confined in a local area. The data of sensors cannot be transmitted out in time [38].
- **Processing capability / memory:** In some practical applications, the number of node is huge. To decrease the cost of the network building, node always keeps the limited memory. One result of the limited memory is confined information processing capability.
- **Prone to failures:** Practically, sensors always work in a poor environment to replace human, such as toxic gas space. In this working environment, it is not an easier thing to keep huge amount of sensors working in a good condition.
- **Lack of global ID:** Sensors still have MAC addresses to be recognized in a global workplace. The local ID will increase more problems during the cooperation of sensor belonged to different groups [39] [40].
- **Easy to be compromised:** A sensor node in a network is easy to be falsified by other nodes intentionally or unintentionally. This falsification may bring whole system failure, data errors, or data security problem [41].
- **Long-term reliability:** In many localization systems, the localization cycle is usually several months or years. Therefore, the long-term reliability is essential in some WSN based systems [42].

- **Security:** Security is a key issue in WSNs and their applications. A detailed discussion can be found in [42] [43].

Chapter 3

2-D Indoor Localization System

While there are already a variety of localization algorithms based on wireless sensor networks, but most of the existing algorithms require additional hardware cost, or are limited by application environments [44]. Many algorithms only have theoretical value, or only are suitable to be used in military applications. One critical issue of these existing algorithms is their communication overhead that will bring additional power consumption. Meanwhile the characteristics of indoor environment are also limiting the application of most localization algorithms.

In order to solve indoor localization problem, decrease the cost, and increase the localization precision, this chapter presents a localization technique using accelerometer and gyroscope to get a high precision location for an indoor scenario. This thesis proposes a new sensing displacement (SD) localization algorithm based on the accelerometers and gyroscopes. The novelty of this proposed technique is on its combination of the distance measurement process and the localization process. The mobile sensor collects its motion information and sends it to the sink sensor which is connected to a computer. The distance estimation process is not affected by the route establishment architecture. Meanwhile the design of this WSN is a multiple-goal and loose-couple structure. In the following subsection, we will describe the details of the application scenario, design ideas, system design and implementation.

3.1 Application Scenarios

Since the wireless radio signals are prone to be affected by the objects of environment (such as the wall, and moving objects), so the situation of a localization environment is very important, which not only decides the localization result precision, but also effects the network's physical structure and internal algorithms. For example, the radio of wireless sensor trends to be affected by the signal of micro oven, mobile phone, and so on. Therefore, a localization algorithm has to fit its application environment.

3.1.1 Issues of Indoor Scenarios

More and more indoor environments need a precious localization system to assist people's living space or workplace. For example, some indoor localization techniques are urged to meet the need of a variety of monitoring and control applications, such as healthcare, construction, facilities management, supply chain management, people and asset tracking. All of those Indoor localization systems have some basic constraints of indoor environments, including:

- **Path loss** and **multi-path reflection:** the signal channels are always blocked or stopped or interdicted by walls, furniture, or equipment in indoor spaces. The reflection, diffraction, interference, and refraction of signals will be a major challenge for any indoor localization systems. For example, sound localization technology and RSSI localization technology are both easily affected by the change of the signal strength.
- **Low accuracy & instability:** One significant requirement of the indoor localization system is high accuracy. Under some situation, localization error can

lead the system to make a wrong decision. Especially, in harsh industrial environments, different machines and equipment affect the radio signals of the sensors.

- **Low energy efficiency:** Tiny nodes of WSNs usually are portable nodes token by people or bond on monitored objects. The nodes carried power that is a kind of limited-power batteries.
- **High computational load:** Computational overhead is a common problem in many localization algorithms, especially in some multi-target localization systems. Since indoor localization systems usually are used to track multiple targets, computational overhead is a challenge for the hardware.
- **High costs:** The costs of installation, deployment, calibration and maintenance are obstacles for wide application of WSNs in industry.

3.1.2 Indoor Scenario under Study

The scenario used in this study is an abstract scenario of many common indoor application environments, which includes universal characteristics of indoor environments. This scenario includes the following characteristics:

- **Small cell space and large scale:** For example, a large scale apartment consists of many small rooms, which is a combination of macrostructure and microstructure in a 3-D space.
- **Multiple stumbling blocks and obstacles:** In this scenario, the space is filled with static obstacles and moving obstacles, which will affect the signals' strength.
- **Channel noise:** This space of the scenario is filled with environment noise, which should affect the radio channel.

The proposed localization system is expected to meet all of the following targets: low power consumptions, multiple targets, high precision, low cost, and loose coupling.

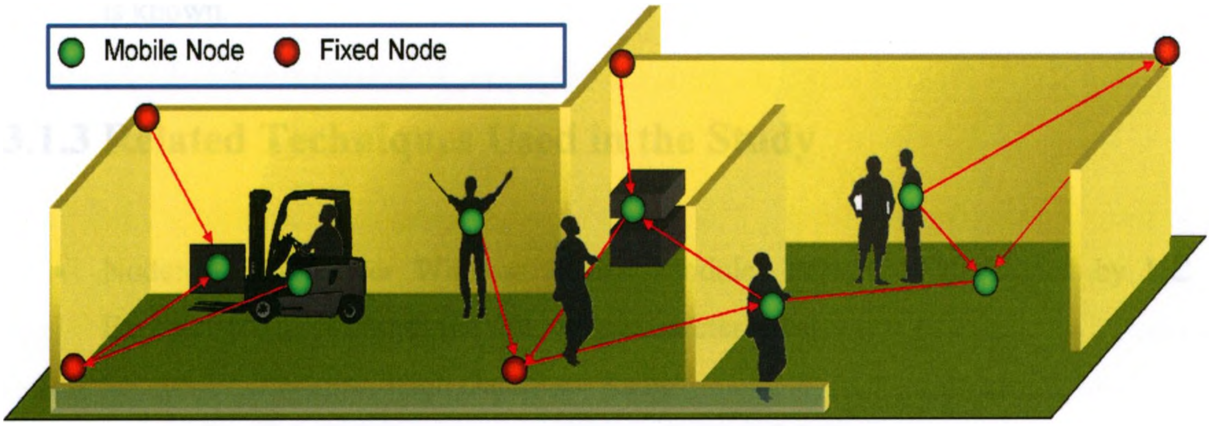

Figure 3.1: Application Scenario of Indoor Localization System

As shown in Figure 3.1, the nodes used in the study have been widely used in a wide range of data collection scenarios, such as temperature and humidity monitoring, forest fire early warning, and intelligent building data acquisition. These applications use a large number of sensor nodes to collect environment data, and then send the data through multi-hop routing to the information center for analysis and processing. Since distributed forms of such networks will be easy to be changed, so it can be suitable to various indoor environment applications.

To facilitate the analysis, this study further simplifies the scenario with following assumptions:

- Two types nodes: localization nodes (or mobile nodes) and communication nodes (or fixed nodes).
- Data collection area is a circular area of radius R.

- Sensor nodes use the same frequency for communication.
- Pre-positioning coordinates of the space are set.
- Localizing nodes are randomly distributed in the region, their initial location (x_i, y_i) is known.

3.1.3 Related Techniques Used in the Study

- Node: A low Power Wireless Sensor Module, TelosB, is developed by UC Berkeley [45], which has the following characteristics:
  - 250 kbps, High Data Rate Radio
  - TI MSP430 microcontroller with 10kB RAM
  - Integrated onboard antenna
  - Data collection and programming via USB
  - Open-source operating system
  - IEEE 802.15.4 compliant
- IEEE 802.15.4 Protocol [46]: It is a low power consumption protocol, which is the basis for the ZigBee [46], WirelessHART [47], and MiWi [48] specification. The followings are the characteristics:
  - Data rates of 250 kbps, 40 kbps, and 20 kbps.
  - Two addressing modes; 16-bit short and 64-bit IEEE addressing.
  - Support for critical latency devices, such as joysticks.
  - CSMA-CA channel access.
  - Automatic network establishment by the coordinator.
  - Fully handshaked protocol for transfer reliability.
  - Power management to ensure low power consumption.
  - 16 channels in the 2.4GHz ISM band, 10 channels in the 915MHz I and one channel in the 868MHz band.

- Gyroscope: LPR530ALH, 300°/s dual-axis.
- Accelerometer: ADXL345, 13-bit resolution, ±16g, triple-axis.

3.2 A 2-D Indoor Localization Algorithm

Most existing localization projects based on the signal's characterizes always are trend to be affected by the characteristics of an indoor environment [49] as the mentioned in the thesis. In order to avoid the failures brought by the indoor environment, we adopt sensors embedded on nodes to sense the motion information of localizing objects to calculate the motion distance in a defined environment. Nodes are embedded with accelerometers and gyroscopes. Accelerometers are used to measure the acceleration of the localizing objects. And the gyroscopes are used to sense the corresponding angular velocity. Then based the motion equations, the displacements of the localizing objects can be calculated during the sensing time. This type of the algorithm used in the indoor localization systems is called sensing displacement (SD) localization algorithm.

According to the analysis in the previous section, the implementation of an SD localization algorithm can be divided into five major steps, and the basic processing flow is shown in Figure 3.2:

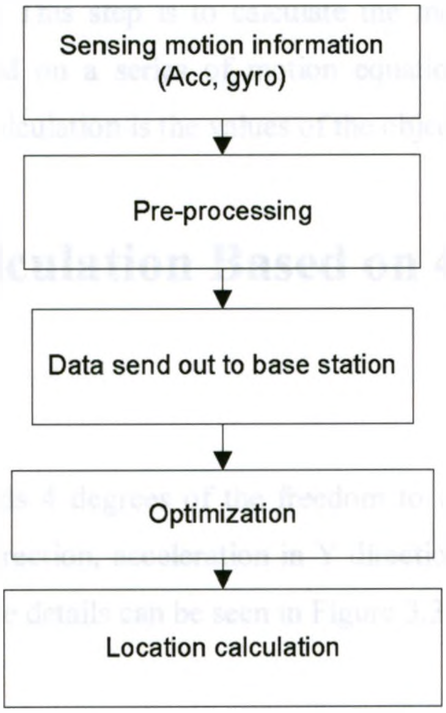

Figure 3.2: Flow Diagram of SD Localization Algorithm

- **Sensing motion information:** Accelerometer and gyroscope embedded in a node are carried by the localizing object to sense the motion information: acceleration and angular velocity.
- **Pre-processing:** The information collected by the sensors should be pre-processed in node boards in order to decrease the amount of the information communication, which is going to be transited on the radio channel.
- **Data sent out to base station:** The motion information is sent out using the Zigbee protocol to the base station that is a sink node plugged to the computer.
- **Optimization:** The data pre-processing is done by the computer, which is a preparing step for the location estimation. Data pre-processing usually includes some classic algorithms in data mining, pattern recognition, and data filtering.

- **Location calculation:** This step is to calculate the motion displacement of the monitored object based on a series of motion equations (detailed below). The result of the location calculation is the values of the object's coordinate.

3.3 Location Calculation Based on 4 Degrees of Freedom

In a 2-D environment, it needs 4 degrees of the freedom to calculate a motion, which consist of acceleration in X direction, acceleration in Y direction, rotation around X axis, and rotation around Y axis. The details can be seen in Figure 3.3.

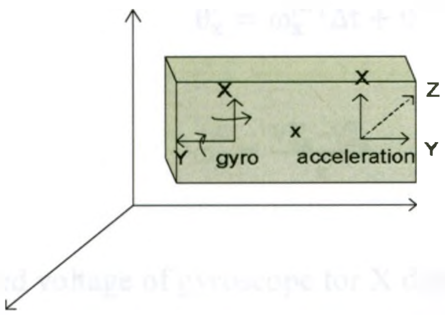

Figure 3.3: Movement Variables Diagram in 2-D Environment

Some common definitions are shown as follows:

- **Definition 1:** (x, y) is the coordinate value of the object in a 2-D coordinate system.

- **Definition 2:** *a* denotes the acceleration, *v* means the velocity, Δt is the sensor' sampling period, *i* is the time serial number, and P(x, y) is a position value in a 2-D coordinate system.

In the 2-D environment, θ_x means the rotating angle value around X axis, θ_y means the rotating angle value around Y axis, θ_x^i means θ_x at the time *i* moment, and ω_i means the angular velocity at the time *i* moment. The position of the monitored object can be calculated using the following equations.

(1) Compute orientation at time t_{i-1}, known:θ_x^i, ω_{i-1}

$$\theta_x^i = \omega_x^{i-1}\Delta t + \theta_x^{i-1} \tag{3-1}$$

$$\omega_x = \frac{V_{\omega x}^m - V_{\omega x}^0}{k} \tag{3-2}$$

where $V_{\omega x}^m$ is measured voltage of gyroscope for X direct, $V_{\omega x}^0$ is given reference voltage of the sensor, and *k* is the sensitivity of the gyroscope given by the manual of the product.

(2) Compute acceleration in 2-D space, and $\vec{a}$ is the acceleration vector.

$$\vec{a} = \begin{Bmatrix} a_x^i \\ a_y^i \end{Bmatrix} = \begin{cases} \sin\theta_x^i a_y^m + \cos\theta_x^i a_z^m \\ \cos\theta_x^i a_y^m - \sin\theta_x^i a_z^m \end{cases} \tag{3-3}$$

where, $a^m = \frac{V^m - V^{og}}{-s}$, where V^m measured voltage of accelerometer on Y or Z axis, V^{og} means zero *g* voltage, *s* is the sensitivity of accelerometer given by the sensor chip manual.

(3) Compute velocity

$$\vec{V}^i = \vec{a}^i \Delta t + \vec{V}^{i-1} \tag{3-4}$$

(4) Compute position

$$P^i(x, y) = \frac{a^i}{2} \Delta t^2 + V^i \Delta t + P^{i-1}(x, y) \tag{3-5}$$

where, $P^i(x, y)$ is the position value of X and Y' coordinates at the moment of time *i*.

3.4 Cloud Computing Based System Architecture

According to the difference of nodes' producers, wireless sensor nodes are widely varied in functions, communication characteristics, and physical characteristics. Mostly, wireless sensor nodes have the capabilities of information collection, data transmission, decision-making, data computation, and data storage. However, in some distributed applications, the nodes have to cooperate and use collaborative information processing techniques in order to fulfill the requirement of their tasks. Therefore, WSNs are greatly promoting the development of indoor localization system. In order to meet the large scale of localization system, cloud computing based system architecture is introduced into this study.

3.4.1 Principle of Cloud Computing Based System Architecture

Since nodes do not have global IDs, an existing indoor localization tracking system can only be available to supply services for users in the monitoring place, which causes a great descent of the range of the service types, and the quality of services is far from satisfying people's need for information. Cloud computing developed in recent years can provide a possibility for meeting the needs of people. Cloud computing is a new model of business computing, where distributed computing tasks on resource pools are composed of a large number of computers. The various application systems are able to access and get computing power, storage space and a variety software services as they need [50]. A typical cloud computing provider delivers common business applications online that are accessed from another Web service or software like a Web browser, while the software and data are stored on servers [51]. If the business architecture is used in an indoor localization tracking system within data mining, information security and service optimizing, it will provide multiple perspective and comprehensive information service products for cloud users.

The combination of smart sensors, wireless network nodes and cloud computing, will overturn our traditional localization mode, and provide a kind of ubiquitous surveillance, such as real-time localization so that people can readily get the information of their localization environment. Back-end cloud computing platform can help in the data analysis, data mining, data search, etc. Under the powerful support of the cloud computing platform, the huge localization data can be calculated and analyzed without manual operation, which can be quickly converted into practical guidance to facilitate localization service. And this guidance can be sent to a banded mobile phone at any time to remind that people should pay attention to the corresponding location information.

In order to support the massive data real time processing, we use cloud computing in localization tracking system within the following principles.

Principle 1: Separation of service supply and calculation: When a system in the provision of services is involving large amounts of the data processing, due to the time-index characteristic of a localization system, it is easy to cause data inconsistencies. Thus, the principle is to avoid this confusion.

Principle 2: Common interface standardization: This principle is particularly important for service layer and infrastructure layer. The underlying layer connects all the hardware and software, which involves various devices within different communication protocols, different channels and connecting ports. Therefore, using a common accessing standard will be very effective in reducing the complexity in the layer.

Principle 3: Hierarchical optimization: Since the system is a combination of hardware, software, and web service, so the system optimization must be strictly following hierarchy. Otherwise, it is difficult to achieve the global optimal design and system's maintenance. Thus we propose a hierarchical principle of optimal design.

3.4.2 Topology of Indoor Localization Tracking System

Cloud computing in the traditional mainstream sense, whereby resources are dynamically provisioned on a fine-grained, self-service basis over the Internet, via web applications/web services, from an off-site third-party provider who bills on a fine-grained utility computing basis. In order to combine cloud computing into indoor localization tracking system, we need a middleware to supply computing service for the cloud node, which can seal the data and service in a standard API for outside users.

Outside Users can grant permission to share data and service provided based on some business contracts. The property company will be more convenient to supply managing service and check basic information of different homes.

Cloud-based indoor localization tracking system and general topology of the cloud is not essentially different. It just encapsulates the living space infrastructure as the web source and published into internet following some business model, as well as the common cloud platform. This cloud structure extends the WSNs into web service and develops an application encapsulation for wireless operating system. Figure 3.4 shows the cloud topology structure of an indoor localization tracking system.

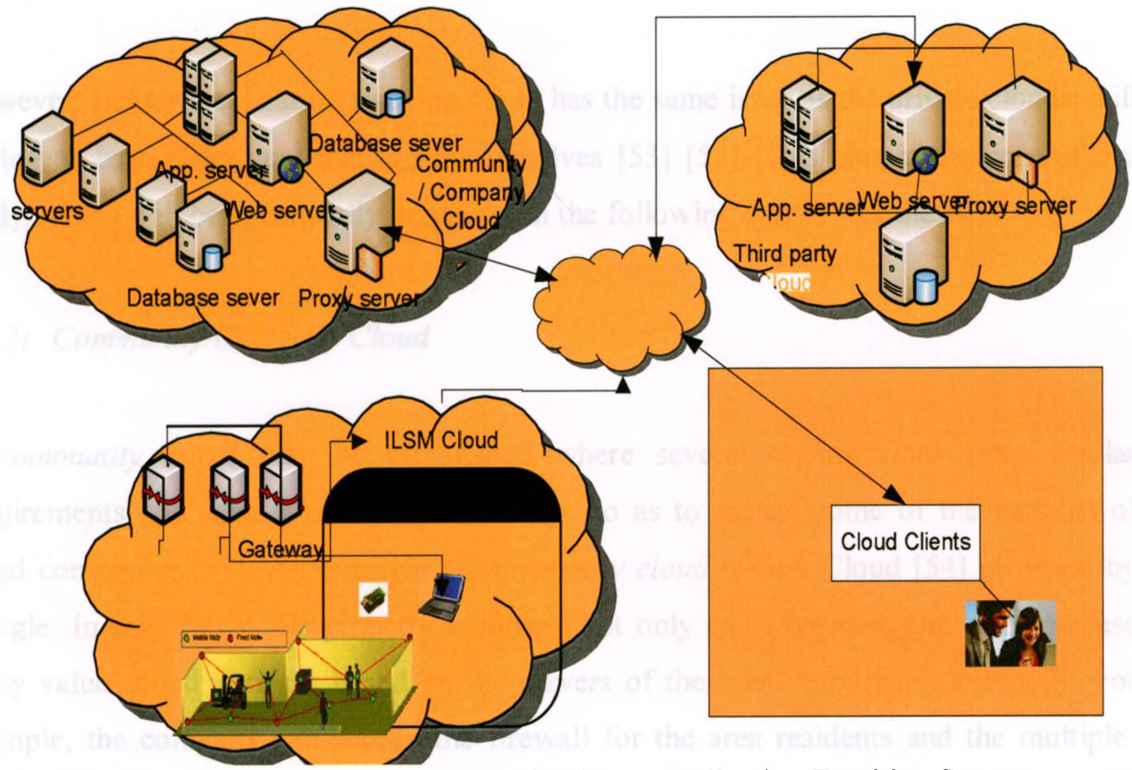

Figure 3.4: A Topology Structure of Indoor Localization Tracking System

1) Indoor localization tracking Cloud

Indoor localization tracking cloud works as a private computer utility, which also can be named as *Private cloud* or *internal cloud* [52]. The cloud works on the living space gateway which is just responsible for providing virtualization and automation of the living space hardware and the monitoring objects, which is different from the commonly private cloud of some vendors. The main contribution for Indoor localization tracking cloud is to abstract the living space into web source which can be used by the property company or community. Of course, the gateway installed with the indoor localization tracking cloud can supply monitoring services and manage operations for the owner or the authorities.

However, Indoor localization tracking cloud has the same issue as the private clouds: still having to buy, build, and manage by ourselves [53] [57]. This part is the core of our study, which will be specifically described in the following part of this thesis.

2) Community/Company Cloud

A *community cloud* may be established where several organizations have similar requirements and seek to share infrastructure so as to realize some of the benefits of cloud computing [51]. An example of *community cloud* is Gov Cloud [54] provided by Google. In this thesis, the property company not only can save cost, but also increase many value-added services based on the servers of the relative property company. For example, the company can supply the firewall for the area residents and the multiple-media stream. Usually, enterprise-wide public cloud is supplied by equipment manufacturers or suppliers, as a kind of value-added services. This kind of cloud should be running independently.

3) Third-party Cloud

Third party cloud describes cloud computing in the traditional mainstream sense, whereby indoor localization tracking resources are dynamically provisioned on a fine-grained, self-service basis over the Internet, via web applications/web services, from an off-site third-party provider who bills on a fine-grained utility computing basis [53] [57]. For example, the hospital or family doctor can access the health data of the monitoring people to diagnose the illness and monitor the health situation. Usually, *community/company cloud* is limited by the company's location, facilities, and existing business model, not providing a better operation and management of cloud. This is the reason why some service should be published on third parties clouds. *Third-party cloud* could be better for the public and private cloud to provide better monitoring and management services.

3.4.3 Design of Cloud based System Architecture

A common cloud computing architecture consist of cloud infrastructure, cloud storage, cloud platform and cloud service. In our project, we mainly focus on the infrastructure which is located on the indoor localization tracking system gateway. The architecture of indoor localization tracking system gateway is belonged to the indoor localization tracking system cloud. We adopt the popular 5-layer architecture to design our system. The top layer is the client layer, and the second layer (*platform layer*) is on the *third-party cloud* or community cloud, which usually is called as Platform as a Service (PaaS) [55]. Since these two layers are commonly public cloud, we only focus on the remaining three layers in this thesis. The details can be found on Figure 3.5.

The indoor localization tracking system cloud, as shown in Figure 3.5, includes three layers: *Service, Application*, and *Infrastructure*.

Infrastructure Layer is the lowest layer in the whole system, which is the first step for the computing. Usually, some researcher call this layer as the "source layer", which provides the automation virtualization of indoor localization tracking system data source, monitoring object, and the relative hardware [56], such as the wireless sensor node, smart appliance, and the communication channel. Infrastructure layer is also the interface to access the living space.

Application Layer is the computing layer, which is responsible for the transformation of data into information. All of the computing is based on the Function 3-2. Of course, $Data(n)$ in the layer come from the *Infrastructure layer*, meanwhile, the $SelectionSpace = Select^1 \times Select^2 \times \ldots \times Select^L$, will be seen as computing domain supplied for the *Service layer*. The *local service* is also designed in *Application layer* in order to supply basically monitoring service as the traditional monitoring system to meet the common needs of users.

Service Layer is designed in two parts: public service and private service. Public service provides products to community or third-party cloud, which should comply with some business rules. Some of the products should also be recomposed to create some new products. Private Service supplies the traditional service, in local host or online via Web service.

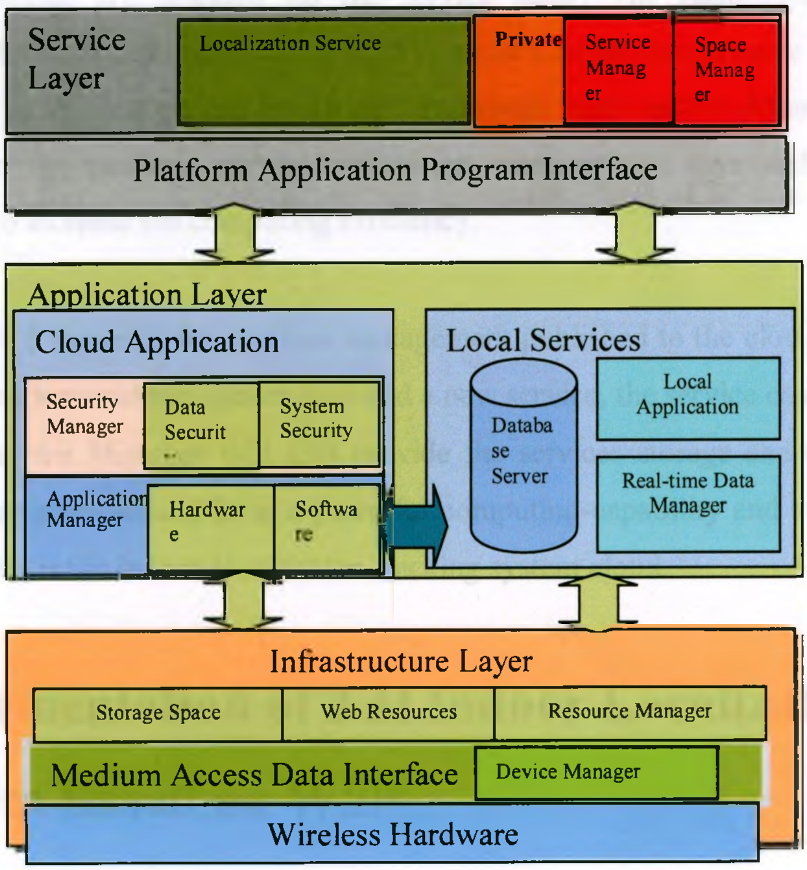

Figure 3.5: Architecture of ILSMS

Device Manager: This module is different from the traditional device adapter. The module not only finds, recognizes, initializes the devices, but also virtualizes the devices in living space devices into web resources. Device manager can automatically optimize the device connection and communication in the living space [53, 57]. Once received a service request from top layer, the Device Manager will be very effective to deploy up to the appropriate appliance, and monitor the process of the service completion.

Application Manager: All the data computing, data-device mapping, and device scheduling operations are shielded for the *service layer*. The relationship between application and device is not one-to-one [58] [59], since a device can provide a variety of application, and an application can be divided into many parts sent to different devices working together. In database server, application manager can save and query the mapping model to increase the computing efficiency.

Service Manager: It provides the services management published to the cloud, and when the indoor localization tracking system is to add a new service, the service can be updated to the clouds. *Service Manager* will also provide the services storage and registration. Many *Service managers* should form a powerful computing-capability and multi-service cluster. The cluster is the indoor localization tracking system cloud.

3.5 Implementation of 2-D Indoor Localization System Based on WSN

Based on the cloud computing based system architecture, a prototype 2-D localization system was developed to validate the proposal. Figure 3.6 is the result of the tracking of one node motion. This motion is shown in the local computer. In the whole indoor localization tracking system, this motion information will be published into web page. In the user interface of the information center, the red ball means the localizing object, and the gray line describes the trail of the moving object.

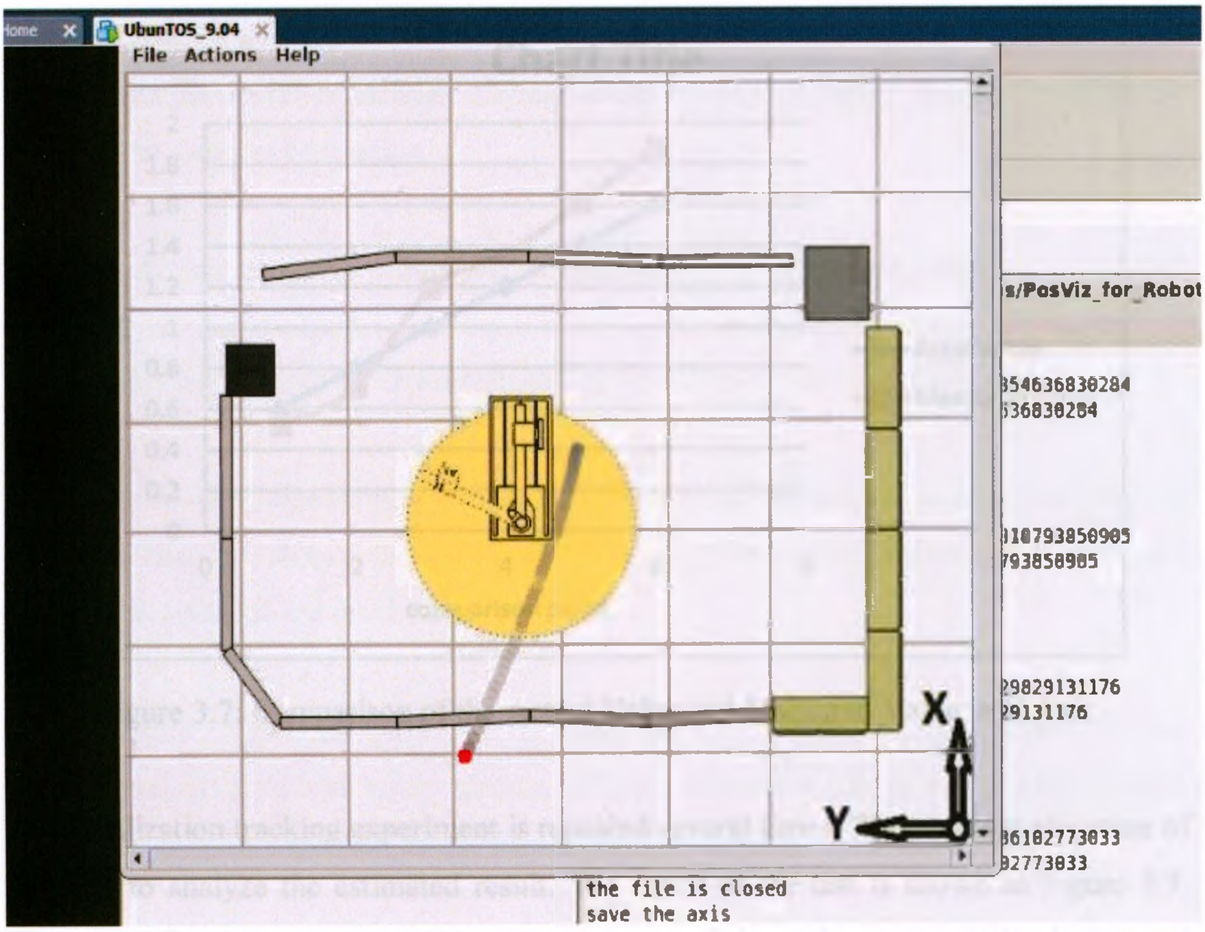

Figure 3.6: Track of the Motion in 2-D Environment

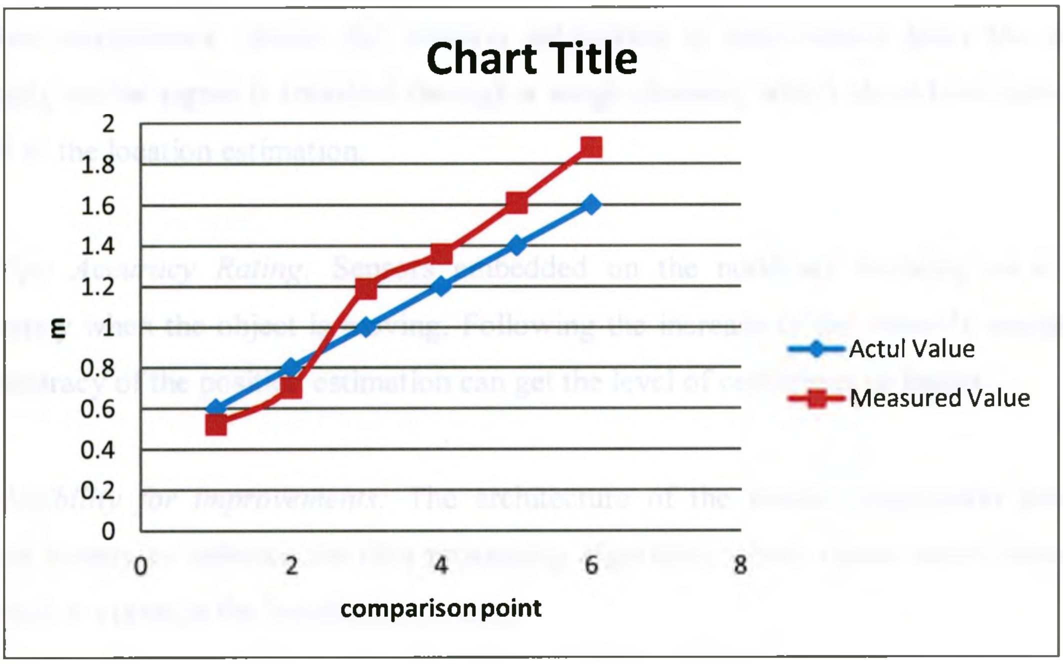

Figure 3.7: Comparison of the Actual Value and Measured Value in X Axis

This localization tracking experiment is repeated several times. We use the mean value of the tests to analyze the estimated result. The result of the test is shown in Figure 3.7. Those experiments are made under same motion conditions (the same initial velocity, and the same acceleration). Through the comparison, we can find that the error values make rapidly increase the affect of the estimated result with the increase of movement distance.

3.6 Analysis of 2-D Indoor Localization System

Based the results of the experiments mentioned above, the SD localization algorithm has some inhere advantages to localize an object in an indoor environment. The advantages include the following:

1) Anti–interference: Since the location estimation is independent from the signal strength, so the signal is transited through a rough channel, which should not affect the result of the location estimation.

2) High Accuracy Rating: Sensors embedded on the node are working on a high frequency when the object is moving. Following the increase of the sensor's sensitivity, the accuracy of the position estimation can get the level of centimeter or higher.

3) Flexibility for improvements: The architecture of the indoor localization tracking system is easy to enhance the data processing algorithm, which create more improving methods to optimize the localization results.

4) Scalability: Since the prototype is based on the cloud computing based system architecture, the hardware layer, application layer, and service layer are loosely coupled, which is easy to be expended according to specific requirements.

However, through analysis of the experimental results, we found that the results of the estimated position are sometimes unstable, which are caused by two elements: sensor's noise and cumulative error.

1) *Sensor's noise:* Although the SD algorithm is not affected by the channel noise, the effect of sensor's noise becomes more prominent in the estimated results. Sensor' noise means the noise of the sensor's own circuit, which is decided by the manufacturing processes and material of the sensor, as well as the sensor's temperature and voltage.
2) *Cumulative Error:* This effect of cumulative error is mentioned in the next section. The cumulative error is caused by the multiple integrations within the SD

algorithm. The current error should be cumulated into next step during the estimating processes.

3.7 Summary

In order to address the special issues of indoor environments, this chapter presents a typical indoor scenario specification as an indoor environment for the indoor localization environment. A new Sensing Displacement (SD) algorithm is proposed to facilitate indoor location estimation which is different from existing outdoor localization algorithms. The SD algorithm estimates the displacement from the sensing motion information of the sensors embedded moving nodes. Meanwhile, a cloud computing based system architecture is designed to develop a localization system prototype with a 2-D virtual environment to validate the proposal, which better solves the issues of the huge information processing and service release of a large scale network. Finally, this chapter analyzes the advantages and disadvantages of the proposed approach, and discusses two major issues of the SD algorithm: sensor's noise and cumulative error, which affect the accuracy of the results and the stability of the system. In the following chapter, the affect of these two issues will be further investigated.

Chapter 4

Analysis of SD Algorithm

According to the estimated results of the SD algorithm in 2-D localization system, this chapter focuses on the analysis of two issues mentioned in the previous chapter: sensor's noise and cumulative error. Both of them affect the accuracy of the estimated results. Cumulative error also has significant impact on the stability of the localization system.

4.1 Sensor's Noise Analysis

As mentioned in the previous chapter, the sensor's noise is a great challenge for the SD indoor localization algorithm. Since the distance estimation of the SD algorithm mostly depends on the motion information sensed by the sensors embedded on the nodes, so sensor's noise plays a critical role in the result error. Sensor's noise is created in the internal structure of the sensor and is affected by the sensor's A/D convertor, voltage, and materials, which is inevitable. The following section gives a detailed analysis of the effect of the sensor's noise on the distance estimation.

4.1.1 Effects of Sensor's Noise

The noise of the sensors is a common problem in most sensors. In this study, the accelerometer and gyroscope both face the same problem. The following part takes the X direction as an example to illuminate the effect of the sensor's noise. Under a stationary state without vibration, the original values of the measured acceleration and angular velocity are shown in Figure 4.1, and Figure 4.2.

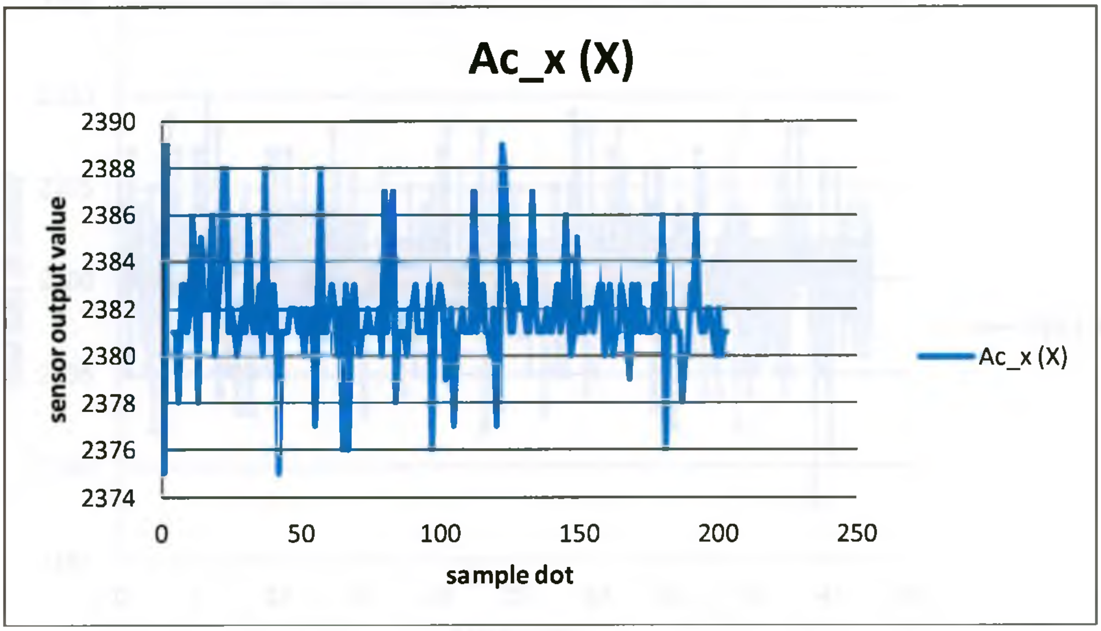

Figure 4.1: Initial Value of Acceleration in X Direction under Stationary State

In Figure 4.1, the average of the 199 samples is 2381.695, and the maximum and minimum values are 2389 and 2375 respectively, which means that the value of about 15 of the difference range are caused by the internal noise of the accelerometer (the number of the measured value is a kind of digital value, not the actual acceleration value, which can be converted into acceleration value based on the equation given by the sensor's producer, same for the following measured value of angular velocity).

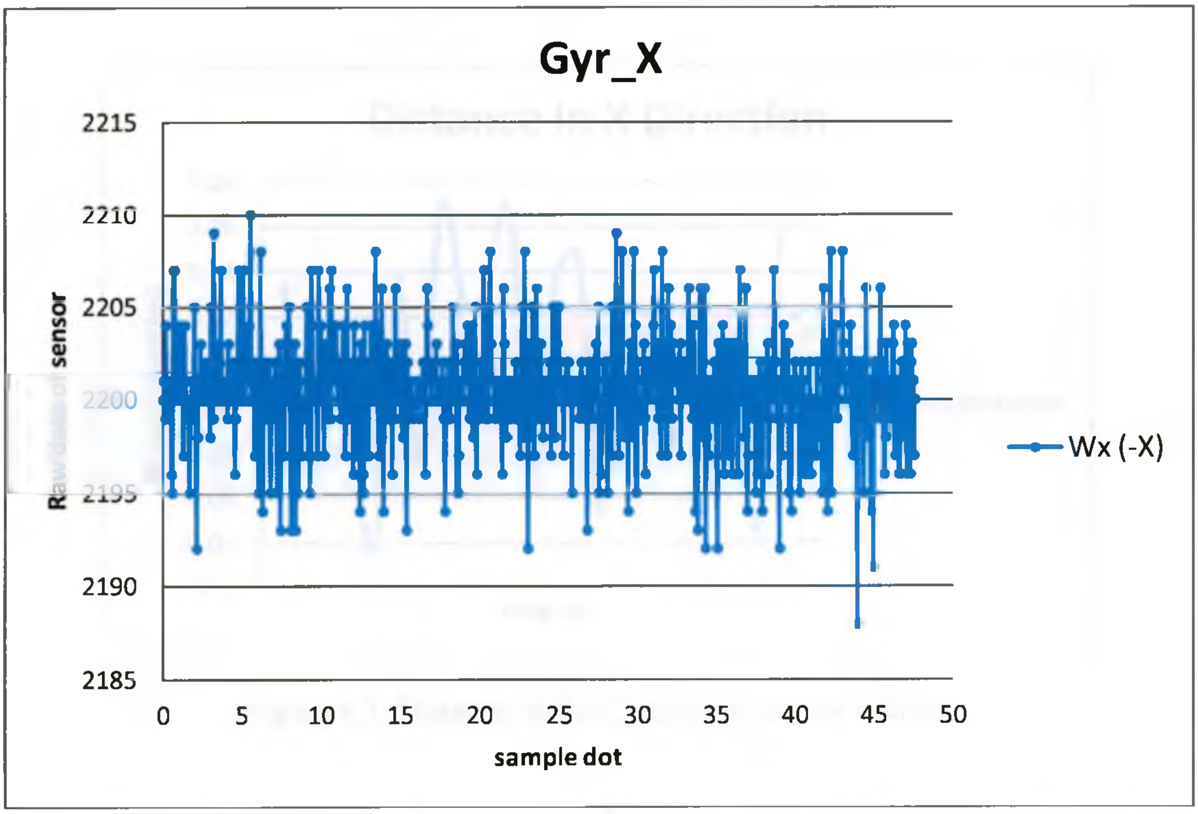

Figure 4.2: Measured Value of Angular Velocity around X Direct Under Stationary State

In the samples shown in Figure 4.2, the maximum value 2207, and the minimum value is 2193. The difference range is up to 24, which causes the instability of the measured value.

4.1.2 Error Analysis of Sensor's Noise

Then tiny changes of the acceleration and angular velocity will signally affect the estimated value of the object's position. Under the stationary state without vibration, the SD algorithm estimates the distance in X direction as shown in Figure 4.3.

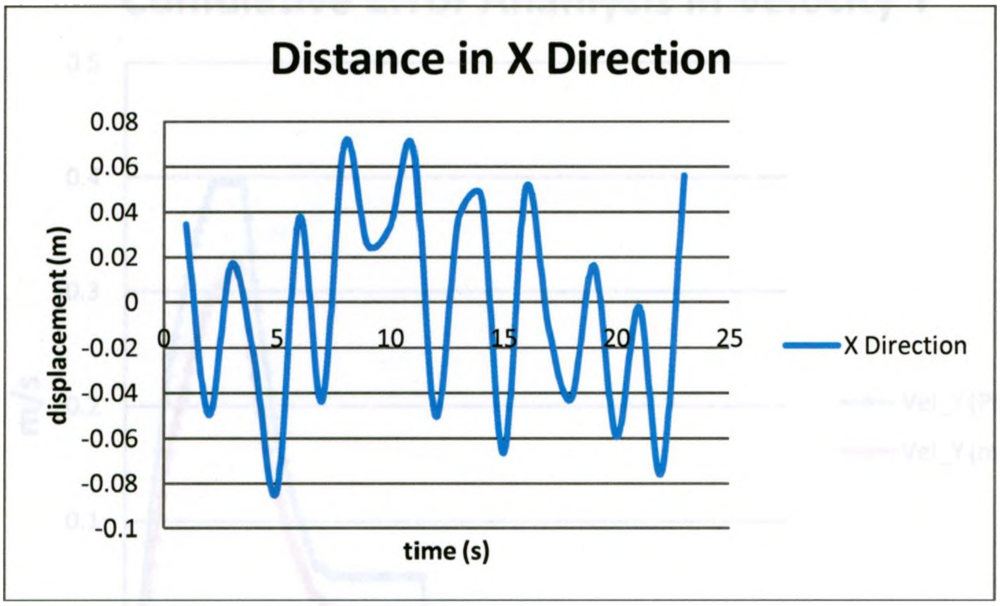

Figure 4.3: Distance Value Caused by Sensor's Noise

From Figure 4.3, the average is very close to 0. But After a long testing period, some certain random drift from the 0 position will be created.

4.2 Cumulative Error Analysis

The cumulative error is caused by the inherent characteristic of the SD algorithm. Multiple integrations within the motion equations of the SD algorithm should amplify the error step by step with the running of the system.

The motion of the monitored object is a continuous process. When a little error happens at time t, this error will be passed to the every future moment. Meanwhile, the following error value will be cumulated, and passed to the next moment. Details can be seen in Figure 4.4 and Figure 4.5.

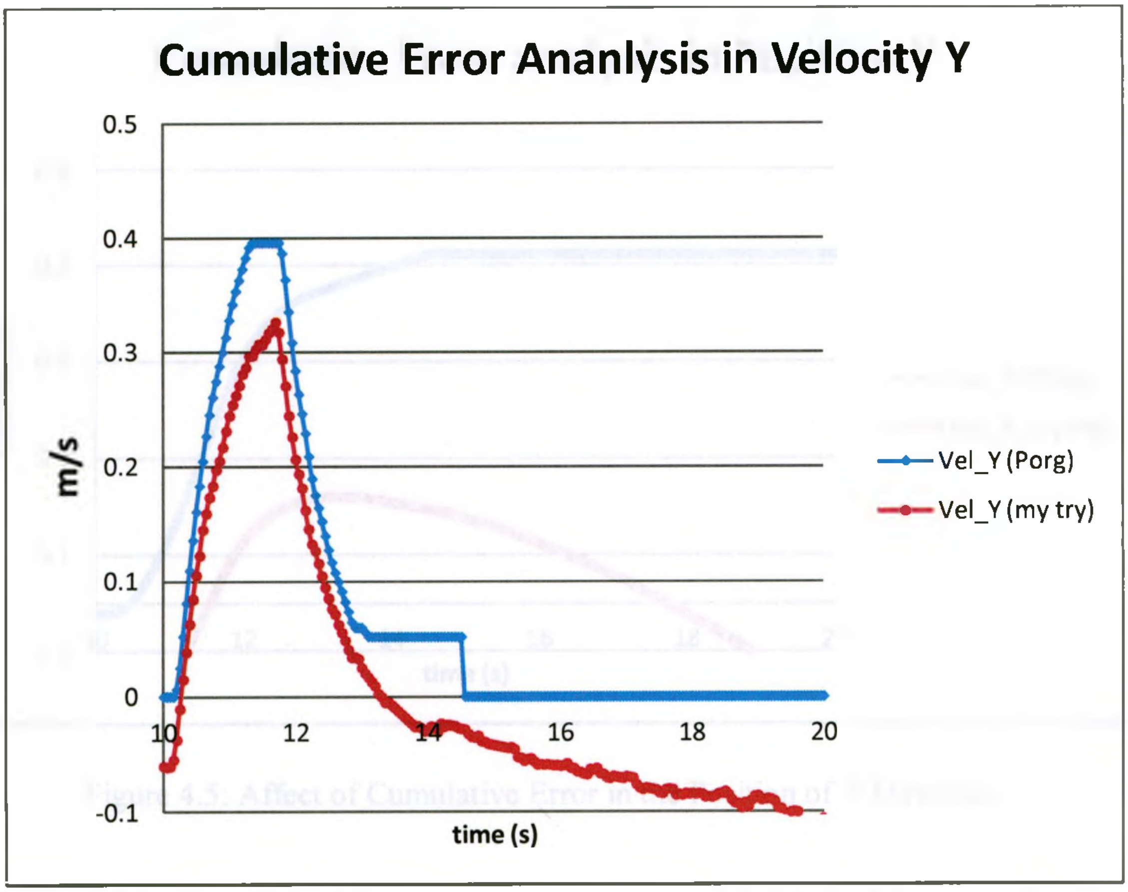

Figure 4.4: Effect of Cumulative Error in the Velocity of Y Direction

Figure 4.4 compares the error effect in the velocity of Y direction. The red line is the velocity value without any error. The blue line is the velocity value affected by the accumulated error. This error will be amplified in the position estimation in next steps. The details can be seen in Figure 4.5.

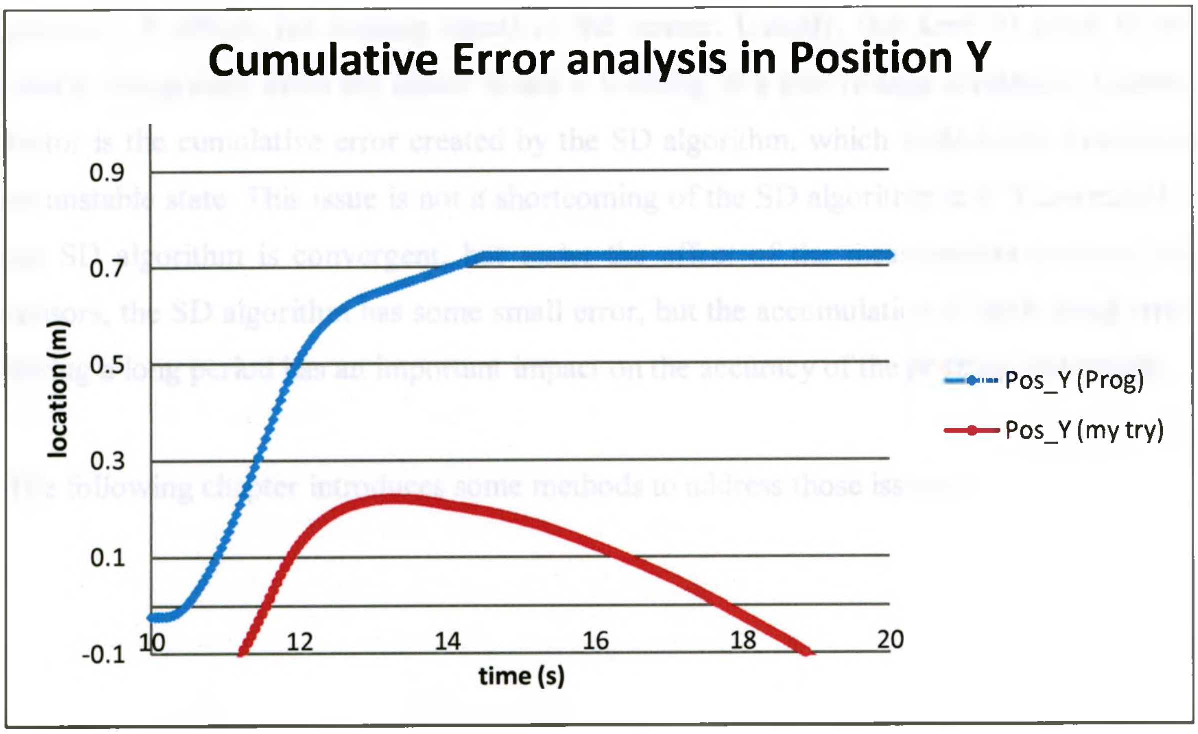

Figure 4.5: Affect of Cumulative Error in the Position of Y Direction

In Figure 4.5, the actual tracking trajectory is represented by the red line, which shows that the object moving out and back. However, the estimated position value doses not return to a steady state, under the effect of the cumulative error. This error will be increasing following the continuous running of the algorithm. Finally, the cumulative error will lead the estimated position value to an uncontrollable state.

4.3 Summary

Through the implementation and experimentation of a 2-D indoor localization system, we concluded that there are two major factors that affect the accuracy of the location estimation. One is the sensor noise that is fixed during the sensor's manufacturing process. It affects the sensing signal of the sensor. Usually, this kind of noise is not clearly recognized when the sensor board is working in a low-voltage condition. Another factor is the cumulative error created by the SD algorithm, which leads to the system in an unstable state. This issue is not a shortcoming of the SD algorithm self. Theoretically, the SD algorithm is convergent, but under the effect of the measurement accuracy of sensors, the SD algorithm has some small error, but the accumulation of such small error during a long period has an important impact on the accuracy of the position estimation.

The following chapter introduces some methods to address those issues.

Chapter 5

3-D Localization System

Indoor localization tracking system can be very useful in various application domains. However, many existing localization algorithms include the SD algorithm mentioned in the previous chapter cannot be directly applied in a complex indoor environment with channel noise, multipath, and obstacles. To address the issues (sensor's noise and cumulative error) mentioned in Chapter 4, this chapter proposes a hardware filter and a modified Kalman filter to address the challenges of 3D-indoor positioning, and presents a SD algorithm that can be used in a 3-D environment based on the previous cloud computing based system architecture.

5.1 Filter Algorithms

According to the previous analysis of the effect of the sensor noise on the SD algorithm, there are two methods to improve the stability and the accuracy of the SD algorithm. One method is to add a hardware filter to eliminate the high frequency noise. Another method is to use a software filter algorithm to estimate an actual value.

5.1.1 Hardware Filter

Through the analysis of the signals of the sensing data, in order to filter out the sensor's noise, we adapted a low-pass hardware filter as a first choice used in our test node. This low-pass filter is added between the sensors and the nodes to filter out high frequency noises. The low-pass filter consists of capacitors, three-stage operational amplifier and resistors. The details can be seen in Figure 5.1 and Figure 5.2.

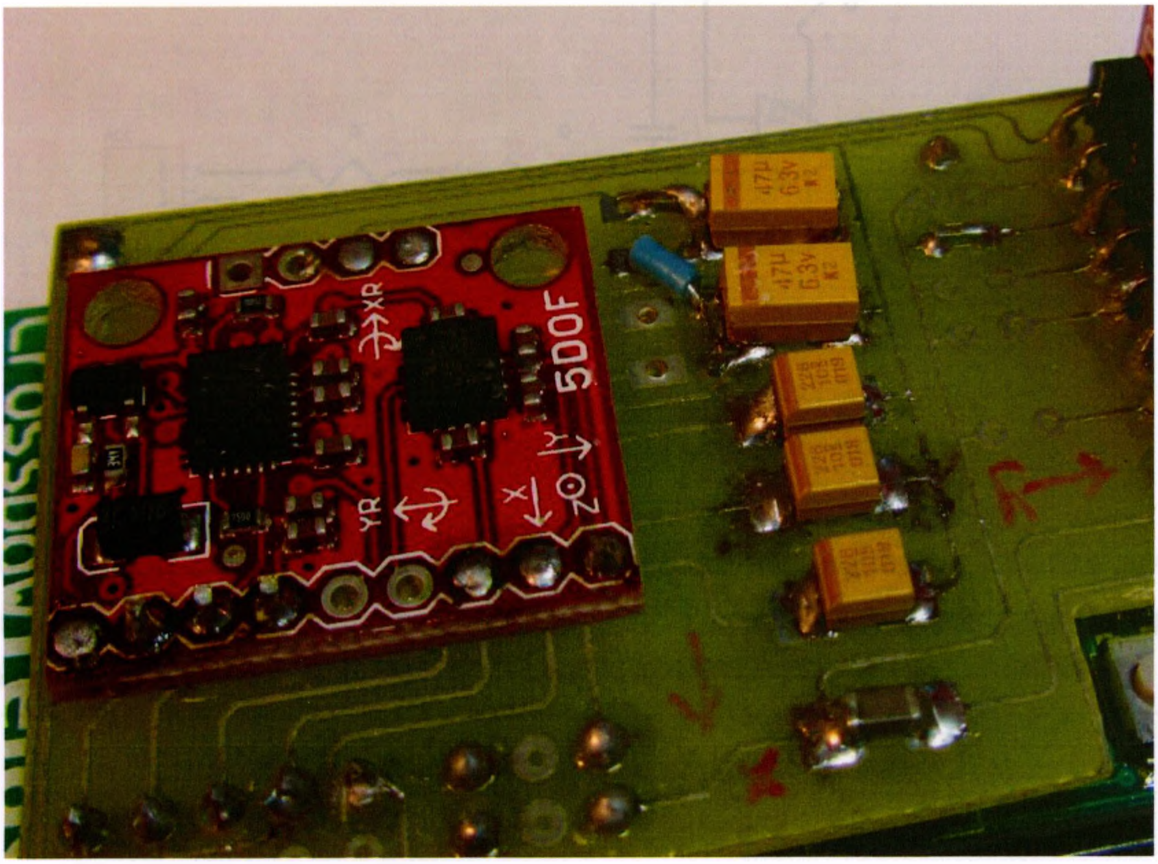

Figure 5.1: Hardware of Low-pass Filter

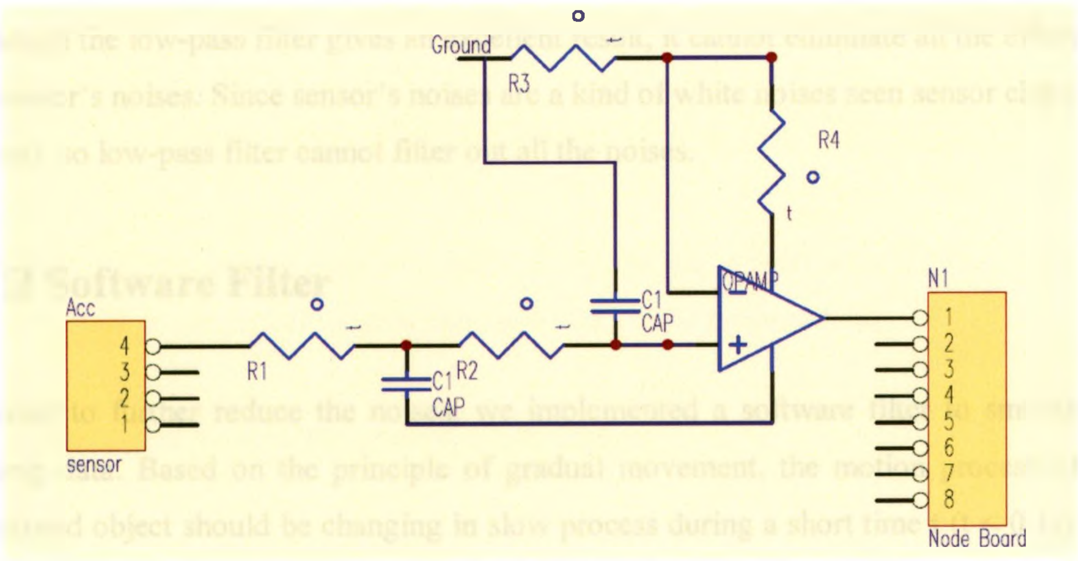

Figure 5.2: Schematic View of Low-pass Filter

By comparing the measured value between before and after using the low-pass filter, the high frequency of the sensor' noises are filtered out. Figure 5.3 is the result of the sensing data through the low-pass filter.

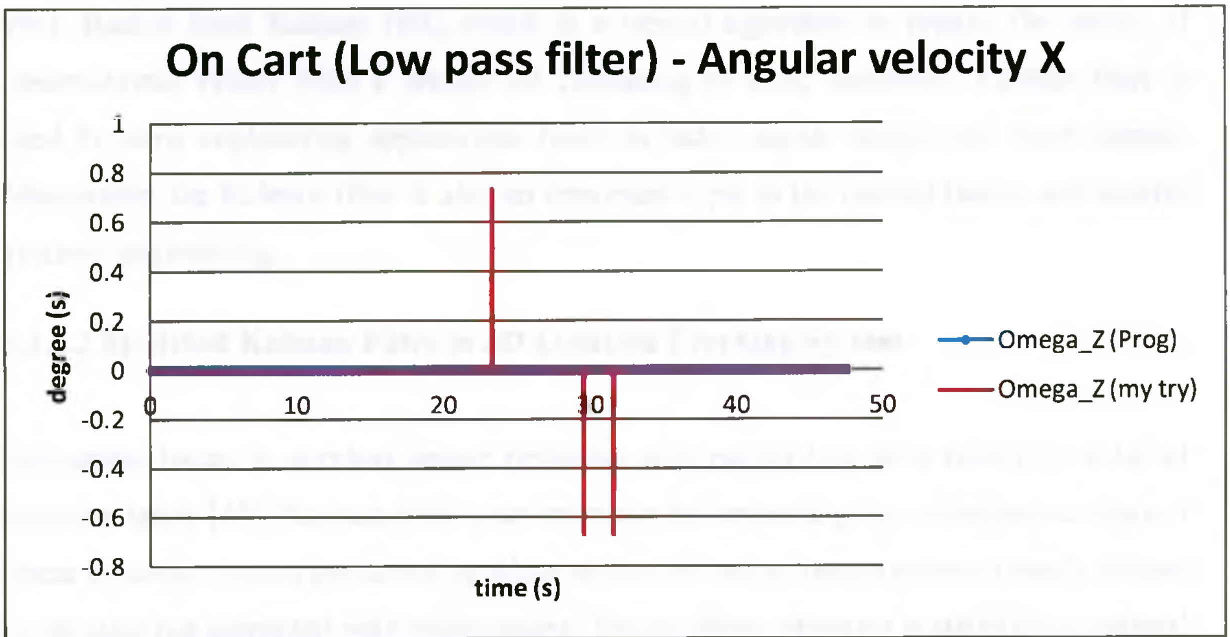

Figure 5.3 Low-pass Filter Used in Angular Velocity in X Direction

Although the low-pass filter gives an excellent result, it cannot eliminate all the effect of the sensor's noises. Since sensor's noises are a kind of white noises seen sensor chips manual, so low-pass filter cannot filter out all the noises.

5.1.2 Software Filter

In order to further reduce the noises, we implemented a software filter to smooth the sensing data. Based on the principle of gradual movement, the motion process of the monitored object should be changing in slow process during a short time t ($t < 0.1s$). So, the value of the motion information can be predicted based on the value of the previous state. Kalman filter algorithm meets these requirements.

5.1.2.1 Kalman Filter Algorithm [60]

Kalman filter algorithm is an optimal recursive data processing algorithm, proposed by Prof. Rudolf Emil Kalman [60], which is a typical algorithm to predict the values of observational values from a limited set consisting of noise sequence. Kalman filter is used in many engineering applications (such as radar, digital image, and voice signal). Meanwhile, the Kalman filter is also an important topic in the control theory and control systems engineering.

5.1.2.2 Modified Kalman Filter in 3D Location Tracking System

Estimation issues in wireless sensor networks with packet-loss have been the center of attention lately [60]. Kalman filter is an estimator for estimating the instantaneous state of linear dynamic system perturbed by white noises, by using measurements linearly related to the state but corrupted with white noises. The resulting estimator is statistically optimal with respect to any quadratic function of estimation error [61].

Firstly, a stochastic process can be described by a linear stochastic difference equation:

$$X(k)= AX(k-1)+BU(k)+W(k) \tag{4-1}$$

where X(k) is the system state of time *k*, *U (k)* for the present state of the controlling variable, *A, B* are the system parameters, and W(k) is the process noise.

The measurement value of the process can be seen as:

$$Z(k)=HX(k)+V(k) \tag{4-2}$$

where Z(k) is the measurement value at time *k*, H is the measurement system parameters, V(k) is the measurement noise.

Usually, Kalman filter consists of five equations. Consider a system represented by a state vector *x(k)* at time *k*, whose dynamics are described by the state transition equation:

$$X(k|k-1)=A\ X(k-1|k-1)+B\ U(k) \tag{4-3}$$

where, *X(k|k-1)* is predicted by the results of the previous state, , *X (k-1 | k-1)* is the optimal result on state *k-1*. If there is not control variable, the value of *U(k)* can be 0.

P is the covariance matrix：

$$P(k|k-1)=A\ P(k-1|k-1)\ A'+Q \tag{4-4}$$

where *P(k|k-1)* is covariance matrix of *X(k|k-1)*，*P(k-1|k-1)* is the covariance matrix of *X(k-1|k-1),* and *Q* is the covariance matrix of the process White Gaussian Noise.

The optimization of estimates *X (k | k)* of the *state (k):*

$$X(k|k)= X(k|k-1)+Kg(k)\ (Z(k)-H\ X(k|k-1)) \tag{4-5}$$

where *Kg* is Kalman Gain:

$$Kg(k)= P(k|k-1)\ H' / (H\ P(k|k-1)\ H' + R) \tag{4-6}$$

where R is the covariance matrix of the testing White Gaussian Noise,

However, with the Kalman filter, in order to keep running down until the system is completed, it needs to update the *k* state *X (k | k)* of the covariance matrix:

$$P(k|k)= (I-Kg(k)\ H)\ P(k|k-1) \tag{4-7}$$

where *I* is the unit matrix.

The Kalman filter cycle is shown in Figure 5.5. The time update predicts the current state estimate in advance. The measurement update adjusts the predict estimate by an actual measurement at the next time.

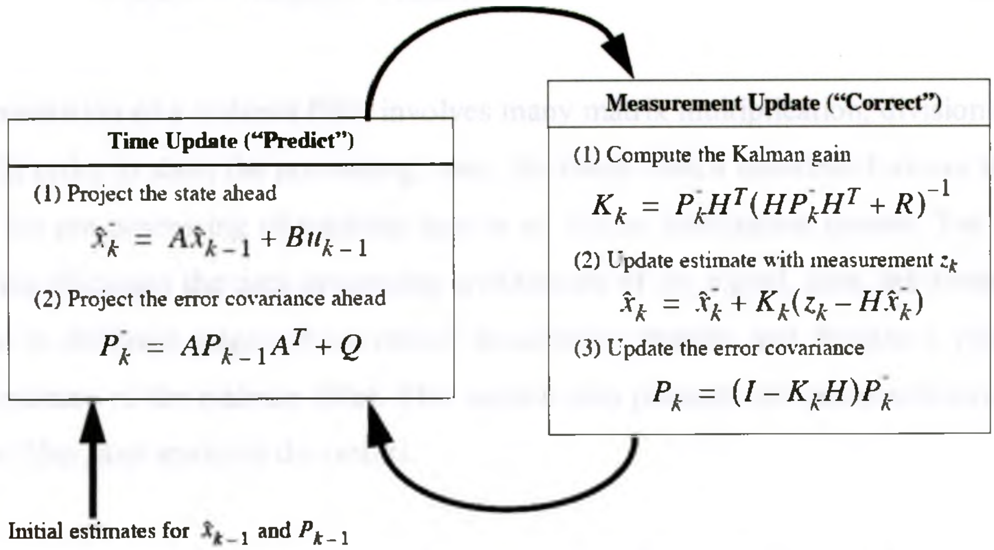

Figure 5.5: Principle of Kalman Filter [62]

5.1.2.3 Implementation of Modified Kalman Filter in Localization

By reviewing the Kalman filter, this thesis simplifies the variables of Kalman filter in order to be easily implemented. Since the sensor's noises are white Guess noises, so we can modify the five equations as follows:

$$X(k|k-1)=X(k-1|k-1) \tag{4-8}$$

$$P(k|k-1)=P(k-1|k-1) +Q \tag{4-9}$$

$$X(k|k)= X(k|k-1)+Kg(k) (Z(k)-X(k|k-1)) \tag{4-10}$$

$$Kg(k)= P(k|k-1) / (P(k|k-1) + R) \tag{4-11}$$

$$P(k|k) = (1 - Kg(k))\ P(k|k-1) \tag{4-12}$$

The implementation of a Kalman filter involves many matrix multiplication, division and inversion. In order to short the processing time, this thesis uses a modified Kalman filter to address the pre-processing of tracking data in an indoor localization system. The rest of the section discusses the data processing architecture of the signal, data, information, and service in different stages of an indoor localization system; and designs a typical topology structure of the Kalman filter. This section also presents the implementation of the Kalman filter, and analyzes the results.

The algorithm flow in the architecture can be described as shown in Figure 5.4.

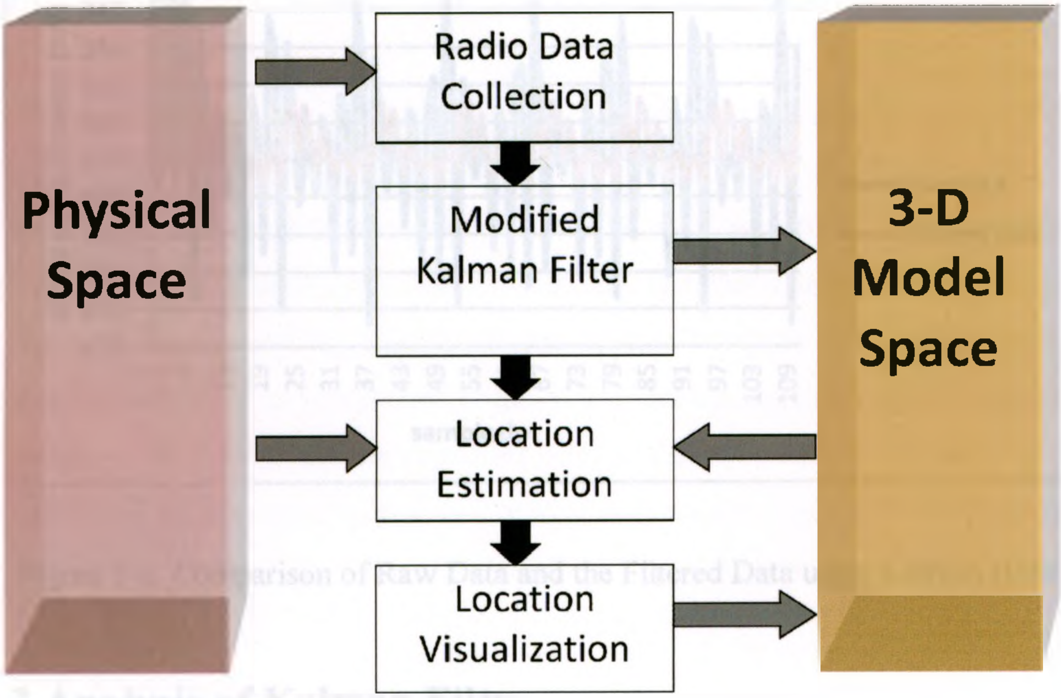

Figure 5.4: Flowchart of Data Processing with Kalman Filter

The algorithm has been implemented using a Java in TinyOS environment. Although this is obviously not ideal, it has proved adequate for test and demonstration purposes. The test program runs within the framework of indoor localization system in which there is a node to be tracked. In the following implementation the pursuers are moving on a 3-D space. Note that this implementation is primarily to prove the usage of the proposed Kalman filter.

The raw data are received by the base station node. The base station takes charge of the data receiving and forwarding. After the raw data are processed using the Kalman filter, the resulting data are smoother, and the details are shown in Figure 5.6.

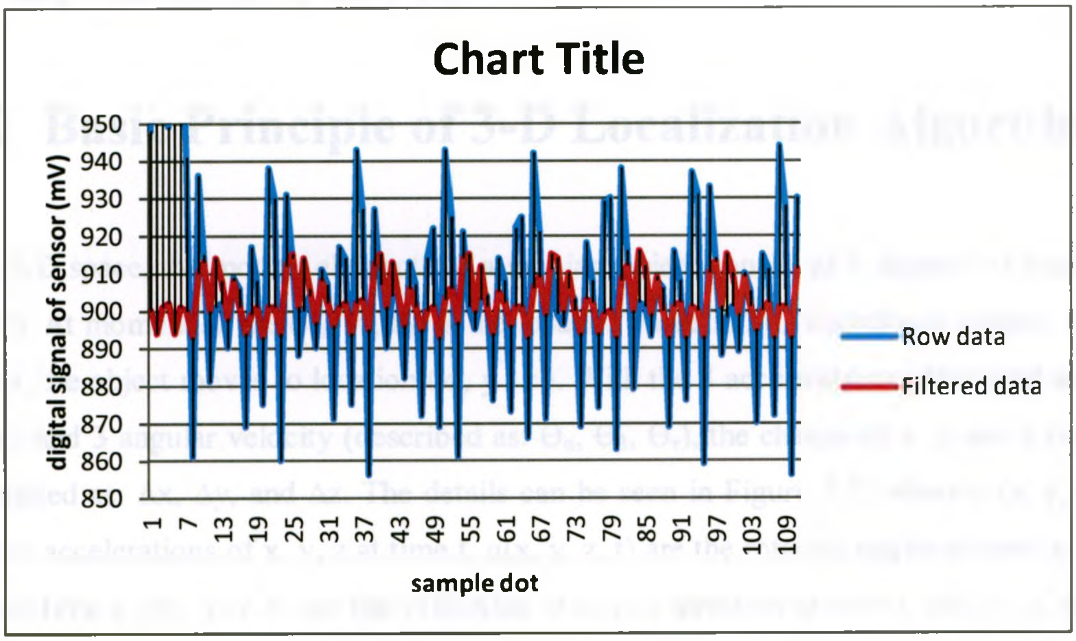

Figure 5.6: Comparison of Raw Data and the Filtered Data using Kalman filter

5.1.3 Analysis of Kalman Filter

This thesis presents a framework for localization system based on WSNs to support flexible service access and expand the system's function and effective range, and discusses a Kalman filter used in the raw data pre-processing. Obviously, the localization system is much more stable and the data are much smoother after using the Kalman filter.

In practical application, this thesis has not discussed the effect of the transit matrix A and the control variable U(x). In the future, with the development of wireless sensors, it will be quickly promoting the monitoring system domain into a new level. A result of this promotion is the dramatic increase of monitoring data and service types, which will be a big challenge for a traditional central Kalman filter [63]. So, this filter will be improved according to the need of the future system.

5.2 Basic Principle of 3-D Localization Algorithm

In a 3-D space, the motion elements of a moving object consist of 6 degrees of freedom (DoF). At moment t_0, the (x_0, y_0, z_0) is the location value in 3-D coordinate system. After time *t*, the object moves to location ($x^{\cdot}$, $y^{\cdot}$, $z^{\cdot}$). With the 3 accelerations (described as: a_x, a_y, a_z) and 3 angular velocity (described as: Θ_α, Θ_β, Θ_γ), the change of *x*, *y*, and *z* can be calculated as: Δx, Δy, and Δz. The details can be seen in Figure 5.7, where a (x, y, z, t) are the accelerations of x, y, z at time t, α(x, y, z, t) are the rotating angles around x, y, z axis at time t, v(x, y, z, t) are the velocities of x, y, z direction at time t, ω(x, y, z, t) are the angular velocities around x, y, z axis, P(x, y, z, t) are the displacement values in x, y, z directions at time t, and A(x, y, z, t) are angles at x, y, z directions at time t.

$$(a(x,y,z,t),\alpha(x,y,z,t)) \rightarrow (v(x,y,z,t),\omega(x,y,z,t)) \rightarrow (P(x,y,z,t),A(x,y,z,t))$$

Figure 5.7: Principle of 3-D Localization Algorithm

5.2.1 3-D Localization Algorithm

1. Definition of the elements: A as transfer matrix, V as the velocity vector, angular $\Theta=\{\alpha, \beta, \gamma\}$, I is the inertia tensor which is defined as follows:

$$I = \begin{bmatrix} I_{xx} & -I_{xy} & -I_{xz} \\ -I_{yx} & I_{yy} & -I_{yz} \\ -I_{zx} & -I_{zy} & I_{zz} \end{bmatrix} \qquad (4\text{-}11)$$

The individual components of the inertia tensor are defined as:

(1) rotate around y axis

$$A_y = \begin{bmatrix} \cos\beta & 0 & \sin\beta \\ 0 & 1 & 0 \\ -\sin\beta & 0 & \cos\beta \end{bmatrix} \tag{4-12}$$

(2) rotate around x axis

$$A_x = \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos\alpha & \sin\alpha \\ 0 & \sin\alpha & \cos\alpha \end{bmatrix} \tag{4-13}$$

(3) rotate around z axis

$$A_z = \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos\gamma & \sin\gamma \\ 0 & -\sin\gamma & \cos\gamma \end{bmatrix} \tag{4-14}$$

2. Eular angle and Transform matrix equation is as the followings:

$$A = A_y A_x A_z =$$

$$\begin{bmatrix} \cos\beta\cos\gamma + \sin\beta\sin\alpha\sin\gamma & -\cos\beta\sin\gamma + \sin\beta\sin\alpha\cos\gamma & \sin\beta\cos\alpha \\ \cos\alpha\sin\gamma & \cos\alpha\cos\gamma & -\sin\alpha \\ -\sin\beta\cos\gamma + \cos\beta\sin\alpha\sin\gamma & \sin\beta\sin\gamma + \cos\beta\sin\alpha\cos\gamma & \cos\beta\cos\alpha \end{bmatrix} \tag{4-15}$$

3. Position and orientation

When an object is moving, node's accelerometer *a* can be described as:

$$a = \begin{Bmatrix} a_x \\ a_y \\ a_z \end{Bmatrix} \tag{4-16}$$

The angular velocity ω as:

$$\omega = \begin{Bmatrix} \omega_x \\ \omega_y \\ \omega_z \end{Bmatrix} \tag{4-17}$$

When a_0, P_0, V_0, means the values of accelerometer a, Position P, velocity V at the time t_0, a, P, V is the value at the next time, k is the change value of the acceleration, and $t>0$. We can get:

since, $a = a_0 + kt$

so,

$$V = \int_0^t a\,dt = V_0 + a_0 t + \frac{k}{2} t^2 \tag{4-18}$$

$$P = \int_0^t V\,dt = \int_0^t \left(V_0 + a_0 t + \frac{k}{2} t^2\right) dt = P_0 + V_0 t + \frac{a_0}{2} t^2 + \frac{k}{6} t^3 \tag{4-19}$$

When a_{i-1}, P_{i-1}, V_{i-1}, means the values of acceleration a, Position P, velocity V at the time t_{i-1}, a, P, V is the value at the time t_i, and $i \geq 1$. k is the change value of the acceleration, which can be described as follows:

$$k = \frac{a_i - a_{i-1}}{\Delta t} \tag{4-20}$$

so, when $t=i$, we can get the velocity V_i and the position P_i.

$$V_i = V_{i-1} + a_{i-1}\Delta t + \frac{k}{2}\Delta t = V_{i-1} + \frac{a_{i-1} + a_i}{2}\Delta t \tag{4-21}$$

$$P_i = P_{i-1} + V_{i-1}\Delta t + \frac{a_{i-1}}{2}\Delta t^2 + \frac{a_i - a_{i-1}}{6\Delta t}\Delta t^3 = P_{i-1} + V_{i-1}\Delta t + \frac{2a_{i-1}+a_i}{6}\Delta t^2 \quad (4\text{-}22)$$

The position equation is expended based on the transform matrix, shown as follows:

$$A_i = A_{i-1}A(\Delta\theta_i) \quad (4\text{-}23)$$

5.3 3-D Localization System Implementation

A 3-D indoor localization system is implemented based on the cloud computing architecture mentioned in Chapter 2. In a mobile node, 6 DoF of two sensor chips are embedded to measure the 6 motion elements. The estimated location value should be updated into a 3-D virtual environment.

In order to represent the states of the monitored object (such as fall, upright, or oblique), the cylinder is used to denote the monitored object.

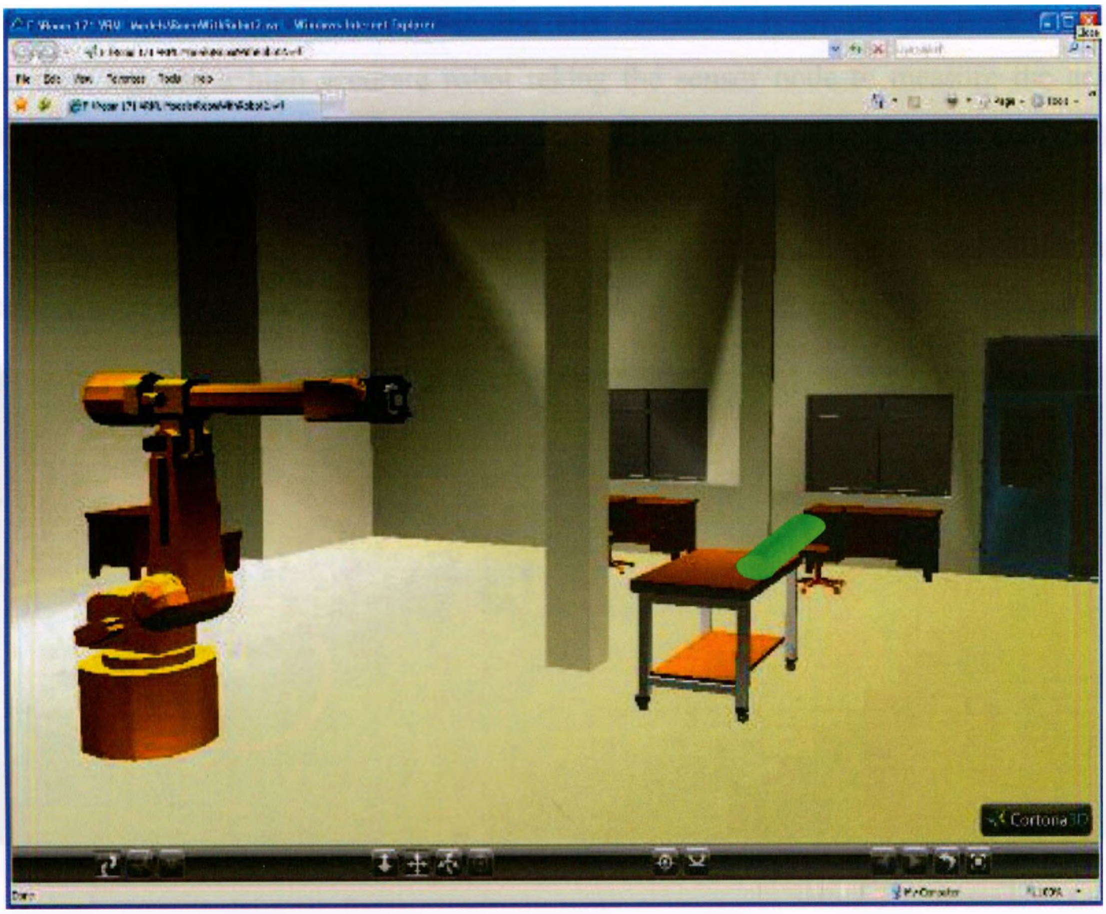

Figure 5.8: Implementation of 3-D Localization System

Figure 5.8 is the result of the location of one node motion. This motion node is show in the local machine. In the whole indoor localization system, this motion information will be published into a web page. In Figure 5.8, the location of green cylinder represents the monitored object. This cylinder can describe three states of the monitored object, such as: upright, fall, and oblique.

- **Testing Scene**

In order to calibrate the sensor node and test the accuracy of the proposed 3-D SD algorithm, we use a high accurate robot taking the sensor node to measure the actual distance. The robot is fixed in the laboratory filled with static obstacles and mobile obstacles, meanwhile, there is some channel noises in the testing space. Figure 5.9 show the scene of the testing. In the figure, the circled box is the node embedded with accelerometer and gyroscope.

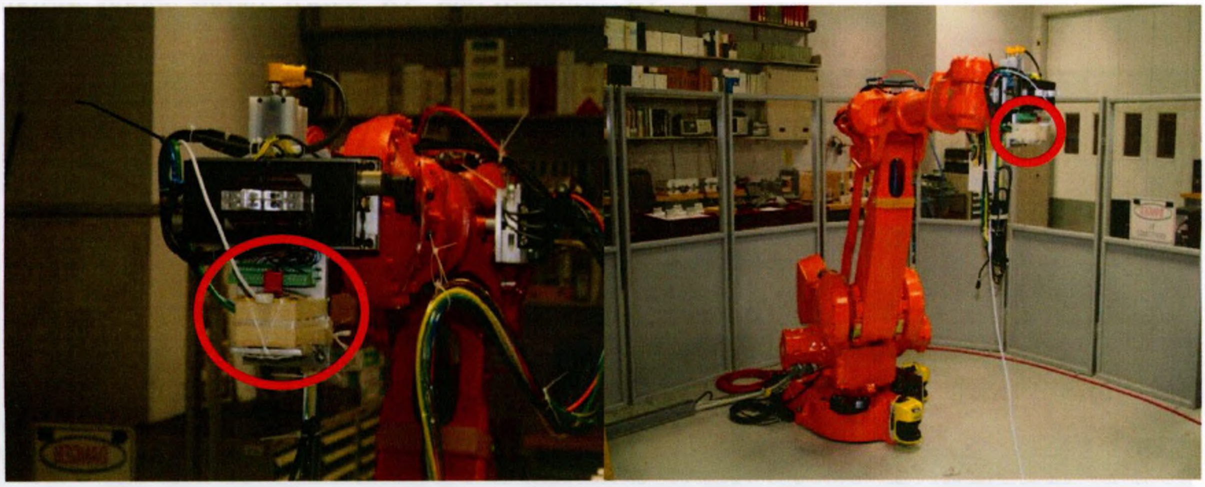

Figure 5.9 Scene of Performance Test on Robot

In the test, since this robot has a much higher accuracy than the localization system, the cumulative error of the robot displacement is ignored. In order to avoid the effect of the changing of the batter's voltage, the testing node uses the stable USB power supply.

- **Anti-interference Testing**

In order to analyze the interference of channel noise and obstacle, two typical anti-interference tests are made in the testing scene: obstacles interference testing and channel noise interference testing. The details are as shown in Figure 5.10.

Obstacles interference testing: Between the sensor node, communication node, and sink node, we set some static obstacles and mobile obstacles in order to observe the effect. The static obstacles include robot fence, wall, and office furniture. Working people are the mobile obstacle.

Channel noise interference testing: The test is the environment filled with WiFi signal, mobile phone signal, fridge' RF, and machine' RF.

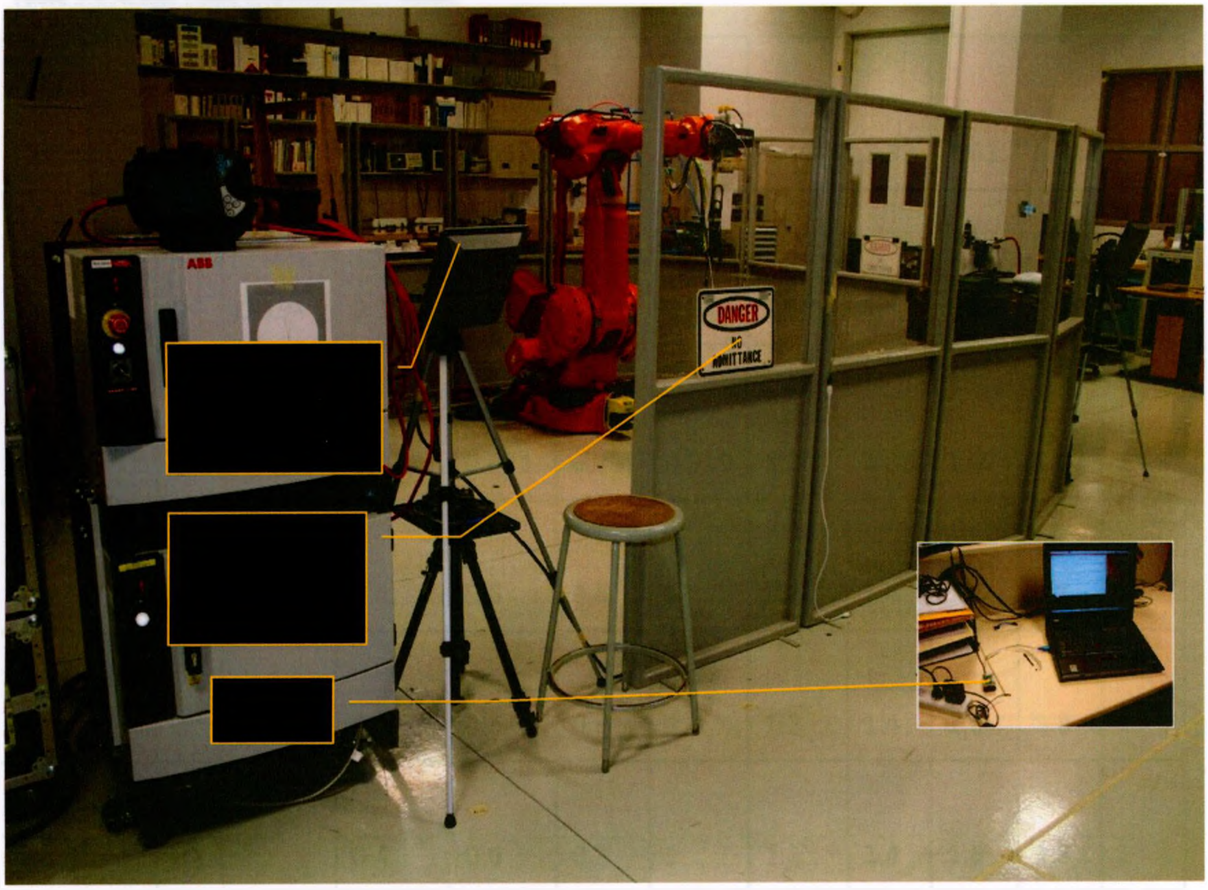

Figure 5.10 Interference Testing Scene

Through the analysis of the test result, the result of the interference test shows that the estimated value of SD algorithm is not affected by those obstacles and this channel's noises.

The following test is the accuracy analysis testing. As same, the displacement of robot is seen as the actual displacement. The actual value and measured value of x, y, z can be seen in Table 5.1.

Table 5.1 Actual value and Measured Value

Measured –X (m)	0	0.193	0.387	0.569	0.77	0.961	1.194	1.39	1.61	1.84	2.07
Measured –Y (m)	0	0.194	0.386	0.579	0.81	0.943	1.188	1.42	1.67	1.79	1.92
Measured –Z (m)	0	0.212	0.409	0.621	0.79	0.919	1.2	1.38	1.67	1.82	1.88
Actual-X (m)	0	0.2	0.4	0.6	0.8	1	1.2	1.4	1.6	1.8	2
Actual –Y (m)	0	0.2	0.4	0.6	0.8	1	1.2	1.4	1.6	1.8	2
Actual-Z (m)	0	0.2	0.4	0.6	0.8	1	1.2	1.4	1.6	1.8	2

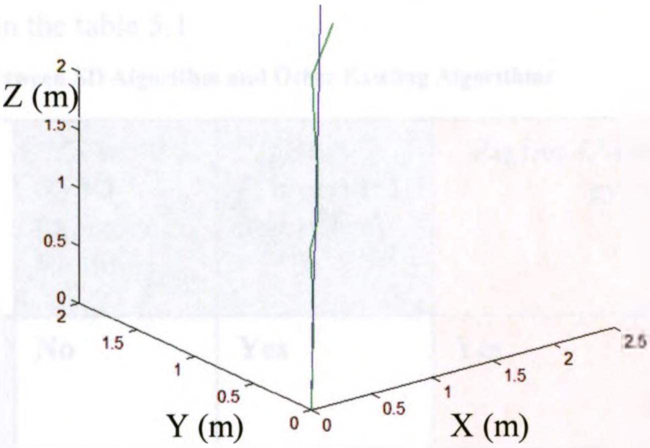

Figure 5.11: Comparison of the Actual Value and Measured Value in X, Y, and Z Axis

In the demo testing, the stability of the system is enhanced. The most offset between the measure displacement and the actual displacement is 12 cm within the testing rang of 200cm. The affect of cumulative error has been well controlled, but not completely eliminated. Of course, a part of error is raised by the sensitivity of the sensor itself.

5.4 Analysis of the 3-D Localization System

From the testing of the demo of the 3-D localization system based on 3-D SD localization algorithm, the effect of the estimated location of the 3-D localization system is more stable than the 2-D localization system mentioned in Chapter 3.

In the 3-D localization system, the effect of the sensor' noises are reduced into a small extent through using the hardware filter and the Kalman filter. Meanwhile, the variable of the inertia tensor I is introduced into the 3-D localization equations, which decreases the effect of the cumulated error. In our testbed, we also make a comparative analysis between the SD localization algorithm and other existing localization algorithms. The details can be seen in the table 5.1.

Table 5.1 Comparison between SD Algorithm and Other Existing Algorithms

Characteristic	WiFi – RFID (Aeroscout, Ekahau)	ZigBee (Fingerprint algorithm)	ZigBee (Accelerometer and gyroscope)
Mesh Networking Capability	No	Yes	Yes
3-D Localization	No	Yes	Yes
Support for Sensing	No	Yes	Yes
Decentralized Control	No	Yes	Yes
Precision	3-10m	1-3m	0.1-0.5m
Infrastructure Cost ($/100m^2)	15,000	1200	1200

5.5 Summary

According to the analysis of the major issues: sensor's noise and cumulative error of the SD algorithm, this chapter presents a low-pass filter (hardware filter) and a modified Kalman filter (software filter) to improve the SD algorithm. The low-pass filter can filter out sensor's high frequency noises. Since the noise spectrum spreads widely, so a dynamic software filter is necessary. A modified Kalman filter is suitable to predict, estimate, and correct the signal, which largely eliminates the effect of sensor's noise in the low-frequency range. The elimination of the effect of sensor's noises creates a condition of the stability of the system. Meanwhile, inertia tensor I is introduced to the 3-D SD localization algorithm used in a 3-D virtual environment with 6 DoF. A 3-D localization system is developed to validate the proposed techniques. A comparison of AeroScout (WIFI-RFID) and Fingerprint algorithm (ZigBee) with the SD algorithm are made, which shows the advantages of the proposed SD algorithm and related techniques presented in this thesis.

Chapter 6

Conclusion and Future Work

6.1 Conclusion and Contributions

With the development of the low-power tiny nodes, as well as self-organizing network technology, WSNs are becoming a hot focal point in academic and industry domains [64]. Wireless sensor networks are increasingly used in military and civilian fields, which can be easily diffused in a very broad application space to sense the environment information. Those sensor nodes are responsible for collecting specific data, self-organizing into a wireless network, and transmitting sensed data to the sink node which connects to a computer with an Internet connection. Finally, remote users can access the information over the Internet. The applications of WSNs should have a good prospect.

Indoor localization is a specific scenario of wireless sensor network localization, which has particularly important commercial application value in large-scale warehousing, logistics management, sports stadiums, intelligent buildings, healthcare and other scenes. Although the 2-D localization demo shows that the proposed SD algorithm has good localization accuracy, it still has many issues caused by the senor's noise, cumulative error raised by the motion equations. In a 2-D environment, for example, some motion components should be divided into the direction Z, which affects the stability of the estimation result. So, the demo should be tested in a horizontal plane. In order to further improve the localization accuracy and the stability of the system, the SD algorithm is combined with a dynamic software filter to decrease the effect of the cumulative error, and adopts the calculation factor: Inertia tensor I to model the motion in a 3-D environment for the indoor localization system, which is better applied to the 3-D indoor environment.

Different from the traditional methods by sending signals to measure the distance, the proposed SD localization algorithm uses the movement information to estimate the moving distance. The innovative point of this work is the combination of two types of sensors to estimate large scale distance in an indoor environment. Meanwhile a hardware filter is used to improve the accuracy of the results. During the implementation, a 3-D virtual space of our laboratory is created to show the effect of the localization results. In order to analyze the validation, both a 2-D space and a 3-D space are developed to test the results of the estimated distances. This thesis also analyzes other existing localization algorithms: AeroScout (WIFI-RFID) and Fingerprint algorithm (ZigBee) in the same testbed. The proposed SD algorithm has a significant advantage in localization accuracy rating in an indoor environment filled with interference noises and moving obstacles.

The major contributions of this thesis are as follows:

- A mathematical definition of localization issue based on WSN and a scenario design of an indoor environment.
- A SD algorithm is proposed for an indoor localization system based on Cloud computing architecture under the 2-D and 3-D virtual environment.
- A low-pass hardware filter design for the sensor board.
- A Modified Kalman filter used in the SD algorithm
- A Comparison of the proposed SD algorithm against the AeroScout (WIFI-RFID) and Fingerprint algorithm (ZigBee)

As many different distance measurement algorithms, however, there are still some issues that have not been addressed [65]. A primary issue is the automatic system initialization. Nevertheless, the SD algorithm has a higher accuracy than some existing algorithms, such as the RSSI algorithm, and its anti-interference is also more suitable to be used in an indoor environment.

6.2 Future Work

Since localization technologies based on Wireless sensor networks are very closely integrated with the applications, so further research needs to further achieve the proposed algorithm and design a practical node initialization algorithm to improve the localization system. We plan to focus on the application of intelligent building scenarios based on an intelligent initialization algorithm. The system will decrease the cost for each node, and is compatible with other types of localization equipment. Also, due to time constraints, the design and analysis of the SD localization algorithm still have some shortcomings, though the algorithm has a better performance in indoor environments. Significant efforts are still required:

- Need to reduce the computational complexity: the existing algorithms are all computationally intensive, especially the SD localization algorithm. This issue will affect the scalability of the WSN.
- Establishing mathematical models to provide a detailed description of the performance parameters.
- There are some functions and coefficients, the values of which did not give the theoretical optimal values. For example, the Kalman Gain of Kalman filter used in the system requires further precision, which should improve the accuracy of the estimated result.

- Decrease the amount of the communication in the WSN. Sensors embedded in the node working in a high frequency deeply rise with the increase of the number of the monitored nodes. Distributed computation to each node to decrease the communication amount is one of the important issues to be studied in the future.

Meanwhile, since the SD localization algorithm system is just at the initial stage of a long term project with the objective to track an object in a large scale indoor environment, this study simplifies the initial state of the object to be tracked. The initial location coordinate values are seen as (0, 0) or (0, 0, 0), namely the starting point. So, in the future the initializations of the monitored nodes should be more realistic and feasible.

Bibliography

[1] K. Römer and F. Mattern. "The Design Space of Wireless Sensor Networks". IEEE Wireless Communications, v.11, n.6, Dec., 2004, pp. 54-61.

[2] S. Hadim, and N. Mohamed. "Middleware Challenges and Approaches for Wireless Sensor Networks". IEEE Distributed Systems Online v. 7, n. 3, Mar., 2006, pp. 1-23.

[3] N. Maluf. An Introduction for Micro Electromechanical Systems Engineering. Artech House: Norwood, March, 2000.

[4] M. Gad-el-Hak, etc. "The MEMS Handbook". CRC Press: New York, NY, 2002.

[5] I. F. Akyildiz , W. Su , Y. Sankarasubramaniam , and E. Cayirci. "Wireless Sensor Networks: A Survey". Computer Networks: The International Journal of Computer and Telecommunications Networking, v.38 n.4, 15th March 2002, pp. 393-422.

[6] K. Bult, A. Burstein, D. Chang, M. Dong, M. Fielding, E. Kruglick, W. J. Kaiser, and H. Marcy. "Low Power Systems for Wireless Micro-sensors". ISLPED, Monterey CA, USA, SN: 0-7803-3571-8/96, 1996.

[7] G.J. Pottie. "Wireless Multiple Access Adaptive Communication Techniques". Encyclopedia of Telecommunications, vol. 18, Ed. Froelich/Kent, Dekker, 1999, pp.1-53.

[8] International Conference on Information Processing in Sensor Networks, [url]: http://en.wikipedia.org/wiki/International_Conference_on_Information_Processing_in_Sensor_Networks.

[9] K. Akkaya and M. Younis. "A Survey on Routing Protocols for Wireless Sensor Networks". Ad Hoc Networks, v. 3, Issue 3, May 2005, pp. 325-349.

[10] P. A. Shoemaker, C. G. Hutchens, and S. B. Patil. "A Hierarchical Clustering Network Based on a Model of Olfactory Processing". Analog Integrated Circuits and Signal Processing, v. 2, n.4, DOI: 10.1007/BF00228713, November 1996, pp. 297-311.

[11] I. F. Akyildiz and X. Wang. "A Survey on Wireless Mesh Networks". IEEE Communications Magazine, 43, 2005, pp.23-30.

[12] H. S. Kim, T. F. Abdelzaher, and W. H. Kwon. "Minimum-energy Asynchronous Dissemination to Mobile Sinks in Wireless Sensor Networks". Proceedings of the 1st International Conference on Embedded Networked Sensor Systems (SenSys' 03), Nov 5-7, 2003, Los Angeles, CA, USA. New York, NY, USA: ACM, 2003, pp.193-204.

[13] Y. Bi, L. Sun, J. Ma, N. Li, I. A. Khan, and C. Chen. "HUMS: An Autonomous Moving Strategy for Mobile Sinks in Data-gathering Sensor Networks", EURASIP Journal on Wireless Communications and Networking, June 2007, pp. 173-184.

[14] Y. Bi, J. Niu, L. Sun, H. Wei, and Y. Sun. "Moving Schemes for Mobile Sinks in Wireless Sensor Networks, Proceedings". The 26th Performance, Computing, and Communications Conference (IPCCC'07), Apr 11-13, 2007, New Orleans, LA, USA. Los Alamitos, CA, USA: IEEE Computer Society, 2007, pp.101-108.

[15] G. J. Pottie and W. J. Kaiser. Principles of Embedded Networked Systems Design. Cambridge University Press, September 2006.

[16] P. Misra and P. Enge, "Global Positioning System: Signals, Measurements, and Performance". International Journal of Wireless Information Networks, v. 1, n. 2, December, 2001, pp. 83-105.

[17] R. Want, A. Hopper, V. Falcão, and J. Gibbons. "The Active Badge Location System". ACM Transactions on Information Systems (TOIS), v.10, n.1, 1992, pp.91-102.

[18] J. Chin, V. Callaghan, and G. Clarke. “Soft-appliances: A Vision for User Created Networked Appliances in Digital Homes”. J. Ambient Intell. Smart Environ. doi:10.3233/AIS-2009-0010, January 2009, pp. 69–75.

[19] D.E. Manolakis, E. Solution. “Performance Analysis of 3-D Position Estimation by Trilateration”. IEEE Tranansactions on Aerospace and Electronic, v.32, n.4, Systems 1996, pp.1239-1248.

[20] L. Lovász. Matching Theory, North-Holland, ISBN 0444879161 M.D. Plummer, 1986.

[21] E. E. L. Lau, B. G. Lee, S. C. Lee, and W. Y. Chung. “Enhanced RSSI-Based High Accuracy Real-Time User Location Tracking System for Indoor and Outdoor Environments”. International Journal on smart Sensing and Intelligent Systems, v. 1, n.2, June 2008, pp. 534-548.

[22] A. Badali, J. M. Valin, F. Michaud, and P. Aarabi. “Evaluating Real-time Audio Localization Algorithms for Artificial Audition in Robotics”. Intelligent Robots and Systems, IROS 2009, IEEE/RSJ International Conference on St. Louis, MO, ISBN: 978-1-4244-3803-7, October 2009, pp. 2033- 2038.

[23] C. Lenz, T. Röder, M. Eggers, S. Amin, T. Kisler, B. Radig, G. Panin, and A. Knoll. “A Distributed Many-Camera System for Multi-person Tracking”. Ambient Intelligence, Lecture Notes in Computer Science, v. 6439/2010, 2010, pp. 217-226.

[24] N. Priyantha, A. Chakraborthy, and H. Balakrishnan. “The Cricket Location Support System”. Proceedings of International Conference on Mobile Computing and Networking 2000, New York: ACM Press, 2000, pp.32-43.

[25] A. Nasipuri and K. Li. “A Directionality Based Location Discovery Scheme for Wireless Sensor Networks”. Proceedings of the 1st ACM International Workshop on Wireless Sensor Networks and Applications, New York: ACM Press, 2002, pp.105-111.

[26] TDOA Geometry, [url]: http://en.wikipedia.org/wiki/TDOA.

[27] L. Girod and D. Estrin. "Robust Range Estimation Using Acoustic and Multimodal Sensing". Proceedings of the IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS 2001), Hawaii, 2001, pp.1312-1320.

[28] M. P. Wylie and J. Holtzman. "The Non-line of Sight Problem in Mobile Location Estimation". Proceedings of the 5th International Conference on Universal Personal Communications, Cambridge, March 1996, pp. 827-831.

[29] C. Savarese, J. M. Rabaey, and J. Beutel. "Location in Distributed Ad-hoc Wireless Sensor Networks". The 2001th IEEE International Conference on Acoustics, Speech, and Signal Processing, Salt Lake City, 2001, pp.2037-2040.

[30] S. Capkun, Maher Hamdi, and J. P. Hubaux. "GPS-free Positioning in Mobile Ad-hoc Networks". Cluster Computing, v. 5, n. 2, 2002, pp.157~167.

[31] M. Hel′en, J. Latvala, H. Ikonen, and J. Niittylahti. "Using Calibration in RSSI-Based Location Tracking System". Proceedings of the 5th World Multi-conference on Circuits, Systems, Communications & Computers (CSCC2001), 2001, pp. 1-5.

[32] J. Hightower and G. Borriello. "A Survey and Taxonomy of Location Sensing Systems for Ubiquitous Computing". IEEE Computer, v. 34, n. 8, 2001, pp. 57-66.

[33] P. Bahl and V.N. Padmanabhan. "RADAR: An In-building RF-Based User Location and Tracking System". INFOCOM 2000, Nineteenth Annual Joint Conference of the IEEE Computer and Communications Societies, v. 2, Mar., 2000, pp. 775-784.

[34] N. Bulusu, J. Heidemann, and D. Estrin, "GPS-less Low Cost Outdoor Localization for Very Small Devices". IEEE Personal Communications Magazine, July 2000, pp. 28-34.

[35] L. Doherty, L. El Ghaoui, and K. S. J. Pister. "Convex Position Estimation in Wireless Sensor Networks". Proceedings of Twentieth Annual Joint Conference of the IEEE Computer and Communications Societies (INFOCOM 2001), Anchorage, 2001, pp. 1655-1663.

[36] D. Niculescu and B. Nath. "Ad-hoc Positioning System". Global Telecommunications Conference, San Antonio, TX: IEEE, 2001, pp. 2926-2931.

[37] J.Hightower and G.Borriello, "Location Systems for Ubiquitous Computing," Computer, v. 34, n. 8, 2001, pp. 57-66.

[38] F.L. Lewis. "Wireless Sensor Networks in Smart Environments: Technologies, Protocols, Applications". Ed. D.J. Cook and S.K. Das, Wiley, New York, 2004.

[39] V. Giordano, F.L. Lewis, P. Ballal, and B. Turchiano. "Supervisory Control for Task Assignment and Resource Dispatching in Mobile Wireless Sensor Networks". Cutting Edge Robotics, ed. V. Kordic, 2005, pp. 133-152.

[40] V. Giordano, F.L. Lewis, J. Mireles, and B. Turchiano, "Coordination Control Policy for Mobile Sensor Networks with Shared Heterogeneous Resources," Proc. Int. Conf. Control & Automation, Budapest, June, 2005, pp. 191-196.

[41] C. Hartung, J. Balasalle, and R. Han. Node Compromise in Sensor Networks: The Need for Secure Systems. Technical Report CU-CS-990-05, Dept of Comp Sci, Univ of Colorado at Boulder, January 2005.

[42] A. S. K. Pathan, H. W. Lee, and C. S. Hong. "Security in Wireless Sensor Networks: Issues and Challenges, Proceedings". The 8th IEEE ICACT 2006, Volume II, February 20-22, Phoenix Park, Korea, 2006, pp. 1043-1048.

[43] L. M. Pestana, L. d. Brito, and L.M.R. Peralta. "A Collaborative Model for Representing Wireless Sensor Networks' Entities and Properties". Proc. of the 3nd ACM Workshop on Performance Monitoring and Measurement of Heterogeneous Wireless and Wired Networks, Vancouver, British Columbia, Canada, 2008, pp.104-111.

[44] G.S. Tewolde and J. Kwon. "Efficient WiFi-Based Indoor Localization Using Particle Swarm Optimization". ICSI'11 Proceedings of the Second International Conference on Advances in Swarm Intelligence, v. 1, Springer-Verlag Berlin, Heidelberg 2011, pp. 203-211.

[45] Telosb Mote Platform [url]: http://www.willow.co.uk/html/telosb_mote_platform.html.

[46] ZigBee [url]: http://en.wikipedia.org/wiki/ZigBee.

[47] WirelessHART [url]: http://en.wikipedia.org/wiki/WirelessHART.

[48] MiWi [url]: http://en.wikipedia.org/wiki/MiWi.

[49] G. Chen, J. Kua, S. Shum, N. Naikal, M. Carlberg, and A. Zakhor. "Indoor Localization Algorithms for a Human-Operated Backpack System". the 2010 International Conference on Indoor Positioning and Indoor Navigation, Zurich, Switzerland, Sep., 2010.

[50] M. Cusumano. "Cloud Computing and SaaS as New Computing Platforms". Communications of ACM, v. 53, Issue 4, doi: 10.1145/1721654.1721667, ACM New York, NY, USA, Apr., 2010, pp. 27-29.

[51] Cloud Computing. [url] http://en.wikipedia.org/wiki/Cloud_computing.

[52] Health vault. [url]: http://www.healthvault.com/personal/index.aspx, and Microsoft Launches 'HealthVault' Records-Storage Site. PCMAG.com.

[53] Defining "Cloud Services" and "Cloud Computing". Blogs.idc.com. 2008-09-23. [url]: http://blogs.idc.com/ie/?p=190. Retrieved 2010-08-22.

[54] J. Chin, V. Callaghan, and G. Clarke. "Soft-appliances: a Vision for User Created Networked Appliances in Digital Homes". J. Ambient Intell. Smart Environ. doi:10.3233/AIS-2009-0010, January 2009, pp. 69–75.

[55] V. Goncalves, and P. Ballon. "Adding Value to the Network: Mobile Operators' Experiments with Software-as-a-Service and Platform-as-a-Service models". Telematics and Informatics, v. 28, Issue 1, Feb. 2011, pp. 12-21.

[56] M. Hachman. HealthVault' Records Storage Site. Retrieved February 2008, [url]: http://www.pcmag.com/article2/0,1895,2191920,00.asp.

[57] F. J. Krautheim. "Private Virtual Infrastructure for Cloud Computing". Proceedings of the 2009 Conference on Hot Topics in Cloud Computing, paper 5, USENIX, Association Berkeley, CA, USA, 2009.

[58] M. Boniface, B. Nasser, J. Papay, S. C. Phillips, and A. Servin. "Platform-as-a-Service Architecture for Real-Time Quality of Service Management in Clouds". ICIW '10 Proceedings of the 2010 Fifth International Conference on Internet and Web Applications and Services, IEEE Computer Society Washington, DC, USA, 2010, pp. 155-160.

[59] H. Alemdar, and C. Ersoy. "Wireless Sensor Networks for Healthcare: A Survey". Computer Networks: The International Journal of Computer and Telecommunications Networking, v. 54, Issue 15, Elsevier North-Holland, Inc. New York, NY, USA, Oct., 2010, pp. 2688-2710.

[60] B. Sinopoli, L. Schenato, M. Franceschetti, K. Poola, M. I. Jordan, and S. S. Sastry. "Kalman Filtering with Intermittent Observations". IEEE Trans. on Automatic Control, v. 49, n. 9, Sep., 2004, pp. 1453–1464.

[61] V. Vij and R. Mehra. "FPGA Based Kalman Filter for Wireless Sensor Networks". Int. J. Computer Technology and Applications, ISSN: 2229-6093, v. 2, n. 1, Apr., 2011, pp.155-159.

[62] G. Welch and G. Bishop, An Introduction to the Kalman Filter, July 24, 2006, [url]: http://www.cs.unc.edu/~welch/media/pdf/kalman_intro.pdf.

[63] P. Zarchan and H. Musoff. "Fundamentals of Kalman Filtering: A Practical Approach". Progress in Astronautics and Aeronautics Engineering Pro-collection

Fundamentals of Kalman Filtering: A Practical Approach, AIAA, v. 208, ISBN: 1563476940, 9781563476945, 2005.

[64] P. F. Akyildiz , W. Su , Y. Sankarasubramaniam , and E. Cayirci. “Wireless Sensor Networks: A Survey, Computer Networks”. The International Journal of Computer and Telecommunications Networking, v. 38 n. 4, March 2002, pp.393-422.

[65] A. Savvides, C. C. Han, and M. B. Strivastava. “Dynamic Fine-Grained Localization in Ad-Hoc Networks of Sensors”. Proceedings of the 7th Annual International Conference on Mobile Computing and Networking, New York: ACM Press, 2001, pp. 166-179.