

Efficient Indoor Localization and Error Correction Algorithm

Yong-Ki Ku*, Choon-Sung Nam*, Dong-Ryeol Shin*

**School of information and Communication Engineering Sungkyunkwan University, Korea*

cutedual@skku.edu, namgun99@skku.edu, drshin@skku.edu

Abstract— Recently, paradigm of system integration changes into distributed computing environment. Advances in the network and hardware accumulation technology have enabled the development of micro-sensors which can manage wireless communication. Therefore, indoor localization services using wireless signal are social issues. Wireless signal is affected by signal distortion, reflection, channel fading, and path loss. Therefore, we propose effective error correction method to obtain accurate distance information. In this paper, the presented approach progressed in two phases: the first phase offers to problems of existing localization method and the Kalman-filter algorithm. The second phase offers to problems of the coverage and power consumption of sensor nodes in indoor. Finally, we propose the effective localization and error correction algorithm.

Keywords—Indoor localization, Kalman-filter, Error correction algorithm

I. INTRODUCTION

Recent paradigm of system integration changes into distributed computing environment and advances in the network and hardware accumulation technology have enabled the development of micro-sensors that can manage wireless communication. Wireless communications was related with daily life closely and has developed as an important technology. The ubiquitous computing technology that providing various and cosy service is social issues. Therefore, many national research teams investigate the ubiquitous computing technology. When Mark Weiser in Xerox research team wrote about ubiquitous computing in 1988, his vision of computing power deeply embedded in objects, places, and devices seemed some wary off. Today, ubiquitous computing is advanced computing environments using intelligent and networked objects that can exchange information to each other and consist of micro-chips [1]. According to the development of these techniques, sensor network applications required a number of sensor nodes and high quality of service for context-awareness. It can offer sensing data to context-aware applications that adapt to the user environments or object in a ubiquitous computing environment. Thus, context-aware service depends on

localization information. In the future, location-dependent services will become more importance.

Although GPS (Global Positioning System) [2] is the most typical outdoor localization system, it does not work well indoor environments because its signals are not designed to penetrate most constructions. In addition, it has a low calibrated accuracy and requires the line of sight. On the other hand, indoor environments require high accuracy of localization technology because it hard to important the existing location algorithms. Figure 1 shows the classification of location measurement technologies [3]. This paper focuses on localization algorithm using wireless signal.

The rest of the paper is structured as follows: section 2 raise problems of existing algorithms and the Kalman-filter. Section 3 describes problems of indoor environments. Section 4 explains the proposed algorithm. Finally, section 5 concludes with a brief summary and mentions future work.

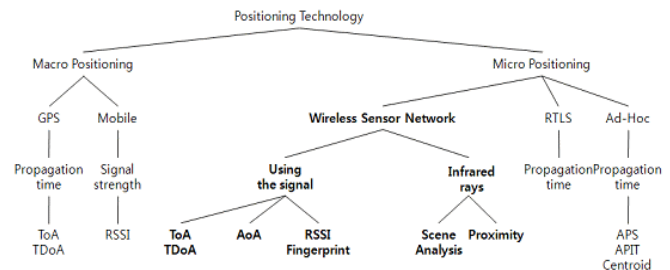


Figure 1. A classification of the location measurement technologies

II. RELATED WORK

A. ToA(Time of Arrival)

The ToA[4] method measures the propagation time between a mobile object and minimum 3 fixed sensor nodes and it uses the relationship between the distance and radio wave. The range between the i^{th} fixed sensor node and the mobile object can be expressed as

$$\text{Distance}_i^2 = (x_i - x_m)^2 + (y_i - y_m)^2 \quad (1)$$

x_i and y_i are the position of the i^{th} fixed sensor node. x_m and y_m are the position of a mobile object. The ToA is obtainable the standard equation of a circle using the result of the expression (1).

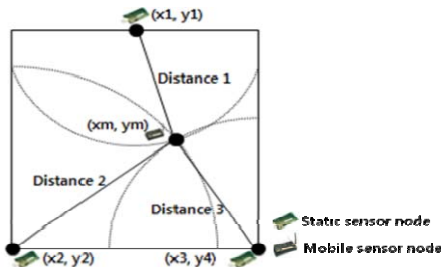


Figure 2. A measuring method of ToA

After that, it decides location of a mobile object to intersection point of three circles. The relationship between the ranges of three sensors, there location, and position of a mobile object are shown in figure 2. In the ToA, it must be solves a problem of accurate synchronization between other sensor nodes.

B. TDoA(Time Difference of Arrival)

TDoA [5] method supposes a signal propagates from a transmitter at static node 1 to known receiver locations at static node 2 and node 3. It is desired to estimate the location of static node 1. If the spatially separated receivers at node 2 and node 3 are time synchronized so that the signal of the ToA can be measured, then the range difference between the two paths can be estimated. That is, it decides location of a mobile object to intersection of two hyperbola curve. If $s(t)$ is a signal of mobile object, $n_i(t)$ is noise, and d_i is propagation delay, the received signal of each static sensors can be expressed as:

$$\begin{aligned} X_i(t) &= s(t - d_i) + n_i(t) \\ X_j(t) &= s(t - d_j) + n_j(t) \end{aligned} \quad (2)$$

The correlation of X_i and X_j at time is denoted as the following mathematical expressed:

$$R_{X_i, X_j}(\tau) = \frac{1}{T} \int_0^T X_i(t) X_j(t - \tau) dt \quad (3)$$

The TDoA is the maximum value of the $R_{X_i, X_j}(\tau)$. Although this method can solve a synchronization problem of the ToA, it does not work indoors because it can't solve the multi-path fading and the nonlinear problem of a hyperbolic curve.

C. RSSI(Received Signal Strength Indicator)

1) LF(Location Fingerprinting)

A typical location technique is Location Fingerprinting [6] [7]. This method based on a database of pre-recorded measurements of network characteristics from different locations and the location of a mobile object is estimated by inspecting current measured signal strength. For instance, the LF compares stored signal strength of reference points and current signal. And then, it calculates the location of a mobile object using a calculated result.

The LF consists of the training steps and the positioning steps. Figure 3 presents the behaviour method of the training steps in detail. First, it selects reference points from various points that frequently occurs the visiting of user and mobile object. After that, training steps deploy a mobile object at

reference points. It measures received signal strength in three fixed sensor nodes from a mobile object and stores that with attribute values of reference points.

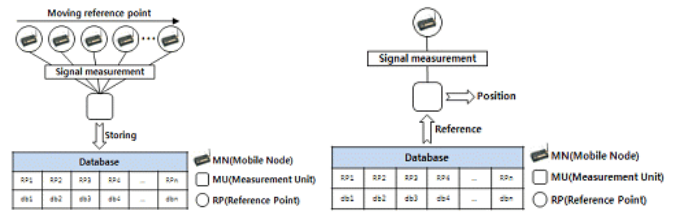


Figure 3. The training steps and the positioning steps

The positioning steps compare stored signal strength of reference points and current signal in the figure 3. And then, it calculates the location of a mobile object using a calculated result.

However, the LF method does not work well in complex indoor environments because it can not perceive change in the indoor environment. If the indoor environment is changed, LF method must be re-measures signals of reference points. We define some elements as the following; during the time it finds the element in database is T_s , during the time it calculates the location of a mobile object is T_c , and for accuracy the value of MU is three because it can't calculate of the mobile object. The quantity of attribute in the database can be expressed as 3RP. Therefore, the total time of the LF method is denoted as the following mathematical expressed:

$$\text{Total time} = T_c + (T_s \times 3R) \quad (4)$$

The expression 4 is not considers a network delay. Just focus on searching time in the database.

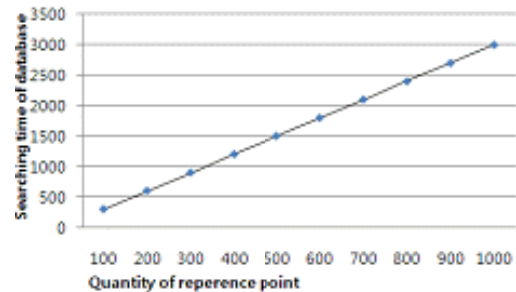


Figure 4. The training steps

Figure 4 describes the relation of reference points and the searching time in the database without delay of the network. As the number of reference points increases, the LF can accurately calculate the location of a mobile object. However, it does not work well indoor environments. If a quantity of reference point increased, it spends more time to find stored values in the database.

Many researchers study on the location algorithms such as NN (Nearest Neighbour) and KWNN (K Weighted Nearest Neighbour) for solving these problems but these location methods could not solve to problem of the indoor environment. When location or quantity of the reference points changed, existing algorithms can not apply for information of changed environments.

2) Kalman-filter

The Kalman-filter [8] [9] [10] is optimal estimation technique that finds a state value of system using the stochastic model of target system and measure value. It designed by Kalman at 1960th and estimates the unknown value using the statistical properties of state value and stored signal. After that, the Kalman-filter extended application field to GPS, navigation, and aviation. Recently, the extended Kalman-filter algorithm has emerged for non-linear systems. The Kalman-filter algorithm consists of the time update equation ("Predict") and the measurement update equation ("Correct").

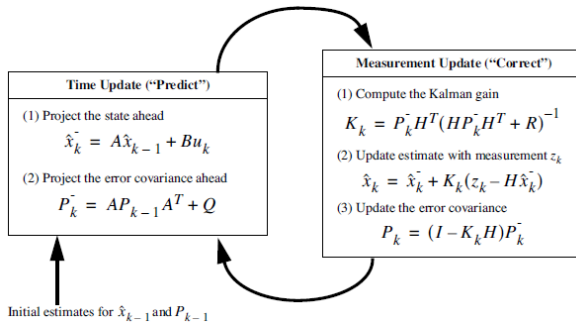


Figure 5. The kalman-filter cycle process

The time update equation is a step to estimate current state of the system. It sends a result of current system to the measurement update equation. The measurement update equation regulates error covariance via received values. According to two equations, the Kalman-filter method can get good signal from weak signal by obstacles and prevents the "signal-jumping" that is a problem of the RSSI method but this method must be submits to unknown signal during the revision-time of error covariance. If the signal attenuation due to obstacles is happened at this time, this method cannot estimates the accurate location of a mobile object because the Kalman-filter depend on predicted state variable of the system in the measurement update equation.

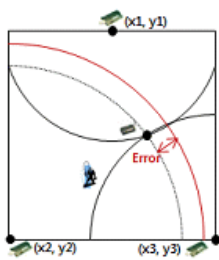


Figure 6. A problem of the Kalman-filter

III. PROBLEM OF INDOOR ENVIRONMENT

Indoor localization method using sensors must carefully consider power consumption and reliability data transmission. If the strength of a radio frequency increases maximally, it can transmit a data and radio signal to other sensor in 50 meters but the strength of radio frequency and power consumption of a sensor are an inverse relationship. For this

reason, if the signal strength of radio frequency increased, the sensor will consume more power in figure 7. In addition, to use the radio frequency communication for indoor localization method is influenced by properties of the indoor environment such as signal distortion, noises, and diffraction of the signal. If distance of sensor nodes more increase, reliability of data or signal will be decreased. When sensors densely deployed, it must spends more the power consumption by collision of each sensor. According to the above conditions, indoor localization method must appropriately selects the distant of each sensor and strength of radio frequency.

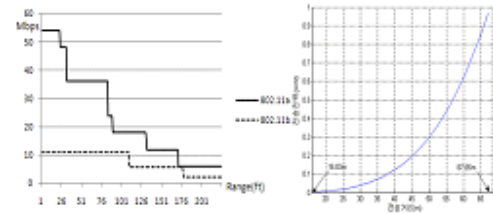


Figure 7. (Left) transmission speed of the 802.11 a/b (Right) power consumption of sensor

IV. PROPOSED ALGORITHM

A. Indoor localization

This localization algorithm uses the Friis formula to calculate distant from mobile object. As the transmitted signal traverses the atmosphere its power level decreases at a rate inversely proportional to the distance travelled and proportional to the wavelength of the signal. This formula used by RF Workbench accounts for only the diminishing voltage without accounting for absorption or dispersion by the atmosphere. It is denoted as the following mathematical expressed:

$$L = 20 \log_{10} \left(\frac{4\pi d}{\lambda} \right) [\text{dbm}] \quad (4)$$

The d (distance) in expression (4) is denoted as the expression (5).

$$d = \frac{\lambda}{4\pi} 10^{\frac{L}{20}} [\text{m}] \quad (5)$$

In expression (5), L means received strength of radio signal. λ means wavelength of a radio wave. And then, it be obtainable the standard equation of the circle using the result of the expression (5). After, it decides the location of a mobile object to intersection point of three circles. When this method measures signal strength between mobile object and three fixed access points, it decides to exist the obstacles for solving problems of the Kalman-filter in the figure 8.

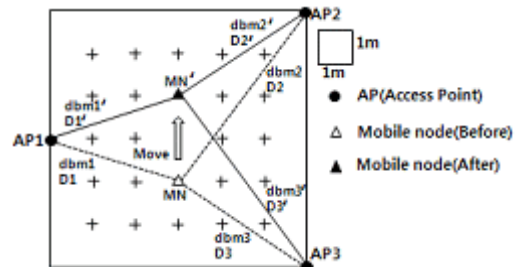


Figure 8. A mechanism of the obstacle detection

If the mobile object move to (3, 2) from (3, 4), we can denoted the following mathematical expressed using the Pythagoras theorem and expression (5).

$$\begin{aligned} D_1 &= \sqrt{3^2 + 1^2} \approx 3.162[m], D_{1'} = \sqrt{3^2 + 1^2} \approx 3.162[m] \\ D_2 &= \sqrt{3^2 + 4^2} = 5[m], D_{2'} = \sqrt{3^2 + 2^2} \approx 3.606[m] \\ D_3 &= \sqrt{3^2 + 2^2} \approx 3.606[m], D_{3'} = \sqrt{3^2 + 4^2} = 5[m] \\ dbm_1 &= 50.40057[dbm], dbm_{1'} = 50.40057[dbm] \\ dbm_2 &= 54.37997[dbm], dbm_{2'} = 54.20271[dbm] \\ dbm_3 &= 54.20271[dbm], dbm_{3'} = 54.37997[dbm] \\ ((dbm_{1'} - dbm_1) + (dbm_{2'} - dbm_2) + (dbm_{3'} - dbm_3)) &\approx 0 \end{aligned} \quad (6)$$

The range of signal fluctuations by the obstacle is 10~20 decibel and the “signal-jumping” of wireless without the obstacle is -3~+3 decibel. Therefore, error values of “signal-jumping” and obstacles defined as follow thing:

- α : jumping error, $\alpha = \{-3dbm \leq \alpha \leq 3dbm\}$
- β : obstacle error, $\beta = \{10dbm \leq \beta \leq 20dbm\}$

Figure 9 describes the average deviation of “signal-jumping” and obstacles using expression (6).

The wavy graph denotes average deviation without “signal-jumping” and obstacle. And the dotted graph denotes average deviation with jumping error. The solid graph denotes average deviation of radio signal with obstacle. The threshold value can distinguish between “signal-jumping” of radio and obstacles. Therefore, the threshold value can be denoted as $7dbm \leq \text{thresholdvalue} \leq 15$ by figure 10.

In other words, if sum of subtraction current signal and previous signal that receiving signal strength from access points is less than 15dbm, this method decides that mobile object move its location. Conversely, if the sum is more than 20dbm, it decides error by obstacles. And then, it removes current received signal strength and use predicted signal strength in the Kalman-filter.

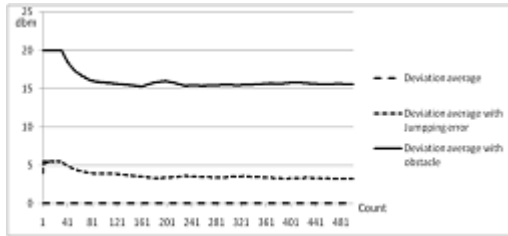


Figure 9. Average deviation of the radio signal

The Kalman-filer algorithm consists of the time update equation (“Predict”) and the measurement update equation (“Correct”).

The time update equation is a step to estimate current state of system and it send a result to the measurement update equation. Unknown variables are denoted as:

- ‘X’ is optimized state values such as signal strength.
- ‘A’ is conversion factor connecting current state value and next state value.
- ‘Q’ is error value in the ‘K’ step.

Mathematical signs in the measurement update equation are denoted as:

- ‘z’ is observed values. It decided by ‘x’ and ‘H’.

- ‘R’ is value of observation error

The Kalman-filter method can get good signal from weak signal by obstacles, and prevents the “signal-jumping” that is a problem of the RSSI method. According to two advantages, proposed algorithms use the Kalman-filter

B. Indoor localization

If the indoor localization method knows the location of fixed access points and reduces “signal-jumping” of radio wave via the Kalman-filter algorithm, to calculate intersection point of three circles is very difficult. Because that be rarely created by property of the radio wave. The form of three circles is denoted as figure 10.

This error revision algorithm use the ‘Q’ value in the Kalman-filter for reducing error by described above problems. That method increases the radius of three circles based on each access points by the ‘Q’ values in the Kalman-filter, or decreases that. If the error revision algorithm be able to calculate a intersection point of three circles, the calculated result will determine the location of mobile object.

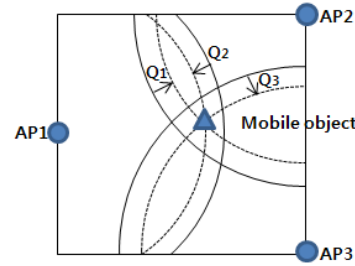


Figure 10. The forms of three circles

V. CONCLUSIONS

The localization of a mobile object is critical technology for realizing the ubiquitous era. So that, most nations are actively developing the localization algorithm. In the future, according to development of system integrate technology and change of the computing environments, the localization technology of a mobile object will be critical technology.

In this paper, we present problems of the existing localization algorithm and indoor environment. We propose the efficient localization algorithm to overcome described above problems using the advanced Kalman-filter and error revision algorithm. Future research works are composed as follows: to solve problems by various properties of the NLOS, research on power consumption and RF range of sensor, and performance evaluation of proposed algorithm via simulation.

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