The Optimized Detection Range of RFID-based Positioning System using *k*-Nearest Neighbor Algorithm

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Abstract

The positioning technology for a moving object is an important and essential component of ubiquitous computing environment and applications, for which Radio Frequency Identification (RFID) has been considered as a core technology. RFID-based positioning system calculates the position of moving object based on *k*-nearest neighbor (*k*-nn) algorithm using detected *k*-tags which have known coordinates and *k*can be determined according to the detection range of RFID system. In this paper, RFID-based positioning system determines the position of moving object not using weight factor which depends on received signal strength but assuming that tags within the detection range always operate and have same weight value. Because the latter system is much more economical than the former one. The geometries of tags were determined with considerations in huge buildings like office buildings, shopping malls and warehouses, so they were determined as the line in 1-Dimensional space, the square in 2-Dimensional space. In 1-Dimensional space, the optimal detection range is determined as 125% of the tag spacing distance through the analytical and numerical approach. Here, the analytical approach means a mathematical proof and the numerical approach means a simulation using matlab. But the analytical approach is very difficult in 2-Dimensional space, so through the numerical approach, the optimal detection range is determined as 134% of the tag spacing distance in 2-Dimensional space.This result can be used as a fundamental study for designing RFID-based positioning system.

Keywords : *k-nearest neighbor, RFID, Ubiquitous Positioning System*

1. Introduction

RFID can be one of the best solutions for overcoming this situation and it can be the most suitable technology for ubiquitous sensor network (USN).

Weiger (1991) suggested an upcoming computing environment in terms of ubiquitous computing which is integrated with physical environment and becoming disappearing, invisible and being everywhere. Huber and Huber (2002) explained two ways that computers can support us wherever we are. First one is to embed computers in everything and everywhere and the other one is to carry devices that can communicate with other computers, sensors in the network.

From this point of view, comparing with other technologies, RFID can give not only locationinformation but also other useful information which is a backbone of the future universal sensor network. In USN environment, RFID tags will be attached to everything and everywhere to sense object information and even environmental information.

RFID is a means of storing and retrieving data through electromagnetic transmission to compatible reading devices. RFID is a powerful technology not only of automated inspection/identification of products but also assisting in conventional positioning system and it has been studied by many researchers (Hightower *et al.* 2001, Kubitz *et al.* 1997, Ni *et al.* 2004). RFID consists of three components, i.e., tags, a reader with an antenna, and software. If tags which store the coordinates of the locations and other information are installed, the location of vehicle or moving object with the reader can be estimated by communicating with the tags. Recently the price of RFID tags becomes cheaper and cheaper, so it can be installed at regular distances for outdoor environment such as wide cities, highways as well as inside of buildings for indoor environment.

RFID-based positioning system calculates the position of moving object based on *k*-nn algorithm using detected *k* numbers of tags which have known coordinates and *k* can be determined according to the detection range of RFID system. But the longer detection range it has, the more expensive it is and the system with longer detection range is not always more accurate and efficient. The purpose of this study is to find out the optimal detection range which makes RFID-based positioning system most accurate and it will be a fundamental study for designing RFID-based positioning system. The paper is organized as follow. In Section 1, technical background of current positioning systems and the purpose of this paper were described. Section 2 describes theoretical background of suggested RFID-based positioning system. Section 3 describes the mathematical proof and designs and results of matlab simulation for getting the optimal detection range in 1- and 2-Dimensional space. Finally, Section 4 concludes the paper and gives directions for future study.

2. Technical background

2.1 *k*-nearest neighbor (*k*-nn) algorithm

k-nearest neighboring is using *k* numbers of reference points, and the coordinate of a target point is

$$(x,y)=\sum_{i=1}^{k} w_i(x_i,y_i)/\sum_{i=1}^{k} w_i \qquad (1)$$

Here, (x_i, y_i) is the coordinate of *I* th reference point, w_i is a weight factor. The weight factor is inverse-proportional to the distance between the reference point and the target point in order to ensure minimal error in coordinate estimation. Figure 1 offers a conceptual view of *k*-neighboring algorithm.

2.2 Accuracy assessment

Accuracy means closeness to the true location. RMSE value is used to analyze the resultsof simulations. The RMSE value is a frequently-used measurement for the difference between values predicted by a model or an estimator and the values actually observed from the thing being modeled or estimated. From equation (2), 2-dimensional RMSE value can be obtained.

$$RMSE=\sqrt{\frac{\sum_{i=1}^{n}[(\hat{x}_i-x_i)^2+(\hat{y}_i-y_i)^2]}{n-1}} \qquad (2)$$

$(\hat{x}_i,\hat{y}_i)$ is an observed coordinate, (x_i,y_i) is a true coordinate and n is the total number of observations.

3. The analytical and numerical approach for the optimal detection range

In this paper, to find out the optimal detection range of RFID-based positioning system, the analytical and numerical approaches were conducted. Here, the analytical approach means a mathematical proof and the numerical approach means a simulation using matlab. The geometries were determined as the line in 1-Dimensional space and the square in

2-Dimensional space.

In 1-Dimensional space, the analytical and numerical approaches were conducted. But it was very difficult to conduct the analytical approach in 2-Dimensional space, so only the numerical approach was conducted in 2-Dimensional space.

In the simulations of proposed RFID-based positioning system, it was assumed that the reference RFID tags were placed with known coordinates and tags within the detection range always operate. The weight factor which gives weight to each RFID tag`s coordinates depending on received signal strength was not considered because the system which doesn`t have weight factor is much more economical than the system which has it. Then the measurement coordinates of each true point was calculated as a mean value of k-detected number of RFID tags` coordinates and RMSE between true coordinates and measurement coordinates was calculated for the accuracy assessment.

3.1 1-Dimensional space

3.1.1 The analytical approach

Figure 2 shows the analytical approach model in 1-Dimensional space. RFID tags are placed with the distance b and true values are regarded as continuous values between 0 and b because RFID tags are placed with every distance b continuous true values between 0 and b can cover all available position on the line. The detection range was determined as

The detection range (R)=$b+a$ $(0 \leq a \leq \frac{b}{2})$ (3)

based on two assumptions. The first one is that at least the detection range should be equal or longer than the tag spacing distance b and the second one is the additional detection range a doesn`t need to be larger than $b/2$ because tags are placed in symmetric geometry. So true values have same measurement coordinates when a is larger than $b/2$ and smaller than $b/2$.

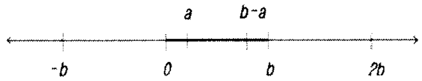

Figure 2. The analytical approach model in 1-Dimensional space

True values are divided into three areas. Then, measurement coordinates can be calculated as a mean value of coordinates of tags which are located within the detection range using k-nn algorithm. Table 1 shows measurement coordinates in each area.

Table 1. Measurement values in each area

Area	Detected tags	Measurement value
$0 \leq x \leq a$	$-b$, 0, b	0
$a \leq x \leq b-a$	0, b	$b/2$
$b-a \leq x < b$	0, b, $2b$	b

The tag spacing distance b can be determined by certain applied area and purpose. In order to find out the optimal detection range, the additional detection range a should be determined.

The optimal detection range is derived from the mathematical proof in the analytical approach. The optimal detection range should minimize the amount of errors between true coordinates and measurement coordinates.

$$\int_0^b (x_{true} - x_{measurement})^2 dx \rightarrow Min \qquad (4)$$

Measurement values in each area were calculated so equation (4) can be rewritten as

$$\int_0^b (x_{true} - x_{measurement})^2 dx = \int_0^a (x-0)^2 dx + \int_a^{b-a} (x-\frac{b}{2})^2 dx + \int_{b-a}^b (x-b)^2 dx$$

$$= \left[\frac{x^3}{3}\right]_0^a + \left[\frac{(x-\frac{b}{2})^3}{3}\right]_a^{b-a} + \left[\frac{(x-b)^3}{3}\right]_{b-a}^b$$

$$= \frac{2}{3}\left[a^3 + (\frac{b}{2}-a)^3\right] = b\left[(a-\frac{b}{4})^2 + \frac{b^2}{48}\right] \quad (5)$$

Figure 3 shows the simple curve of equation (5) and the integration of errors is minimized when $a$is equal to $b/4$.

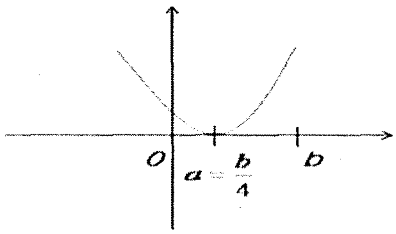

Figure 3. The graph of error equation

So through the analytical approach, the optimal detection range for 1-Dimensional space is 125% of the tag spacing distance b.

3.1.2 The numerical approach

To verify the result of analytical approach, the numerical approach was conducted using matlab. In the analytical approach, true values were considered as continuous values between 0 and $b$but in the numerical approach, true vales are considered as points between 0 and b with 0.1 interval. For example if b is 10 then 101 points between 0 and $b$are set up as true values. Simulations were conducted with the detection range which varies between the tag spacing distance b and $1.5b$ with increment of 0.1 to find out the optimal detection range.

Figure 4 shows the result of numerical approach according to detection ranges and table 2 shows the optimal detection range which minimizes the integration of errors is consistent with that of the analytical approach as 125% of the tag spacing distance. Here, the optimal detection range is 126% when tag spacing distance is 9. It is because the simulations were conducted with 0.1 increment of detection range for computational efficiency. So extra simulation was conducted with detection range between 11.2 and 11.3 with 0.01 increment and the result is consistent with 125% of tag spacing distance.

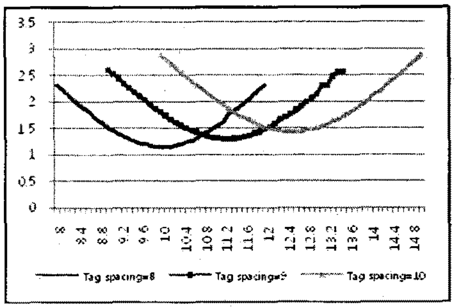

Figure 4. The result of numerical approach in 1-Dimensional space

Table 2. The optimal detection range in 1-Dimensional space

Tag spacing distance	The optimal detection range	Percentage
8	10	125%
9	11.3	126%
9	11.25	125%
10	12.5	125%

3.2 2-Dimensional space

3.2.1 The numerical approach

True vales are considered as points between 0 and b with 0.1 interval on x- and y-axes. Figure 5shows true values of simulation. For example if b is 10 then 101 pointsbetween 0 and b on x-axis and 101 points on y-axis are set up as true values. Simulations were conducted with the detection range which varies between the tag spacing distance b and $1.5b$ with increment of 0.1 to find out the optimal detection range.

Figure 6shows the result of numerical approach according to detection ranges and table 3 shows the optimal detection range which minimizes the integration of errors is consistent with that of the analytical approach as 134% of the tag spacing distance.

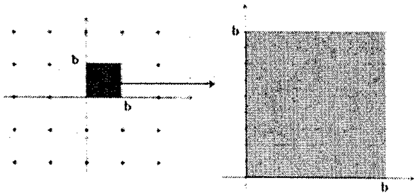

Figure 5. True values of simulation in 2-Dimensional space

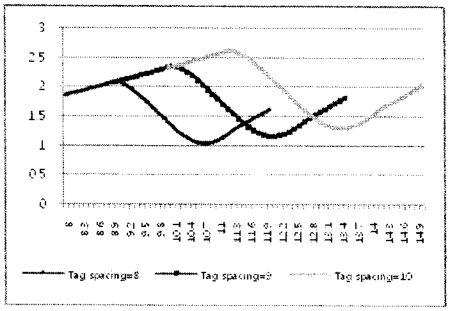

Figure 6. The result of numerical approach in 2-Dimensional space

Table 3. The optimal detection range in 2-Dimensional space

Tag spacing distance	The optimal detection range	Percentage
8	10.7	134%
9	12.1	134%
10	13.4	134%

4. Conclusion and future study

In the advent of ubiquitous computing environment, the positioning technology becomes more and more important and essential and RFID-based positioning system using *k*-nn algorithm can be a core technology. In the economical aspect, the system was suggested without weight factor and the optimal detection range should be determined in 1-, 2-Dimensional space. Table 4shows the simulation results, the optimal detection range is 125% of tag spacing distance in 1-Dimensional space and134% of tag spacing distance in 2-Dimensional space. It can be used as the premise theory for the design guideline for RFID-based positioning system and other applications using *k*-nn algorithm.

In the future study, simulations will be expanded to 3-Dimensional space. In this paper simulations were conducted to determine the optimal detection range of RFID-based positioning system but there are many design factors such as detection rate of tags, standard deviation of detection range of RFID reader and multi-level range which gives weight factor to each tags` coordinates according to received signal strength. In order to know how each design factor affects on the positioning accuracy, the optimal detection range should be adjusted. So study about guidelines for these design factors of RFID-based positioning system will be conducted based on this optimal detection range.

Table 4. The simulation results in 1- and 2-Dimensional space

Dimension	The optimal detection range of tag spacing distance
1	125%
2	134%

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