A review of RFID Localization: Applications and Techniques

T. Sanpechuda and L. Kovavisaruch, *IEEE Menber*
National Electronics and Computer Technology Center 112 Phahoyothin Road
Pathumthani, Thailand 12120

***Abstract*- Indoor localization has been actively researched recently due to security and safety as well as service matters. Previous research and development for indoor localization includes infrared, wireless LAN and ultrasonic. However, these technologies suffer either from the limited accuracy or lacking of the infrastructure. Radio Frequency Identification (RFID) is very attractive because of reasonable system price, and reader reliability. The RFID localization can be categorized into tag and reader localizations. In this paper, major localization techniques for both tag and reader localizations are reviewed to provide the readers state of the art of the indoor localization algorithms. The advantage and disadvantage of each technique for particular applications will be also discussed.**

I. INTRODUCTION

Localization has been an actively researched recently due to the security and safety issues as well as service matters. For outdoor localization, GPS technology is often used to locate people, equipment and other tangible objects. However, this technology might not be suitable for indoor localization since GPS requires a direct line-of-sight communication to the satellites.

Application like people finding, intruder location, patient location or navigation along the building are commonly found in indoor localization. It is possible to utilize other wireless technologies for indoor location sensing. Existing wireless indoor localization techniques are infrared, *IEEE 802.11* wireless LAN and ultrasonic [1]. However, these technologies have some drawbacks. Infrared localization method requires direct line-of-sight and is a short-range signal transmission which is not suitable for indoor location sensing. Wireless LAN technique determines the location of object by using signal strength and signal-to-noise ratio of the signal transmitted from wireless devices. In order to obtain the object location, the target objects must include wireless LAN systems and, hence, it might not be a good solution for small and power constrained devices. The localization method using ultrasonic sensor networks usually requires either a transmitter or receiver in the target objects. Normally, this technology utilizes Time of Flight (TOF) method to obtain the location information. However, it requires a great deal of infrastructure to accurately determine the location.

Radio Frequency Identification (RFID) has become popular and typical application, spanning from asset tracking, service industries, logistics, and manufacturing, to supply chains. This large number of applications drives the price of RFID system down, creating a reliable device for automatic identification. RFID has some desirable features, such as contactless communications, high data rate and security, non line-of-sight readability, compactness and low cost [2]. With these capabilities, RFID system is a good candidate for the indoor localization issues. However, there are some difficulties in using RFID for localization. For example, it requires a large number of infrastructures to accurately determine the location and most RFID devices lack Received Signal Strength Indication (RSSI) functions, which can help improve the accuracy. Moreover, since RFID is available from Low Frequency to Microwave, it is necessary to choose a proper operating frequency to fit the application. Various choices of tags, such as active, passive and semi-active tags, can affect the localization accuracy as well.

This paper will review existing RFID localization techniques. Many researchers develop algorithms to utilize RFID systems for localization such as scheme to locate and navigate mobile robot [2-5], SpotOn [6], and LANDMARC [7]. Localization based on RFID can be categorized into two types: reader and tag localization. The advantage and disadvantage of each technique for particular applications will be also discussed.

The paper is organized as follows. Section II describes the reader localization including application advantages and disadvantages of each technique. Section III explains the tag localization with the application, advantages and disadvantages of the different application procedure. Finally, section IV is the conclusion.

II. READER LOCALIZATION

A. Applications

In this localization method, the reader is usually attached to tracked object while tags are installed in the underlying area. These tags can be either active or passive. Normally, active and passive tags are on the ceiling and floor respectively. This localization technique provides not only absolute location of a moving object but also displacement information due the movement. Autonomous robots can benefit from this displacement information. There are many algorithms for reader localization. However, in this paper, only four algorithms are discussed.

B. Techniques

Lee and Lee [4] propose localization for a mobile robot using RFID system to reduce the accumulated errors due to robot movement mechanism. They show that the RFID

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localization system can provide the absolute position. In order to determine the reader location and orientation, tags are arranged on the floor at known locations in square pattern. The reader acquires all readable tag locations. Having these tags location, the reader can estimate its location and orientation by using weighted average method and Hough transform respectively. The accuracy and resolution of location estimation are increased when the distance between tags is small. However, to reduce the distance between tags, a large number of tags are required and, hence, the system cost is increased.

To overcome the location accuracy without increasing the number of tags, Han et al. [5] arrange tags in triangular pattern so that the distance in x-direction is reduced. They show that the maximum estimation error is reduced about 18% from the error in the square pattern. They also utilize motion continuity property to provide cheap and fast orientation estimation without the knowledge of multiple sets of estimated position. Motion continuity property allows us to predict the current orientation using an initial orientation. The accuracy can be further improved by taking the advantage of absolute position data provided by the RFID system. The compensation algorithm is proposed to reduce the accumulated error of orientation estimation.

Instead of calculating the reader position from tags using geometrical relationship, Yanano et al. [2] utilize the received signal intensity to determine the reader position by using machine learning technique. In the training phase, the reader acquires the signal intensity from every tag in various locations. However, it is not possible to obtain the signal intensity from every location and, hence, they propose a method to synthesized the intensity data from real intensity data acquired in the training phase. A Support Vector Machine (SVM) is trained by using signal intensity vector for each location. In the training phase, ineffective tags for the SVM will be removed. Thus, the optimal number of tags is obtained. When the reader enters the area, it will pass the received signal intensity vector to the SVM to determine its position. This method, however, does not provide the reader orientation information and it also requires the reader with received signal intensity information which is not a standard in the RFID market.

A Bayesian approach is also proposed to predict the position of a moving object [8]. The posterior probability of the reader location for a given time-of-flight measurement is defined by movement probability of the object. Having the posterior probability, the reader detects all tags in the reading range and used the tags' location to determine the reader location by maximizing posterior probability. Then, the reader position is calculated by averaging the inferred position from all tags. It is well known that Bayesian inference technique suffers from false-positive and false-negative samples. To remedy this problem, the algorithm rejects any signal which is not in the detection range. Hence, it is inherently insensitive to Non Line Of Sight (NLOS) since NLOS signal will not in the detecting range. The accuracy of the algorithm depends on the movement probability model. However, the true probability model is difficult to obtain. Hence, the accuracy of this technique is not as high as geometry based technique.

Table 1 summarizes advantage and disadvantage of reader localization techniques.

TABLE I

READER LOCATION SYSTEM PROPERTIES

System	Technique	Accuracy& Precision	infrastructure	Advantage	Disadvantage
Lee& Lee [4]	Weighted average & Hough Transform	0.026m	Tag interval 0.05m Speed:0.3m/s	- Both position and orientation. - Reduce the error due to the boundary tag of read range	- Require a large number of tags to improve the accuracy
Triangular pattern for tag [5]	Tagarrangement & preestimation and compensate position	0.016m	Tag interval 0.05m and the next line shift by 0.025m Speed: 0.25m/s	- Provide both position and orientation. - With the same accuracy as Lee & Lee, it requires less number of tags - Can obtain the orientation by 1 reader	- More computation at the server
Self localization using SVM [2]	Support Vector Machine	80%	0.5x0.5 m^2	- Self-localization - No tag pattern need - Propagation environment independent - Optimal number of tags.	- Need a training set for SVM. - Require the reader with signal intensity output - Lack of orientation information
Random Sampling Algorithm [8]	Bayesian inference	1.5m	Tag interval 5m in 40x40 m^2 room	- Fewer sample number - Insensitive to NLOS	- Depend on movement probabilistic model

III. TAG LOCALIZATION

A. Applications

Tag localization is suitable for many applications because the tag price is much cheaper than the reader. The applications span from locating books in the library to tracking patients in the hospital. These methods can provide the same accuracy as reader localization technique. The tag localization algorithms can be tracking both stationary and moving object, although, the speed of moving object might not as fast as in the reader localization application. There are many algorithms for tag localization. In this paper, only six algorithms are discussed.

B. Techniques

One of the earliest locations sensing system using the RFID is proposed by Hightower and et al called SpotON [6]. This algorithm uses aggregation algorithm for three dimensional location sensing based on signal strength analysis. With small cluster sizes, the reader or base station can locate tags position more accurate than using triangulate method. They design and customize tag so that it can utilize radio signal attenuation to estimate inter-tag distance. However, the location accuracy is still very low and the server requires 10 to 20 second to determine the tag location. With long processing time, it can easy miss significant change in position of the tag. Last and not least this system has been not complete yet.

Instead of deploying the customize tag, Ni and et al. [7] propose an algorithm which utilize off the shelf active RFID tags. They attempt to determine tag location by using placing readers in sub-region. When the tags enter each sub-region, the distance between tag and the reader will be computed. Then, tracking tags should be correctly associated with the reader. However, the signal fluctuation due to the environment results in uncertainty of distance computation and, hence, it is difficult to correctly associate tag with the reader. To overcome this problem, they propose LocAlizatioD iDentification based on dynaMic Active Rfid Calibration (LANDMARC) technique. This technique places reference tags in known location. The reference tags serve as landmarks to the system. This system can compensate the environmental dynamic since the reference tags are in the same environment as tracking tags. The signal intensity of the reference tags is used to calibrate the uncertainty of the distance for tracking tags. The distance calibration is performed by weighing summation of the *k*-nearest reference tags location. The highest weight is assigned to the reference tag with smallest signal intensity. By utilizing the reference tags, LANDMARC can provide more accuracy with few Readers. Usually, LANDMARC deploys active tags as reference tags since they can provide information about the signal strength to detect the range of tracking tag. This method benefits in reducing a large number of expensive readers by using extra cheap tags instead. The configuration of LANDMARC is shown in Figure1. Since LANDMARC compute all the reference tags as the candidate for the neighbor tags, this process causes unnecessary computation. Because the target tag's location is obtained by the neighboring reference tags, the accuracy of locating results relies on the placement of reference tags, especially the density of the deployed reference tags. The lower deployment density of reference tags, the higher error range will be result in. However, with more tags, the interference among tags will be more serious problem since the interference might alter the accuracy of signal strength between tags.

To obtain the same degree of location accuracy as LANDMARC with less computation complexity, Jin et al. [9] proposed an improvement of LANDMARC by reducing the number of candidates for neighboring tags. When the neighboring tags are selected, this method get the target position by further adding the computed coordinate result with the average error range of all the neighboring tags which provide a higher accuracy than LANDMARC.

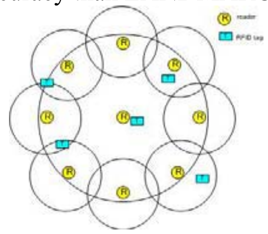

Figure 1 Placement of 9 readers with two different range and the sub-regions of LANDMARC

While previous algorithms rely on active tag, Alippi and et al. [10] propose an algorithm for localize passive tags within the environment where known positions of reader antenna are deployed. This algorithm based on the polar localization since off-the-shelf UHF readers and tags provide only information about the tag presence within an angular sector. Each antenna spans the environment through rotation and acquires the IDs of the tag in the reading range and also explored the angular section with difference transmitting powers. This algorithm utilized both the different detection power and a Bayesian approach to combine information from different reader. However, the localization accuracy depend on the lay out and the number of the reader.

While the previous algorithm utilized one set of frequency, Tsai et al.[12] deployed algorithm based two set of frequency to expand the coverage of the system for tracking psychiatric patient. The field generators act as a repeater for reader which use frequency range at 433 MHz for calling the tags and then tags communicate with reader on 916 MHz. However, using field generator usually causes the degradation of tracking reliability. Tsai et al. proposed a graphic coloring theorem for scheduling the field generator to reduce the interference. With the proposed algorithm the average of response of the system increase almost 50% which is consider to improve the efficiency of the system.

Another popular application for localization using RFID is searching book in library. Choi et al.[13] proposed RFID-based Library Information Management (R-LIM) system. Normally library counter will be able to tell the user whether the books they want are in the library or not. However, the system fails to tell the user where exactly the book is. This R-LIM will manage to keep ID of book and shelf together in database for locating the book. The reader scans multiple shelves by moving alongside each row of shelves as shown in Figure 2. Since the book ID at the boundary might face the problem of choosing shelf ID. This algorithm solves this problem by choosing the shelf id with frequent read than the other. By recording the read count of each shelf tag, relative distance between tag and reader can be determine and then it can determine the book tag will belong to which shelf tag. However, it is necessary to reset the read counts periodically to distinguish the old read and the recent read. The accuracy of system depends on most updated database. However, updating database by scanning all shelves takes a long time. Therefore it is possible to have shuffling of the books between scanning to update database.

The advantage and disadvantage of each technology are shown Table 2.

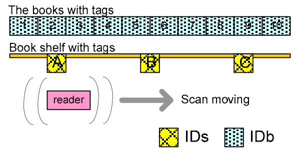

Figure 2 Reader scans book-tag and shelf-tag association establishment in R-LIM

TABLE II
TAG LOCATION SYSTEM PROPERTIES

System	**Tech.**	**Accuracy& Precision**	**infrastructure**	**Advantage**	**Disadvantage**
SpotON [6]	Ad hoc lateration	Depend on cluster size	Cluster at least 3 tags	-3-D localization, -No fixed infrastructure -low cost	-Attenuation less accurate than time of Flight, -Need special tag
LANDMARC [7]	k nearest neighboring + weighting	50%, 1.09-18m	4 readers /room, extra reference tags	-Use off the self active tag -Accuracy with less Reader and low cost	-Dense configuration of reference tags -Require the reader with signal intensity output
Jin et al. [9]	k nearest neighboring	N/A	4 readers /room, reference tags	-uses off the self active tag -Fewer computation -Accuracy and low cost	-Require the reader with signal intensity output
Alippi et al. [10]	Bayesian	0.6m	5x4 m^2 4 readers	-Passive tag, low cost -insensitive to NLOS signal	-Depend on lay out and the number of reader
Tsai et al. [12]	Field generator graphic coloring theorem	N/A	Whole floor	-Larger coverage	-Need field generator
R-LIM [13]	Data filtering	N/A	Whole book shelf	-Suitable for very large coverage area	-Reset reading counting -Require item location data base to be updated regularly

IV. CONCLUSION

This paper reviews existing RFID localization techniques to give the broad idea of the current research on localization based on this technology. While RFID technology is available from Low Frequency to Microwave, it is crucial to choose a proper operating frequency to fit the application. Various choices of tags, such as active, passive and semi-active tags, can affect the localization accuracy as well. Many researchers develop algorithms to utilize RFID system for localization such as the SpotOn [6], LANDMARC [7], and location and orientation of mobile robot [2-5]. This paper categorized localization based on two types of RFID: reader and tag localization. The advantages and disadvantages of each technique for particular applications have also been discussed.

Future trend application for the localization will require more reliability, availability and precision, therefore hybrid technology system will be the optimum solution. Since no single positioning technology provides all requirements, some researchers are already working on the combination system like Wireless LAN and RFID [11].

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