LIVERPOOL JOHN MOORES UNIVERSITY

LJMU Research Online

Yang, P

PRLS-INVES: A General Experimental Investigation Strategy for High Accuracy and Precision in Passive RFID Location Systems

http://researchonline.ljmu.ac.uk/id/eprint/3101/

Article

Citation (please note it is advisable to refer to the publisher's version if you intend to cite from this work)

Yang, P (2015) PRLS-INVES: A General Experimental Investigation Strategy for High Accuracy and Precision in Passive RFID Location Systems. IEEE Internet of Things Journal, 2 (2). ISSN 2327-4662

LJMU has developed **LJMU Research Online** for users to access the research output of the University more effectively. Copyright © and Moral Rights for the papers on this site are retained by the individual authors and/or other copyright owners. Users may download and/or print one copy of any article(s) in LJMU Research Online to facilitate their private study or for non-commercial research. You may not engage in further distribution of the material or use it for any profit-making activities or any commercial gain.

The version presented here may differ from the published version or from the version of the record. Please see the repository URL above for details on accessing the published version and note that access may require a subscription.

For more information please contact researchonline@ljmu.ac.uk

http://researchonline.ljmu.ac.uk/

PRLS-INVES: A General Experimental Investigation Strategy for High Accuracy and Precision in Passive RFID Location Systems

Po Yang

Abstract—**Due to cost-effectiveness and easy-deployment, RFID location systems with passive floor tags are commonly utilized into many industrial fields, particularly in the emerging environment of the internet of things (IoT). High accuracy and precision are key demands for these location systems. Numerous studies have attempted to improve localisation accuracy and precision by using either dedicated RFID infrastructures or advanced localisation algorithms. But these studies on improving RFID location systems mostly consider utilization of novel RFID localisation solutions rather than optimization of their utilization. Practical use of these solutions in industrial applications can lead to increased cost and deployment difficulty of RFID system. This paper attempts to investigate how accuracy and precision in passive RFID location systems are impacted by RFID infrastructures and localisation algorithms. A general experimental based investigation strategy, RFID-Loc, is designed for analyzing and evaluating the factors that impact the performance of a passive RFID location system. By experimenting a case study on passive HF RFID location systems with this strategy, it is discovered that (1) RFID infrastructure is the primary factor determining the localisation capability of a RFID location system. (2) Localisation algorithm is capable of improving localisation accuracy and precision, but limited by the primary factor. A discussion how to efficiently improve localisation accuracy and precision in passive HF RFID location systems is given.**

Index Terms— **RFID, accuracy, precision, object localisation**

I. Introduction

Radio frequency Identification (RFID) technology has been widely adopted in various industrial tracking and location applications [1-6]. The rapid proliferation of these RFID location systems in the past decade has given rise to an important concept of the Internet of Things (IoT). For most RFID location applications, accuracy and precision are two key performance indicators to measure the localisation capacity of RFID location systems. In literature, distributing dense passive RFID tags [7-13] on the floor as landmarks has been recognized to be an effective and efficient solution. By comparison with other RFID location systems using signal analysis methods [14-16] or active RFID tags [17], passive RFID location systems are more welcomed by industry due to their low cost, high accuracy and good scalability.

Copyright (c) 2014 IEEE. Personal use of this material is permitted. However, permission to use this material for any other purposes must be obtained from the IEEE by sending a request to pubs-permissions@ieee.org.
Po Yang is with University of Bedfordshire, Park Square, Luton, UK, LU1 3JU.

Typical passive RFID location systems are categorized by types of radio frequency, including low frequency (LF), high frequency (HF), ultra high frequency (UHF) and microwave. LF and microwave are not popularly applied into RFID location systems for enhancing accuracy because of low data read rate and high sensitivity to environment interference. UHF RFID location systems [9] [14] [18-19] are widely applied for single item tracking in 3D environment due to long sensing range and high transmission rate. But its accuracy is limited to meter level by the interference in proximity to liquids or metals. HF RFID location systems rarely suffer from obstacles between tag and readers, and perform better near metals and liquids than UHF. These advantages provide opportunities for HF RFID location systems [11-13] [28-29] by employing dense tags distributions to achieve accuracy up to 3 centimeters and precision up to 2 centimeters. This paper will consider priorly investigating the problem on how to reach high accuracy and precision in HF and UHF RFID location systems.

Numerous studies in passive RFID location systems [20-23] have attempted to improve accuracy and precision by using either dedicated RFID infrastructures [20-21] or advanced localisation algorithms [22-23]. But these studies on improving RFID location systems mostly consider utilization of novel RFID localisation solutions rather than optimization of their utilization. Practically, due to lack of specialist RFID technique knowledge, most users merely consider the basic specification of RFID devices from market and then deploy them in the simplest way to localize objects. In these cases, many passive RFID location systems cannot be fully utilized and explored for optimal performance, particularly on accuracy and precision. Practical use of these solutions in industrial applications leads to increased cost and deployment difficulty of RFID system.

This paper aims to investigate how accuracy and precision in passive RFID location systems are impacted by some factors like, RFID infrastructures, localisation algorithms, etc. A general experimental based investigation strategy, RFID-Loc, is designed for analyzing and evaluating the factors that impact the performance of passive RFID location systems. RFID-Loc provides a coherent and consistent solution with three modules and experimental based investigation strategies. Following this strategy, a number of experiments on the case study of typical passive HF RFID devices are carried out. The findings discover that: (1) RFID infrastructure is the primary factor determining the localisation capability of a RFID location system. (2) Localisation algorithm is capable of improving accuracy and precision in a RFID location system, but limited by the primary factor. (3) Environment factors in a RFID location system may influence its localisation stability, but can be partially managed by some localisation algorithms. The major contributions of this paper are as follows:

1. A general experimental based investigation strategy is designed for analyzing and evaluating the factors impacting accuracy and precision in passive RFID location systems.
2. A thorough experimental evaluation following the proposed strategy has been carried out, the findings of which explore how RFID infrastructure and localisation algorithm influence the performance of passive HF RFID location systems.
3. A discussion and guidance on how to efficiently improve localisation accuracy and precision in a passive HF RFID location system is given.

The rest of the paper is organized as follows. Section 2 gives a description to the proposed experimental based investigation strategy. Section 3 represents the experimental observations and findings following this strategy. Section 4 discusses and analyses how to improve localization performance of passive RFID location systems. Section 5 provides a summary of the conclusions and future work.

II. RFID-Loc Strategy

A. *Preliminary definition*

The fundamental of passive RFID location systems is that multiple passive RFID tags are distributed on the floor with certain pattern for defining a preliminary position; an RFID reader is usually attached to the moving object; object position is captured by processing the observed RFID data with some localization algorithms. The concept of localisation accuracy and precision in this paper is referred the same definitions from our papers [11] [26]. Here, accuracy refers to a capability of passive RFID location systems of measuring the minimum moving distance of an object. Accuracy directly depends on the minimum tag distance. Precision is named as accuracy error, which reflects how consistently a passive RFID location system works. For instance, shown in equation (1), the capability of a passive RFID location system can be measured as up to 10 (+ /- 3.45) centimeters (i.e., accuracy is up to 10 centimeters and precision is within 3.45 centimeters).

$$\textbf{Measurement} = \text{Value} \times \textbf{Units} + \textbf{Error} \qquad (1)$$

Where: Units refers to accuracy, **Error** refers to precision

B. *Design goal*

The idea of RFID-Loc strategy is to use a series of experimental investigation methods for analyzing and evaluating the factors impacting accuracy and precision in a passive RFID location system. Though these experimental studies, RFID-Loc strategy enables delivering a practically efficient RFID location solution with higher accuracy and precision than traditional ones for indoor use. Two main objectives are considered:

Analyticity and Guidance: this strategy provides a series of investigation procedures and guidance for users to understand the possibility of improving their RFID location systems and how to achieve it.

Feasibility and Generic: this strategy cannot be limited on certain type of RFID devices and infrastructures, or particular localisation algorithms. It is supposed to be utilized wholly by dissimilar requirements of RFID location applications.

C. *Description of work flow*

RFID-Loc strategy is built upon a whole work flow of passive RFID location system in Fig.1. The work flow consists of three modules: RFID-Loc infrastructure, RFID-Loc data filter and RFID-Loc localisation algorithm. As an object moving, a sequence of raw RFID tag IDs is observed by a RFID-Loc infrastructure module; and then RFID-Loc data filter module matches these raw IDs with corresponding position information and selects reliable features from them; RFID-Loc localisation algorithm module deals with these features for generating a sequence of moving object position.

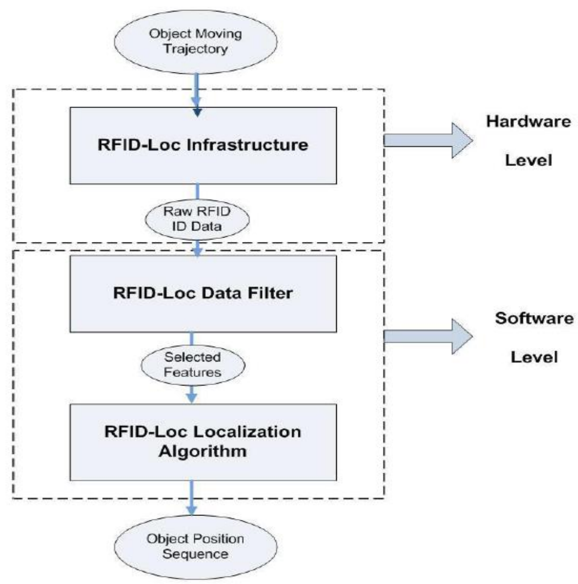

Fig. 1 Work flow diagram of RFID-Loc Strategy

RFID-Loc Infrastructure: It contains the selection and the configuration of RFID hardware devices. A benchmark named as *system reading efficiency (SRE)* is defined and used to reflect the successful detection ability of a passive RFID location system. SRE is defined as the ratio of the number of successful RFID tag readings to the total number of RFID tag readings attempted, shown in equation (2). SRE is eventually relevant to a concept of false reading in RFID location systems, including false-positive reading errors (unexpected) in UHF systems and false-negative reading errors (missing) in HF systems. An issue here is that we also treat the false reading error in UHF systems as negative. It is because theoretically UHF RFID reader has a long sensing range, so that no tags within its sensing range are detected as "Unexpected".

$$\textbf{\textit{SRE}} = \textit{Practical readings of tags / Ideal readings of tags} \qquad (2)$$

Where: 0 < *SRE* < 1

RFID-Loc Data Filter: It aims to select useful and reliable features from the raw data streams generated by RFID readers. Unreliability of these data streams is among the primary factors which limit the improvement of accuracy and precision in RFID location systems. Data filter is, therefore, an essential task in the RFID middleware systems in order to reduce reading errors, and to allow these data streams to be used to make a correct interpretation and analysis of the physical world they are representing. Current passive RFID location systems [7-13] prefer directly processing RFID raw data stream to generate a target position without data filter. They believe completeness and large-volume of data contain more useful and reliable information. But it may contain more false reading errors for reducing localisation accuracy and precision.

RFID-Loc Localisation Algorithm: it uses certain type of localisation algorithm to deal with selected reliable features by RFID-Loc Data Filter module, for generating moving object position over time. In literature, typical localisation algorithms used in RFID location systems are mostly deterministic and have a weak ability to resist some unexpected false readings errors. The possibility of other possible localisation algorithms, like probabilistic localisation algorithms, is examined in this module.

D. *Localisation Accuracy and Precision in RFID-Loc*

In order to analyze the issues affecting accuracy and precision by the proposed RFID-Loc strategy, Fig.2 illustrates a diagram to demonstrate potential issues affecting localisation accuracy and precision in three defined modules of a RFID-Loc strategy. The evaluation of localisation accuracy and precision in a RFID-Loc strategy is though a comparison between a practical object moving trajectory and the estimated position sequence of object moving. Their difference reflects how accurate and precise a passive RFID location system can be.

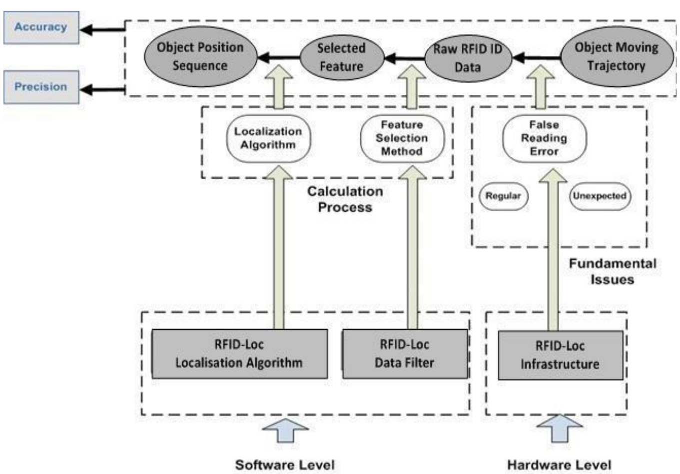

Fig. 2 Issues affecting Accuracy and Precision in RFID-Loc

Fig.2 shows that all three modules of a RFID-Loc strategy have some impacts on localisation accuracy and precision. Some benchmarks are defined in each module to access their impacts on accuracy and precision of a passive RFID location system. In a RFID-Loc Infrastructure module, *Tag Distance* and *SRE* can be used as benchmarks, as discussed in last section. Table.I shows the use of benchmarks to access impacts of each module in a RFID-Loc strategy on localisation accuracy and precision.

Table. I Benchmarks on accessing localisation accuracy and precision in RFID-Loc strategy

	Infrastructure	Data Filter	Algorithm
Accuracy	Tag Distance	position sequences	position sequence
Precision	SRE	position sequence	position sequence

E. *Investigation procedure*

RFID-Loc Infrastructure: The key point of this module is to study how to achieve a high *SRE* (leading to a high precision in Table.I), with some methods of selecting and configuring RFID hardware devices. The explicit investigating tasks are shown as below:

1. To analyze and identify the considerable issues in the RFID-Loc infrastructure module.
2. To determine the controllable items and uncontrollable items in these issues.
3. To design an experimental approach to explore the relationship between those uncontrollable items and *SRE*.
4. To evaluate the characteristics of RFID devices and Tag arrangement in terms of experimental approach.
5. To analyze and discuss the experimental findings and results.
6. To propose a strategy to design the RFID infrastructure.

RFID-Loc Data Filter: The practically captured RFID raw data stream contains incorrect and incomplete information. One objective of this model is to use a trail-and-error experiment approach for building a false reading error estimation function. Based on false reading error estimation function, the different feature subsets can be evaluated and compared. In terms of the evaluation results, the justified feature selection method is used to extract reliable features in an RFID-Loc data filter module. The explicit investigating tasks are shown as below:

1. To analyze and identify the considerable issues in the RFID-Loc Data Filter module.
2. To design an experimental approach to explore the false reading error distribution.
3. To capture the experimental dataset.
4. To evaluate feature selection methods on the dataset.
5. To analyze and discuss the experimental findings and results.
6. To propose a feature selection method.

RFID-Loc Localisation module: the goal of this module is to investigate feasible localisation algorithms for achieving high accuracy and precision of a passive RFID location system. In literature, typical localisation algorithms used in RFID location systems are mostly deterministic due to simplicity. This paper studies the utilization of probabilistic localisation algorithms on processing the reliable features. The explicit investigating tasks are shown as below:

1. To analyze and identify the considerable issues in the RFID-Loc localisation algorithm module.
2. To analyze and compare both deterministic localisation algorithms and probabilistic localisation algorithm.
3. To simulate those algorithms and discuss the findings.
4. To propose a novel localisation algorithm for RFID-Loc use.

III. EXPERIMENTAL INVESTIGATION

In theory, the proposed RFID-Loc strategy can be used for evaluating and analyzing on accuracy improvement of any arbitrary given RFID location systems. Literatures show that current passive HF RFID location systems [11-13] [28-29] have the highest localisation accuracy up to 3centimeters and precision up to 2 centimeters. Thus, this paper uses passive HF RFID location systems as a case study to verify the RFID-Loc Strategy. This section presents the experimental findings with the proposed RFID-Loc strategy for analyzing localisation accuracy and precision in a passive HF RFID location system.

RFID system used for the experiment is one RightTag RFID Fixed Panel mid-range reader with specifications as follow: operating frequency 13.56 MHz, anti-collision, antenna size of 66×30 cm^2, and multiple passive button (3×3 cm^2) and card tags (5×8 cm^2) with high frequency. The antenna used in RFID reader is a directional antenna. The antenna bandwidth is 1MHz @ -3dB and the antenna impedance is 50Ohm @ 13.56 MHz. The experimental platform is established in indoor environment. Passive RFID tags are regularly placed at predefined locations following a pattern to store known absolute-position. RFID tag arrangement is used as a full distribution with grid pattern. The tag distance is initially given as 5-10 centimetres regarding the shape and size of passive tags, for providing the highest density in this experimental platform. For controlling the movement of mobile object, four small wheels are separately installed on the corners of RFID reader with a height 3-5 cm to floor. The moving trajectory is assumed to be a simple straight line. The observation of *SRE* follows equation (2) in section II.

A. *RFID-Loc Infrastructure*

Characteristic examination of RFID devices is the primary step of the RFID-Loc infrastructure module. The performance of a RFID location system is relevant to many influencing issues, i.e. the type, position, and direction of tags; the moving speed of moving object; the type, position and angle of antenna; the power, type, gain, frequency range, and number of antenna; the work environment. Some issues are controllable factors that can be adjusted and selected in the procedure of RFID devices configuration; while some issues are uncontrollable factors that are formerly determined by RFID hardware manufactures.

Theoretically, multiple-reader RFID location system possibly provides better flexibility and applicability in large scale indoor environments. They mostly adopt time difference of arrival or signal strength analysis methods for localization; so that their accuracy and precision are limited up to centimetres level. Considering the issues of RFID reader mobility and reduced multi-readers collision, single RFID reader with anti-collision ability are primarily considered in the scope of this paper.

Thus, RFID devices configuration here particularly refers to the arrangement of passive RFID tags. The fundamental of passive RFID location systems illustrates that the density of a RFID tags distribution pattern can determine accuracy of a passive RFID location system, which directly depends on the distance between two adjacent tags. Consequently, an assumption of setting RFID tag arrangement as a well-proportioned grid pattern is established shwon in Fig.3. Other possible ways of RFID tag arrangements are discussed later.

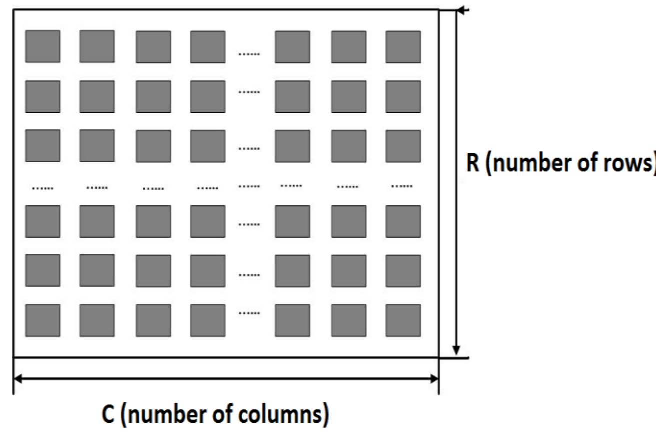

Fig. 3 Fully RFID tag distribution with grid pattern

Regarding as operating frequency, we evaluate the performance of UHF (865 MHz) based handheld Alien technology RFID reader (ALH-9011) under grid based G-Tag (93×19 mm^2) pattern. The results show that UHF reader can sense multiple tags within 2-meters, but merely deliver accuracy up to 50 centimetres. The similar evaluation on HF testing platform shows that localisation accuracy reaches at least 20 centimetres. HF range has a promising localization accuracy and precision for indoor applications, since it has a reasonable accuracy and read speed, feasible reading distance, and data transfer speed comparing to others frequency range.

Two variables are defined in RFID-Loc infrastructure. The first one is RFID tag distance of a well-proportioned grid pattern; the other one is the total number of RFID tags placing in a well-proportioned grid pattern. Both of those two variables are evaluated by a series of experimental methods.

In Section II, *SRE* is used as a benchmark to access the sensing capability of an RFID-Loc infrastructure. The capability of an RFID-Loc infrastructure delivering stably high *SRE* over time is crucial to stably accurate and precise localization. Therefore, an experimental approach is designed in this section to explore the influence of the controllable factors on *SRE* in an RFID-Loc infrastructure. The proposed experimental approach is designed into two parts in Table. II.

Part 1 in Tab. II focuses on evaluating characteristics of chosen RFID devices. Regarding experimental findings, a fundamental RFID hardware configuration suggestion can be concluded for the design of an RFID infrastructure. The results are shown in Table. III and Table. IV, also Figure.4. Part 2 in Tab. II focuses on a deep study of RFID tag arrangement. A qualitative study on the relationship between *Global Tag Density* and *SRE* is carried out in this part. A qualitative study on the relationship between Directional Tag Density and *SRE* is done later.

Table. II Benchmarks on measure localisation accuracy and precision in RFID-Loc strategy.

Parts	*Contents*	*Items*
Part 1 : Evaluation of RFID Device Characteristics	**Single Tag Operating Characteristics**	Tag Size and Operating Range; Tag Orientation;
	Single Reader Operating Characteristics	Reader Size and Operating Range Reader Orientation; Reader Moving Orientation;
	Multiple Tags Operating Characteristics	Tag Operating Successful Rate;
Part 2 Study on Tag Arrangement	**Global Tag Density and SRE**	Reduced Tag number Reduced Columns of Tag Pattern
	Directional Tag Density and SRE	Reduced Rows of Tag Pattern Reduced Both Rows and Columns of Tag Pattern

Table. III Single RFID tag operating performance.

	Button Tags	*Card Tags*
Tag dimensions	3 cm (R)	5.5 (w) × 8.5 (d) cm
Tag surface area	7.065 cm^2	46.75 cm^2
Operating range	1-3 cm	0 – 18 cm
Antenna dimensions	31 × 62 cm^2	31 × 62 cm^2
Antenna effective area	470 cm^2	1800 cm^2
Operating range	1cm	14cm

Table. IV Multiple RFID tags operating performance.

	Button Tags				*Card Tags*			
Number of Tags	**5**	**10**	**15**	**20**	**5**	**8**	**10**	**15**
Operating successful rate	**60%**	**50%**	**40%**	**30%**	**100%**	**100%**	**100%**	**93%**

By examining characteristics of RFID devices, it appears that card tags have a longer effective sensing distance than button tag. This may because card tag has a larger area to reflect radio frequency signal. But, due to a smaller area of button tags, the density of button tags distributing in an assumed grid pattern is higher than the density of card tags. This advantage of button tags potentially leads to a smaller tag distance and higher localization accuracy than card tags. Considering this issue, button tags are more feasible to use in RFID-Loc infrastructure module with potential higher localization accuracy.

The experimental results also show that the angle of tags has a slight influence on the detection capability of an RFID reader within an effective sensing range. This may because passive RFID tags cannot continuously send signals; and RFID reader communicates with passive RFID tags by coupling techniques. It means that if any passive RFID tags are within an effective sensing zone of an RFID reader, the distance between RFID tags and RFID readers has stronger impacts on the successful detection than the angle of RFID tags.

As for the characteristics of multiple tags operating, RF wave travels from the transmitter to the receiver, it can be affected by various factors, i.e. absorption, attenuation, dielectric effect, diffraction, free space loss, interference, reflection, refraction, scattering. Table. IV shows a performance comparison of button tags and card tags under multiple RFID tags operating mode. The results appear that as the density of tag distribution increases, both card tags and button tags cannot be detected completely in practical. It means that tag collision occurs sensitively and uncertainly, and cannot be removed completely in a passive RFID location system. Thus, false-reading error is indefensible in an RFID-Loc infrastructure.

The moving direction of RFID reader also influences on the value of *SRE* on both card tag and button tag conditions as shown in Figure.4. The antenna used in this experiment is not square so the power gains are not equal along four edges of antenna. In card tag situations, the moving direction of RFID reader along its width axis obviously has a higher *SRE* than the ones of moving direction of RFID reader along its length axis. Similarly, in button tags situations, the moving direction of RFID reader along its width axis does not apparently enhance *SRE* comparing to the one moving along its length axis. Thus, the suggestion for deploying a RFID reader is that RFID reader moves along its width axis direction, and parallel to the plane of passive RFID tag pattern.

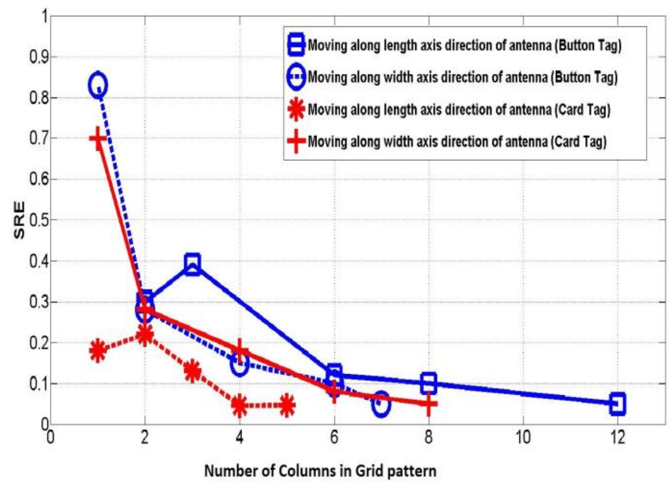

Fig. 4 Antenna Orientation and moving direction impacting on SRE

The second experiment mainly considers RFID tags density and RFID tags arrangement in a RFID-Loc infrastructure as the key influencing factors. RFID tags density is normally a value relating to the size of an effective detection area of RFID reader and the number of passive RFID tags in this area.

Global Tag Density refers to the whole number of RFID tags placing in an efficient detection area. The investigation of relationship between Global Tag Density and *SRE is* actually to study the impacts of reducing a total number of RFID tags in an efficient detection area. The procedure of reducing the total number of RFID tags in this section is to regularly make a reduction in columns and rows of a RFID tags pattern. At the first step, RFID tags are placed in a seamless non-overlap grid pattern, with 9×4 number of RFID tags. From the second step, the rows or columns in this seamless non-overlap grid pattern will reduce one by one, with the number of RFID tags as: 9×3, 6×3, 3×3, 3×2, 2×2, 2×1. The result is shown in Fig.5.

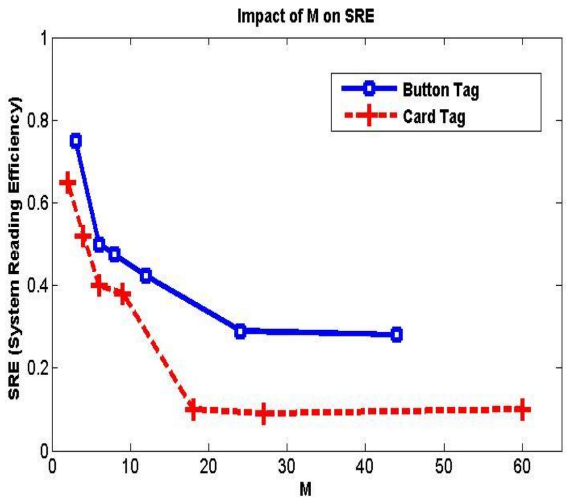

Fig. 5 Global Tag Density impacting on SRE

Directional tag density refers to the number of RFID tags placing on row or column directions in an efficient detection area. The effect of *SRE* is examined by merely reducing the number of columns in a grid pattern, or merely reducing the number of rows in a grid pattern. By using similar procedure, the result is shown in Fig.6.

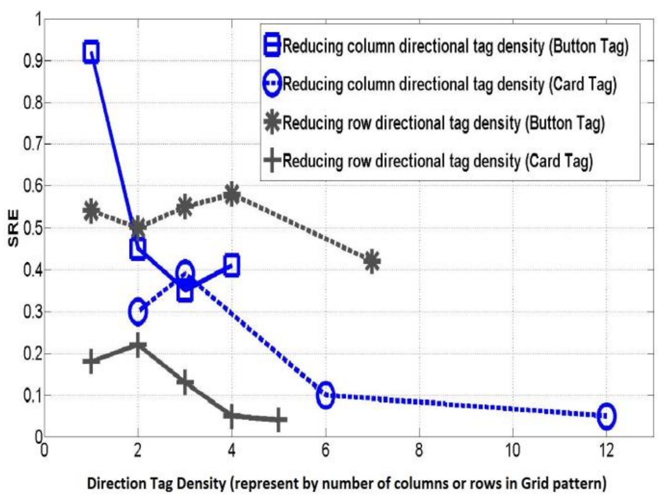

Fig. 6 Direction Tag Density impacting on SRE

The above experiments give a qualitative study on relationship between tag arrangement and *SRE*. The experimental findings are concluded as follow:

(1) High accuracy of passive RFID location systems requires a high density of tag distribution with short tag distance. But this increases the problem of RFID tags collision, further as a result that *SRE* is reduced. Oppositely, stability of passive RFID location systems can be enhanced by increasing *SRE*. But in this case, accuracy of passive RFID location systems will be decreased due to an increasing tag distance. Therefore, it is challenging to get both high accuracy and stability under the current start of art of RFID-Loc infrastructure, a possible solution is to make a balance on accuracy and stability to achieve an acceptable tag density and *SRE*.

(2) An overall trend is that *SRE* can be enhanced by reducing global tag density in an RFID reader efficient detection area. It means that as the total number of RFID tags in an RFID reader efficient detection area reducing, *SRE* will be enhanced. The relationship between *SRE* and the total number of RFID tags in an effective reading area approximately follows a decreasing function.

(3) The varying tag arrangement indeed impacts on *SRE*. The regularly reducing columns and rows directional tag density in an RFID tag pattern will generate some odd points. However, directional tag density is not a major issue influencing *SRE* under an RFID gird tag pattern. On equivalent conditions, the passive RFID button tag performs a higher *SRE* compared with the passive RFID card tag, and owns a smaller physical size. Consequently, passive RFID button tag is recommended in an RFID-Loc infrastructure.

(4) The moving direction of RFID reader has some impacts on *SRE*. In this case, the moving direction can be along the width axis of RFID reader. If using different RFID reader antennas, the moving direction of RFID reader can be determined by practical experimental results.

(5) There are some suggestions on selecting columns and rows in a passive RFID tag distribution pattern. A straight way is firstly to decide an accuracy with given tag distance on a fully tag distribution grid pattern; and then regarding its total number of tags find out corresponding SRE in Fig.5; finally remove some tags on grid pattern gradually to get an higher SRC in Fig.5. The detailed strategy has been reported in our previous paper [11].

B. *RFID-Loc Data Filter*

Last section shows that under current HF RFID experimental platform, practical value of *SRE* in an RFID-Loc infrastructure is in a range from 40% to 60%. It means that RFID data being observed at each time frame are raw and unornamented. These data are inaccurate and uncertain. Meanwhile, the observation process of RFID data is spatial and temporal, which can be dynamically variable over time. RFID data at each time step cannot be completely equivalent. Utilizing an RFID-Loc data filter module can filter some useless information from raw data, and select reliable features for localization algorithms.

Inaccuracy and uncertainty of RFID raw data are two major challenging characteristics. False-readings in RFID raw data are normally classified into three types: false negative readings, false positive readings, and repeated readings. An experimental approach is designed for exploring the impact of RFID-Loc data filter module on localization accuracy and precision. The experimental procedure contains two parts. The first part is an analysis of false-readings in RFID raw data; the second part is a performance evaluation of typical data filter methods under various types of RFID-Loc infrastructures.

The experimental platform is built in an indoor environment as similar as previous section. RFID tags are regularly placed at predefined locations following a pattern to store known absolute-position. The distance between tags is 10 centimeters; and the number of tag in the effective RFID detection area is

24. The moving trajectory of mobile object is assumed to be a simple straight line, so that the mobile object can be manually moving forward. Within a time interval, mobile object moves forward with known accuracy (10 centimeters), which equals to the tag distance. If any tags are correctly observed once, RFID reader reads their ID and transfers them to computer. The total number of sampling time steps is taken as 25.

Practically, RFID reader has to wait sufficient time period until the majority of RFID tags within an effective detection area of RFID antenna are scanned and their data are processed. Time interval is an important issue that affects the correctness of *SRE* measurement. The time intervals of the experiments are tested in 5, 10, 20, 40, 60, 90 and 120 seconds respectively. The results show that the period of 40 seconds can approximately give an *SRE* up to 50%, but after that the increase of time intervals cannot significantly enhance *SRE*, the period of 60 seconds and 120 seconds only gives SRE to 52% and 55%. An interval less than 40 seconds significantly decreases SRE. Here in this experiment, the period of every interval is initially taken as 40 seconds, which means that mobile object has to stay for 40 seconds once it moves to a new position. A noticeable issue here is that the time interval as 40 seconds is too long to trace a mobile object. Considering the research purpose, we take the highest value of SRE to verify the proposed RFID-Loc strategy. The practical feasibility will be discussed in next section. Table.V gives a qualitative result on which kind of error reading occurs mostly.

Table. V Results of false-reading from RFID-Loc infrastructure.

	X axis	*Y axis*	*Randomly*
False positive reading	1/25	1/25	0/25
False negative reading	25/25	25/25	25/25
Redundancy reading	22/25	23/25	23/25

The results show that false-negative reading occurs more than false-positive reading; and the repeating detection are easily occurring. The key error reading is false-negative reading. The redundancy reading does not impact on system localisation performance. The reason resulting a frequent redundancy reading might be that the slow moving speed of object keeps some RFID tags in a relative constant position of RFID reader detection area.

Three typical data filter methods: average of points set, centroid of polygon area, centroid of rectangle area, are used to evaluate the impact of an RFID-Loc data filter on localization accuracy and precision. In practical experimental processes, the distance of RFID reader moving between two time steps is equal to given accuracy (10 centimeters, 15 centimeters and 20 centimeters). Two moving trajectories of moving along X axis and Y axis are respectively tested. Time step of localisation sequence for each trajectory is measured by 12. The time intervals at each time step are given 40 seconds for guaranteeing sufficient number of tags detected. Precision is measured by Mean Absolute Error (MAE) of localisation accuracy, as illustrated in Table.VI.

The experimental findings can be concluded as follow:

(1) In a known RFID-Loc infrastructure with the optimal value of SRE, an efficient data filter method is useful to improve localization precision of passive RFID location systems. For instance, the rectangle area based data filter method is capable of delivering higher localization precision than points set and polygon area based data filer methods.

(2) The enhanced value of SRE in an RFID-Loc infrastructure improves localization precision of RFID location systems in general. SRE reflects a general detectable capability of a passive RFID location system. But, the increased value of SRE is also along with the sacrifice of localization accuracy, due to the reduced tag density and the increased tag distance.

(3) Regarding equation (1) for defining localization accuracy and precision in passive RFID location systems, its localization capability replies more on weight of location accuracy rather than the weight of location precision. Data filter has a capability of improving localization precision, but limited by RFID-Loc infrastructure.

Table. VI Evaluation of the impact of RFID-Loc Data Filter.

Accuracy 10 cm		**X Trajectory**		**Y Trajectory**	
		X-axis	**Y-axis**	**X-axis**	**Y-axis**
	Points set	5.43 cm	6.63 cm	0.91 cm	8.89 cm
SRE :	**Polygon**	1.07 cm	5.42 cm	4.05 cm	6.59 cm
38%	**Rectangle**	0. 83 cm	5.00 cm	2.08 cm	2.52 cm
Accuracy 15 cm		**X Trajectory**		**Y Trajectory**	
		X-axis	**Y-axis**	**X-axis**	**Y-axis**
SRE :	**Points set**	3.33 cm	4.23 cm	0.56 cm	5.64 cm
45%	**Polygon**	1.07 cm	4.22 cm	3.25 cm	3.59 cm
	Rectangle	0. 54 cm	3.50 cm	1.08 cm	3.12 cm
Accuracy 20 cm		**X Trajectory**		**Y Trajectory**	
		X-axis	**Y-axis**	**X-axis**	**Y-axis**
SRE :	**Points set**	2.83 cm	3.33 cm	1.00 cm	4.54 cm
54%	**Polygon**	1.27 cm	3.42 cm	3.05 cm	4.53 cm
	Rectangle	0. 00 cm	5.00 cm	2.50 cm	0.00 cm

C. *RFID Localization Algorithm*

Existing localisation algorithms used in passive RFID location systems can be classified into three main types: deterministic [12-13][30], probabilistic [26-27] or hybrid above two [31]. Deterministic localisation algorithms generate position of a RFID reader by using RFID data merely from current time interval. The computation of a target's position at each time interval is independent to other time frames, so there are no drift errors on the target's position in deterministic localization. But it has weak resilience ability to error motion of the target. Probabilistic localisation algorithms generate object's position by not merely using observed data at current time frame, but also employing historical data from previous time frames as a supplement. They normally include the prediction and update processes, so as to the computation of a target's position at each time frame is highly relevant to other time frames. The merit is that this algorithm is more robust and resilience to error motion than deterministic localisation due to its probabilistic basis. But probabilistic localisation algorithms may suffer with drift errors due to the dependence of present target's position on previous target's positions. A hybrid of deterministic and probabilistic method normally introduces an adaptive execution between above two processes.

In order to evaluate the impacts of localization algorithms on accuracy and precision, two typical deterministic localisation algorithm, two probabilistic localisation algorithms and one hybrid localisation algorithm are selected to execute theoretical comparisons, including Arithmetic average mean (AAM) [13], Weighted Centroid Localisation (WCL) [31a], Hyrbid [31b], EKF (Extended Kalman Filter) [27] and Fast SLAM Particle Filter [26]. In [31], it proposes a hybrid method for achieving high accuracy and efficiency in passive RFID location systems by adaptively switching between using WCL and particle filter. This paper here evaluates these methods as a comparison. The experimental setup is similar to previous section III B in a real deployment environment. Localisation accuracy for all validations, is given as 10 centimeters, 15 centimeters and 20 centimeters. Two moving trajectories of moving along X axis and Y axis are respectively tested. Time step of localisation sequence for each trajectory is measured by 12. The time intervals at each time step are given as 40 seconds for guaranteeing sufficient number of tags detected. Precision is measured by Mean Absolute Error (MAE) of localisation accuracy, as illustrated in Table.VII.

The experimental findings are concluded below:

(1) In a known RFID-Loc infrastructure with the optimal value of SRE, the impact of localisation algorithm on accuracy and precision is similar to data filter method. They are capable of improving the localisation precision, but are limited by the SRE of RFID-Loc infrastructure.

(2) Deterministic localisation algorithms [13] [31a] have better performance than probabilistic localisation algorithms [26-27]. As the increasing SRE, localisation precision of probabilistic methods is actually decreased. It is probably because Kalman filter and particle filter are more efficient to process non-linear tracking, but the trajectories in our experiment are linear.

(3) Localisation accuracy of a hybrid algorithm [31b] is not good as deterministic localisation algorithms [13] [31a], and more close to particle filter algorithm [26-27]. It is probably because the adaptive switching scheme of hybrid algorithm [32] has a larger emphasis on particle filter.

IV. Discussion and Suggestion

Regarding experimental investigations following the proposed RFID-Loc strategy, it is discovered that (1) RFID infrastructure is the primary factor determining the localisation capability of a RFID location system. (2) Data filter and localisation algorithm is capability of improving localisation accuracy and precision, but limited by the primary factor. (3) Environment factors may influence localization stability but not significantly.

But, there is a trade-off between getting a high value of SRE and processing in real-time mode. There are numerous works reporting the achievement of real-time RFID location systems, but their accuracy is not high up to 5 centimeters. The demand for high accuracy in passive RFID location systems normally requires a collection of sufficient data at each time intervals.

Table. VII Evaluation of the impacts of Localization Algorithms.

Accuracy 10 cm		*X Trajectory*		*Y Trajectory*	
		X-axis	*Y-axis*	*X-axis*	*Y-axis*
SRE : 38%	**Kalman [27]**	8.43 cm	7.63 cm	5.91 cm	6.89 cm
	Particle [26]	8.2 cm	8.7 cm	4.05 cm	6.59 cm
	Han [13]	4.5 cm	5.00 cm	4.70 cm	6.10 cm
	WCL [31a]	6.8 cm	6.78 cm	4.79 cm	6.98 cm
	Hybrid [31b]	7.9 cm	8.3 cm	4.32 cm	6.78 cm
Accuracy 15 cm		**X Trajectory**		**Y Trajectory**	
		X-axis	**Y-axis**	**X-axis**	**Y-axis**
SRE : 45%	**Kalman [27]**	10.3 cm	8.23 cm	4.56 cm	6.64 cm
	Particle [26]	9.07 cm	7.22 cm	7.25 cm	6.59 cm
	Han [13]	0. 54 cm	3.50 cm	1.08 cm	3.12 cm
	WCL [31a]	4.45 cm	4.38 cm	2.34 cm	5.43 cm
	Hybrid [31b]	8.1 cm	6.78 cm	6.52 cm	7.18 cm
Accuracy 20 cm		**X Trajectory**		**Y Trajectory**	
		X-axis	**Y-axis**	**X-axis**	**Y-axis**
SRE : 54%	**Kalman [27]**	12.8 cm	8.83 cm	7.04 cm	8.52 cm
	Particle [26]	10.7 cm	12.2 cm	13.05 cm	9.23 cm
	Han [13]	0. 00 cm	5.00 cm	2.50 cm	0.00 cm
	WCL [31a]	2.18 cm	6.24 cm	3.25 cm	3.98 cm
	Hybrid [31b]	8.91 cm	10.3 cm	11.57 cm	8.48 cm

While the time intervals in current experimental platform in this paper is selected as 40 seconds for SRE up to 45%, it is possible to utilize more advanced RFID devices for shortening the time intervals with high SRE. The proposed RFID-Loc strategy is still valid for these cases.

Consequently, for normal industrial users, in order to achieve high localisation accuracy and precision for passive RFID location systems, the primary suggestion is to attempt to find out RFID reader well supporting anti-collision. An outstanding anti-collision capability can potentially reach a high SRE in an RFID-Loc infrastructure. But as observing in experiments, it is impossible to get a perfect SRE in an RFID-Loc infrastructure due to the physical limitations of radio signals. It means that false-reading is an unavoidable phenomenon in all passive RFID location systems. Thus, the optimal utilization of RFID infrastructure and localisation algorithms is demandable to efficiently reduce the impacts of false-reading on localisation accuracy and precision.

In terms of equation (1), localisation accuracy is directly related to minimum tag distance in a RFID pattern. High density of tag distribution becomes a straightforward solution to improve accuracy in passive RFID location systems. However, our experimental investigation indicates that high density of tag distribution increases the tag collision problem as a result that SRE of an RFID-loc infrastructure is reduced. Oppositely, if localisation precision is potentially enhanced by increasing SRE, localisation accuracy will have some loss due to the larger tag distance. Therefore, it is very challenging to get both the high accuracy and precision under the current start of art of RFID infrastructure. The second suggestion for normal users is to identify requireable minimum accuracy and precision before designing a passive RFID location system. Also, it is advisable to carry out some initial experiments to test the SRE of RFID-Loc infrastructure in terms of different scenarios. The possible solution for optimizing RFID-Loc infrastructure is to get a balance on accuracy and precision to achieve the acceptable tag density and system reading efficiency.

Finally, it recommends that industrial users use traditional deterministic algorithms into passive RFID location systems. Regarding the experiment findings, advanced probabilistic localisation algorithms have lower localization precision than traditional deterministic algorithm. The benefit of using these advanced algorithms is probably for dealing with non-linear localisation tasks with unexpected environment noises.

In terms of above suggestions, we evaluate overall performance of a passive RFID location system for achieving high accuracy with our proposed RFID-Loc strategy, as shown in Table.VIII. The system (1) is a traditional setting of passive RFID location systems with a grid pattern based full distribution, pointers set based feature selection method and WCL method [31]. The system (2) improves the system (1) using polygon based feature selection method and particle filter localization method. The system (3) fully optimizes the system (1) with a sparse tag distribution [11], rectangle based feature selection method and Han's [13] localization method. The experimental setup is similar to previous section III. Localisation accuracy for all validations is given as 10 centimeters. Two moving trajectories of moving along X axis and Y axis are respectively tested. Precision is measured by Mean Absolute Error (MAE) of localisation accuracy.

The results demonstrate that given a known accuracy 10 centimeters, the optimized system setting (3) can deliver a better localization precision than other system settings, particularly for traditional system setting (1). This implies that traditional system setting of passive RFID location systems has huge potential space to optimize their utilization for improved accuracy. The proposed RFID-Loc strategy in this paper offers an investigation solution for exploring this possibility.

Table. VIIII Overall performance evaluation of a passive RFID location system.

Accuracy 10 cm	**X Trajectory**		**Y Trajectory**	
	X-axis	**Y-axis**	**X-axis**	**Y-axis**
System 1 : Full grid, Points set, WCL	9.85 cm	6.52 cm	11.25 cm	7.85 cm
System 2 : Full grid, Polygon, Particle	8.50 cm	8.96 cm	5.25 cm	4.80 cm
System 3 : Sparse distribution, Rectangle, Han [13]	3.35 cm	2.60 cm	3.90 cm	4.25 cm

V. CONCLUSION AND FUTURE WORK

This paper addresses the major technical issues of how to use passive RFID location systems to efficiently achieve the object localisation with high accuracy and precision. This research work proposes a formal strategy RFID-Loc for investigating the problem of optimal use of passive RFID location system to accurately and precisely localize the moving object in an indoor environment. The strategy provides a coherent and consistent solution with three modules and experimental based investigation strategies to study the factors impacting the performance of an indoor passive RFID location application. By using this strategy, it can guide the optimal use of passive RFID location system with enhanced accuracy and precision. A case study using normal passive RFID devices is carried out to verify the usefulness of this strategy. The results show that in comparison with the conventional passive RFID location system; passive RFID location system under the guidance of RFID-Loc strategy can deliver a higher localisation precision for the required accuracy. While this possibility may be not generic to every case, its existence is effective in many passive RFID location cases.

The limitation of this work is that firstly the RFID products vary from one manufacturer to another; it depends on performance of tags or readers so the experimental results might lead to different values. Secondly, the experimental trajectory in this work is only evaluated in limited moving trajectory situations. If the object does not move along straight line, the efficiency of new RFID tag distribution requires more investigations. The future work on this field will include the investigation of the above limitations.

REFERENCES

[1] T.M. Choi, "Coordination and Risk Analysis of VMI Supply Chains with RFID Technology", *IEEE Trans on Ind Informatics*, pp.497–504, vol.7, issue 3, March. 2011.

[2] J. Manessilp, C. Wang, H. Y. Wu and N. F. Tzeng, "RFID support for accurate 3D localisation", IEEE Trans on Computers, pp. 1447-1459, vol 62, issue 7. July, 2013.

[3] A. Motamedi, M. M. Soltani and A. Hammad, "Localization of RFID-equipped assets during the operation phase of facilities original Research", *Advanced Engineering Informatics*, pp.566-579, vol. 27, issue. 3, October. 2013.

[4] Y. J. Zhu, "Surviable RFID systems: Issues, Challenges, and Techniques," *IEEE Trans. Syst. Man. Cy. C,* vol. 40, no. 4, pp. 406-418, July, 2010.

[5] G.M. Gaukler, "Item-Level RFID in a Retail Supply Chain with Stock-Out-Based substitution", *IEEE Trans on Ind Informatics*, pp.362–370, vol.7, issue 2, Feb. 2011.

[6] M. L. Chuang and W.H. Shaw, "RFID: Integration stages in supply chain management," *IEEE Trans. Eng. Manage. Review*, vol 35, no 2, pp. 80-87, April. 2007.

[7] T. Unander, J. Nilsson and H.E.Nilsson, "Designing of RFID-based sensor solution for packaging surveillance applications," *IEEE Trans. Sensors.Journal.* vol. 11, no. 11, pp. 3009-3018, Nov. 2011.

[8] L. Jing and P. Yang, "A localisation algorithm for mobile robots in RFID system", *Proc. Int. Conf. Wireless Commun., Netw. Mobile Comput.,* pp.2109 -2112, 2007

[9] E. DiGiampaolo and F. Martinelli, "A passive UHF-RFID system for the localisation of an indoor autonomous vehicle", *IEEE Trans. Ind. Electron.*, Vol. 59, No. 10, pp. 3961–3970, Oct. 2012.

[10] S.D. Park and H.C. Lee, "Self-Recognition of Vehicle Position Using UHF Passive RFID Tags," *IEEE Trans. Ind. Electron.*, Vol. 60, No. 1, pp. 226–234, Jan. 2013.

[11] P. Yang, W.Y. Wu, M.Moniri and C.C.Chibelushi " Efficient Object Localisation Using Sparsely Distributed Passive RFID Tags ", *IEEE Trans. Ind.Electron.,*vol 60, no.12, pp.5914-5924, 2013.

[12] S. Park and S. Hashimoto, "Autonomous Mobile Robot Navigation Using Passive RFID in door environment", *IEEE Trans Ind. Electron*, Vol. 56, no. 7, pp. 2366–2373, 2009.

[13] S. S. Han, H. S. Lim and J. M. Lee, J. M, "A Efficient Localisation Scheme for a Different-Driving mobile robot based on RFID system", *IEEE Trans Ind. Electron*, Vol. 54, no. 6, pp. 3362–3369, 2007.

[14] Z. Zhang, Z. H. Liu, V. Saakian, X. Qin, Q. Chen and L. R. Zheng, "Item-Level Indoor Localization with passive UHF RFID based on tag

interaction analysis," *IEEE Trans. Ind. Electron*, Vol. 1, no. 4, pp. 2122-2135, April. 2014.

[15] L. Catarinucci, R. Colella, L. Mainetti, L. Patrono, S. Pieretti, I. Sergi and L. Tarricone, "Smart RFID Antenna System for indoor tracking and behavior analysis of small animals in colony cages," *IEEE Sensors. Journal*, Vol. 14, no. 4, pp. 1198-1206, December. 2013.

[16] X. Zheng, H. Liu, J. Yang, Y. Chen, R. Martin and X. Li, "A study of localisation accuracy using multiple frequencies and powers," *IEEE Trans. Para. Dist. System*, Vol. PP, no. 99, pp. 1, December. 2013.

[17] J. Maneesilp, C. Wang, H. Y. Wu and N. F. Tzeng, "RFID support for accurate 3D localization," *IEEE Trans. Computers*, Vol. 62, no. 7, pp. 1447-1459, April. 2012.

[18] E. DiGiampaolo and F. Martinelli, "Mobile robot localization using the phase of passive UHF RFID signals", *IEEE Trans. Ind. Electron.*, Vol. 61, No. 1, pp. 365–376, Jan. 2014.

[19] M. Scherhaufl, M. Pichler, E. Schimback, D.J.Muller, A. Ziroff and A. Stelzer, "Indoor localization of passive UHF RFID tags based on phase-of-arrival evaluation", *IEEE Trans. Micro. Theo. Tech.*, Vol. 61, No. 12, pp. 4724–4729, Dec. 2013.

[20] M. Y. Ahmad and A. S. Mohan, "Novel bridge-loop reader for positioning with HF RFID under sparse tag grid", *IEEE Trans on Ind Electronis,* pp.555-566, vol.61, issue 1, Jan, 2014.

[21] A. Athalye, V. Savic, M. Bolic and P. M. Djuric, "Novel semi-passive RFID system for indoor localisation", *IEEE Sensors. Journal,* pp.528-537, vol.13, issue 2, 2013.

[22] J. Pomarico-Franquiz and Y. Shmaliy, "Accurate self-localization in RFID tag information grids using FIR filtering", *IEEE Trans on Ind Informatics,* pp.1, vol.PP, issue 99, 2014.

[23] Y. T. Ma, L. J. Zhou, K. H. Liu and J. L. Wang, "Iterative Phase Reconstruction and Weighted Localization Algorithm for Indoor RFID-Based Localization in NLOS Environment ", *IEEE Sensors. Journal,* pp.597-611, vol.14, issue 2, 2014.

[24] P. Yang, W.Y. Wu, M.Moniri and C.C.Chibelushi " SLAM Algorithm for 2D Object Trajectory Tracking based on RFID Passive Tags", *Proc. 2008 IEEE Int. Conf. RFID.,* pp.165-172, 2008

[25] S.S. Saad and Z. S. Nakad " A standalone RFID indoor positioning system using passive tags", *IEEE Trans. Ind.Electron.,*vol 58, no.5, pp.1961-1970, May, 2011.

[26] T. Bailey and H. Durrant-Whyte "Simultaneous localisation and mapping (SLAM): Part II: State of the art", *IEEE Robot. Autom. Mag.*, vol. 13, no. 3, pp. 108–117, Sep. 2006.

[27] A. Bekkali, H, Sanson and M. Matsumoto, "RFID Indoor Positioning Based on Probabilistic RFID Map and Kalman Filtering", *Third IEEE Int Conf Wireless and mobile computing, networking and communications*, pp21-28.

[28] U. Tomohiro, M. Yasushi, I. Kenji, A. Tatsuo, and Y. Jun-ichi, "Pose estimation of objects using multiple id devices," *Journal of the Robotics Society of Japan*, vol. 23, no. 1, pp. 84–94, 2005.

[29] S. Masahiro, K. Takayuki, E. Daniel, I. Hiroshi, and H. Norihiro, "Communication robot for science museum with rfid tags," *Journal of the Robotics Society of Japan*, vol. 24, no. 4, pp. 489–496, 2006.

[30] N. Bulusu, J. Heidemann, and D. Estrin, "Centroid localization of uncooperative nodes in wireless networks using a relative span weighting method," *EURASIP Journal on Wireless Communications and Networking*, 10(11):1C11, 2010.

[31] L. Yang, J. N. Cao, W. P. Zhu,and S. J. Tang, "A hybrid method for achieving high accuracy and efficiency in object tracking using passive RFID", IEEE International Conference on Pervasive Computing and Communication 2012, pp. 109-115, 2012.