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The Effect of a Hybrid Method for Indoor Location

Hyeoncheol Zin[2], HyunJin Park[1], ChongGun Kim[*1]

[1]*Dept. of Computer Engineering, Yeungnam University, 280 Daehak-Ro, Gyeongsan, Gyeongbuk 38541, Republic of Korea (38541 Korea)*
[2]*SejoongIS CO, 831 Bon-dong, Dalseo-gu, Daegu, Republic of Korea.*

Abstract

One of the popular methods studied for indoor positioning is based on Wi-Fi signal strength. Variation in signal strength that depends on communication distance is an important parameter. But signal strength shows not only intuitive results but also irregular results. Depending on the experiment, using only wireless signal strength to determine communication distance may have evident positioning errors. Therefore, some additional methods for increasing positioning accuracy are needed. Time of flight (ToF) and additional sensors to support positioning are needed.In this study, a method based on only Wi-Fi signal strength and other hybrid methods which are used additional upon wireless signal method are studied. Compass sensors and laser sensors were proven to be good additional methods for better positioning in a Wi-Fi-based system.

Keywords: *Wi-Fi, RSSI, Indoor Position, Triangulation, Laser, Compass, Time of Flight*

1. Introduction

The need for indoor location tracking of mobile objects is increasing for a variety of applications, so various studies for location tracking are ongoing [9,10,16,18].

Methods for determining indoor position include Wi-Fi, radio frequency identification (RFID), Bluetooth, and ZigBee. The triangulation positioning method for indoor location based on Wi-Fi signal strength is used by selecting at least three access points (APs) based on received signal strength indication (RSSI) values, which reflect shorter distances. To increase positioning correctness, the topology of the APs within an indoor area is also considered. To decrease positioning error based on only Wi-Fi RSSI, a laser sensor and a geomagnetic sensor are additionally used for precise locations in some environments.

2. Previous and Related Studies

Wi-Fi signal strength is used to find distances through the ChipconCO function. Some of the APs are arranged to measure indoor location using triangulation. Major methods of indoor location tracking are cell-ID, triangulation, and fingerprint [1]. Triangulation calculates the location of mobile terminals based on the distance from three known reference points. Comparing the mobile terminals' real-time signal patterns with a previously tracked signal pattern database is called the fingerprint method [1] to determine a mobile terminal's location. This paper uses triangulation as a position measurement method. Due to the deficiency in distance measurement using only RSSI [2], solutions to this problem use a laser sensor and a geomagnetic sensor.

2.1 A Method for Distance Prediction by Radio Signal Strength

The Friis formula and the ChipconCO formula can be used for calculating distance between two objects (http://www.ti.com).

Although prediction and calculation of distance based on radio signal strength is

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thought to be straightforward, the results are complex depending on the environment. In particular, calculation error in a distance decision is a major problem that has to be solved. In this study, the ChipconCO formula is used for simplicity in distance calculations based on signal strength:

$$RSSI = -(10n\log_{10}d + A) \quad (1)$$

In Formula (1), RSSI is the signal strength, n is propagation loss, d is distance, and A is the signal strength at a 1m distance from the signal transmitter. The distance between the receiving object and the signal transmitting AP can be calculated using the ChipconCO formula with the above parameters.

Signal strengths affected by the surrounding environment can vary depending on the time. Therefore, the distance from the receiving object to the AP is difficult to calculate precisely.

Even so, accurate determination of A and n in Formula (1) can increase the accuracy of the distance calculation based on RSSI [11].

2.2 The RSSI Signals Strengths depend on Different Distances

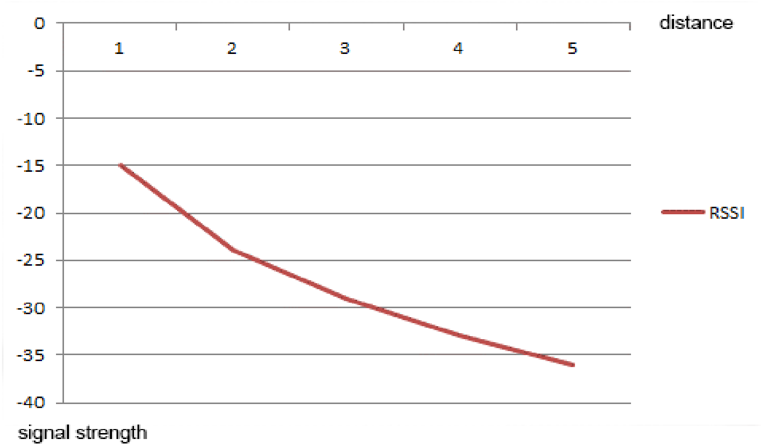

Figure 1. Change of the RSSI Values Corresponding to the Distance between a Transmitter and a Receiver

Figure 1 shows propagation loss n is 3.0, and signal strength at 1m from transmitter A is 15dBm from Formula (1).

Figure 1 shows that some RSSI values correspond to distance.

Significant phenomena shown in Figure 1 are as follows: in a 1m to 3m range, the signal strength apparently depends on distance, but the signal strength shows an insignificant change when the distance is greater than 4m.

2.3 The Characteristics of RSSI Signal Strength

Table 1 shows the signal strength from 1m to 7m at 1m intervals which is the distance from the AP to the mobile object.

Table 1. RSSI Values Corresponding to Distance

Distances	RSSI values
1m	-16.5 dBm
2m	-19.2 dBm
3m	-24.0 dBm
4m	-28.8 dBm

5m	-31.5 dBm
6m	-31.9 dBm
7m	-31.7 dBm

In the 1m to 5m range, the difference in the signal strength can be recognized. At 1m to 3m, the calculated distance using RSSI signal strength is similar to the actual distance [5], and signal strength from 4m to 5m shows relatively insignificant change. In distances farther than 6m, there is almost no change in signal strength for several distances [8]. Therefore, we decide that a meaningful distance is within 5m when calculating distance from RSSI signal strength.

Radio signals used by wireless communications have transmission losses, and example causes of transmission loss are as follows [8]:

-an increase in distance in a free zone
-raindrops scattering radio waves
-the diffraction of radio waves

Table 2. RSSI Signal Samples at a 2m Distance between Transmitter and Receiver

RSSI values	Numbers
-18dBm	23
-19dBm	17
-20dBm	2
-21dBm	1
-50dBm below	7

Table 2 shows the collected data for RSSI signals from an AP that used a 5GHz bandwidth 50 times. Even when the same devices were used for the experiments, the data at a 2m distance between transmitter and receiver showed various RSSI values, depending on time. As shown in Table 2, some weak signals below -50 dBm were occasionally obtained in an actual test.

If we use the average of the 50 sample data as the representative value, without filtering, then some abnormal values can have serious effects. And an abnormal value will cause a large error in positioning. So, the median value is used from the sample data to solve this problem [14].

2.4. Compass Sensing

A compass sensor is a digital compass that measures the Earth's magnetic field.

It measures distance using a laser sensor when the sensor indicates the direction to any wall based on the room layout [15].

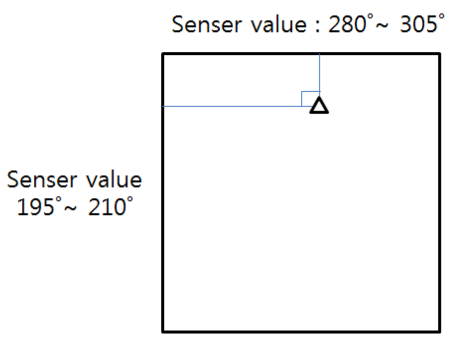

Figure 2. Target Wall

Figure 2 shows the direction values from the two walls.

The position of the triangle in Figure 2 was measured using direction information from mapping the room layout. By positioning a laser sensor perpendicular to the wall using compass sensor information, the correct distance can be obtained.

Because a compass sensor obtains a wide range of geomagnetic values, the accuracy of the compass sensor is determined by correctly evaluating the magnetic field.

A magnetic field is the magnetic effect of electric current and magnetic material. A magnetic field is influenced by metal, and the magnetic field of the Earth's surface is 25 ~ 65uT.

If the magnetic field value at a position is not 25 ~ 65 uT, the position is under the influence of the metal.

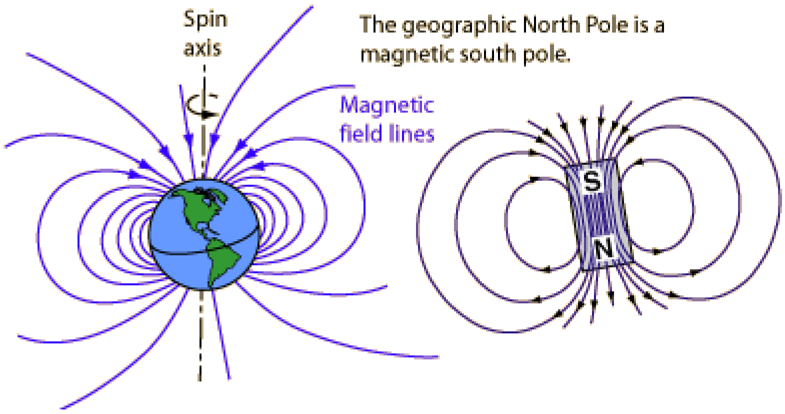

Figure 3. Earth's Magnetic Field

Figure 3 shows the generation principle of the Earth's magnetic field. The cause of the Earth's magnetic field is described by the dynamo theory whereby magnetic material is formed over the whole Earth, generating an electric current within the Earth [19].

2.5. Laser Sensor

A laser sensor calculates distance using the time taken to send and receive a laser beam between the transmitter and the receiver. The position and orientation of the walls are very important for estimating the position of a mobile robot in [4]. To obtain the wall parameters, a predefined room layout is one solution.

Table 3. The Laser Sensor Measures the Distance Error Rate

Actual distance	1m	2m	3m	4m	5m
Measurement distance	1.01m	2.02m	3.02m	4.03m	5.05m
Error rate	1cm	2cm	2cm	3cm	5cm

Table 3 shows error rates when measuring distance using a laser sensor.

The results from the laser sensor show smaller distance errors.

2.6. LoS Components from Multipath Components

RSSI simply capture the total received power at the mobile object. Because of irregular signal attenuation is caused by multipath fading. To mitigate the effect of multipath fading, extract LoS(Line of sight) components from multipath components is needed. Signal components except the LoS components may be delivered with some reflection from wall, floor and/or other objects, therefore it is natural to consider the reflected components have relatively low amplitude. CSI(Channel State Information) contains information about the channel at the level of individual subcarriers. CSI consists of amplitude and phase per subcarriers. Initially, CSI value is a frequency domain representation. IFFT(Inverse Fast Fourier Transform) can invert frequency domain to time domain. By filtering out signal components which are lower than 50% of peak amplitude and remained signal components are again changed to the frequency domain one with applying FFT(Fast Fourier Transform). The signal is used for distance estimation. It can decrease multipath effects [17].

2.7. Time of Flight

ToF is the time it takes for the wireless signal to travel between transmission and reception devices. ToF uses the channel status information (CSI) provided by the communication devices under WiFi.

The CSI is measured at all of 64 different subcarriers, it is more advantageous for distance measurement than RSSI represented by a single index.

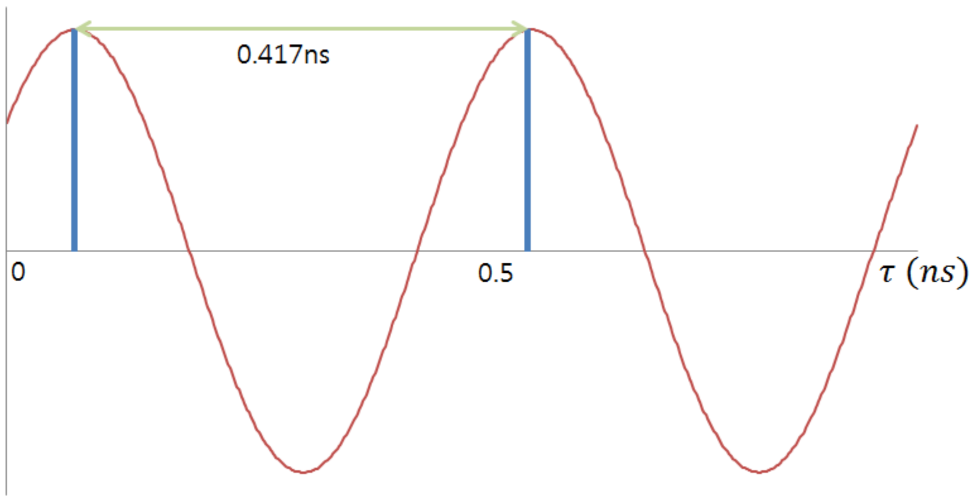

Figure 4. 2.4GHz Frequency Form

Figure 4 shows the 2.4GHz frequency on Wi-Fi. ToF is calculated using a phase difference of a frequency. But Wi-Fi based positioning is hard to get time of flight. A system that can accurately measure the absolute time of flight is needed. Some ultra-wideband radios that span multiple Ghz can be used. A Wi-Fi radio can emulate a wideband multiple-GHz radio. Packets on multiple Wi-Fi bands and stitches their information together for giving the illusion of a wideband radio. Stitching information across such packets need to overcome three challenges. Resolving phase offsets, Eliminating packet detection delay, combating multipath are required[16].

A cycle of the frequency at 2.4GHz is 0.417ns. The distance between the transceiver and receiver can be obtained by using the TOF. By multiplying the ToF with the speed of light, a mobile client device can compute the distance between the transmitter and each of the receiver[16].

$$\tau = -\frac{\angle h}{2\pi f} \; mod \; \frac{1}{f} \quad (\tau\text{: time of flight}) \qquad (2)$$

Formula 2 is used for getting the ToF with the Chinese remainder theorem in several channels.

3. Distance Decision based on RSSI

Obtaining the position of an object based on a Wi-Fi signal depends on the accuracy of the distance corresponding to the RSSI values. As shown before, RSSI values change irregularly. To get more reliable signal values, the number of sampling data must be large. To decrease errors, more signal sampling data are needed.

Table 4. Calculated Distance Error According to the Number of Samples at 1m from the Signal Transmitter

Sampling number	Error distance
1 time	3.01m
4 times	1.53m
6 times	1.10m
8 times	1.12m

3.1 RSSI Signal Characteristics in the 5GHz

Table 5. RSSI Values at a 1m Distance between Transmitter and Receiver

RSSI	Number
-7 dBm	6
-12 dBm	3
-13 dBm	3
-15 dBm	3

Table 5 shows 15 samples taken at a 1m distance between the transmitter of an AP and the receivers of mobile objects in an indoor space. RSSI signal strength at 1m between the transmitter and the receiver shows a variety of data ranging from -7dBm to -15dBm [9]. Another AP and mobile object were used for sampling, and almost similar results were obtained. To get more accurate results by using Formula (1), deciding the correct A (signal strength at 1m) is more important. But, as shown in Table 3, the RSSI values at 1m that were used as A in Formula (1) have some errors.

Therefore, getting reliable, stable signal values at 1m for Formula (1) must be considered. More accurate RSSI values at 1m could be estimated using 2m to 5m signal values. The effects of variations of A (RSSI values at 1m) and n (propagation loss) must be studied to calculate correct distances by using RSSI signals [5,12].

Table 6. Signal Strength Differences in Distances

Distance	Difference A -5dBm		Difference	Difference A -3dBm		Difference
	CASE1	CASE2		CASE1	CASE2	
1m	-15dBm	-20dBm	5	-15dBm	-18dBm	3
2m	-24dBm	-29dBm	5	-24dBm	-27dBm	3
3m	-29dBm	-34dBm	5	-29dBm	-32dBm	3
4m	-33dBm	-38dBm	5	-33dBm	-36dBm	3
5m	-36dBm	-41dBm	5	-36dBm	-39dBm	3

Table 6 shows two cases. CASE 1 and CASE 2 both use a value of 3.0 for n (propagation loss). In CASE 1, the signal at 1m is -15dBm, and in CASE 2 the signal at 1m is -20dBm; the difference in the RSSI values for CASE 1 and CASE 2 is 5dBm. The difference in RSSI values depending on distance in CASE 1 and CASE 2 show the same

-5dBm from 1m to 5m. The values from 2m to 5m are calculated using Formula (1) based on 1m. The regular difference characteristic in Table 6 can be used to decide n. A (the RSSI value at 1m from the AP) can be decided using n with the given RSSI values from 2m to 3m under any circumstance.

3.2 Fluctuation of the RSSI Values by Antenna Directions

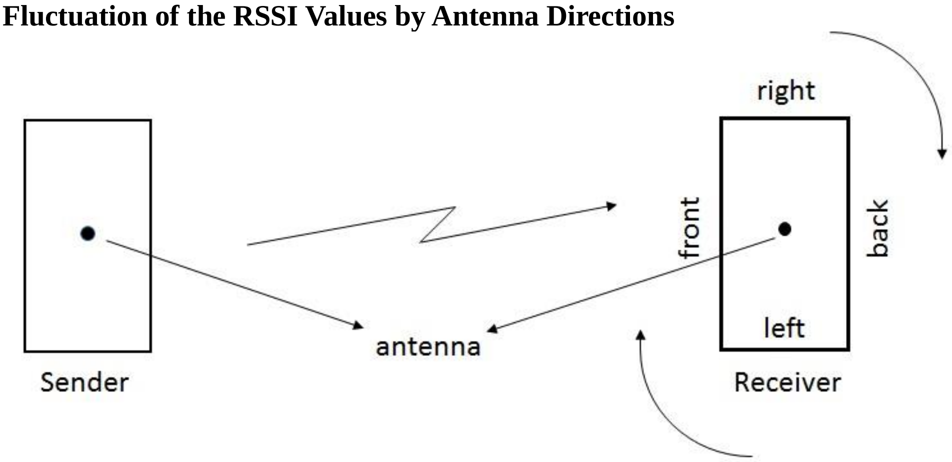

Figure 5. Four Directions of the Receiver

Figure 5 shows the direction of the receiver antenna in relation to the sender.

Table 7 shows the median value from 50 sample data. The RSSI values of a receiver for various antenna directions at a 2m distance are shown.[18]

Table 7. RSSI Values According to the Direction of the Antenna

Direction	First	Second
front	-26dBm	-28dBm
right	-27dBm	-22dBm
back	-27dBm	-22dBm
left	-28dBm	-27dBm

The strength of a signal changes depending on time and receiver antenna direction for the same position. To get more reliable data, some of the extraordinarily weak RSSI values are eliminated, and then an average of the remaining data is used.

3.3 Errors Depend on Propagation Distance

Signal strength of sampled data from farther away than 5m is almost unchanged in Table 1. It is hard to distinguish distance using signals farther than 5m between AP and mobile objects based on the experimental RSSI values.

Therefore, the distance between each AP and mobile object must be determined from within 5m for location tracking. A 6m x 6m square topology is considered an effective placement in the experimental area for location tracking. To use triangulation, at least three meaningful AP signals are needed. The distance from an AP to the mobile object must be less than 5m. At any position in the square, the distance between the mobile object and three APs is within 5m. One considerable arrangement of APs is the 6m x 6m square topology shown in Figure 6 [6,7].

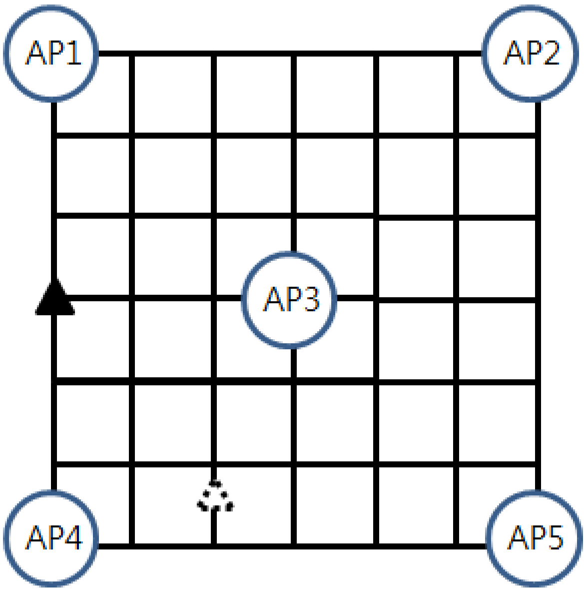

Figure 6. AP Arrangement in 6 x 6m Square

The measured signals at the black triangle position in Figure 6 are shown in Table 8. The chosen three closer APs based on the signals should be AP1, AP3, and AP4 [10,18].

Table 8. Signal Strength Calculation for each AP

AP1	AP2	AP3	AP4	AP5
4.68m	6.62m	2.45m	1.61m	4.43m

But some abnormal situations are observed. Table 8 shows the results of calculating distance using Formula (1) for RSSI signals. The errors in the signals give incorrect results.

In Figure 6, APs closer to the mobile object, shown as a black triangle, are AP1, AP3, and AP4, but the calculation results show that AP3, AP4, and AP5 are closer.

This may lead to a mistaken position for the mobile object, placing it at the triangle with square dotted lines. Other types of topology must be studied.

4. Experiment Environments for Location Decision

4.1 Positioning using RSSI from Wi-Fi

An experiment was carried out based on the Figure 6 topology. The five APs are Iptime's dual band Wi-Fi AP Multi, and the receiver of the mobile object is Iptime's A2000UA.

In the experiment, signal reflectance by the floor is observed. Therefore, all of the devices were placed and measured at a height of 2m above the floor [13].

Table 9. RSSI Values According to Real Distances from each AP, based on the Figure 6 Topology

	2m	3m	4m
AP1	-28.5	-31.5	-36
AP2	-26.5	-31	-32.7
AP3	-27	-31	-33.5
AP4	-26.5	-29	-32.5
AP5	-28	-32.5	-36

Table 9 shows the RSSI values corresponding to the distance. Using the results of table 9, the values of n and A at 1m are estimated.

Table 10. Values for n and A at 1m from the APs

Propagation Loss				
AP1	AP2	AP3	AP4	AP5
2.0	2.0	2.0	2.0	2.0
RSSI value at 1m				
AP1	AP2	AP3	AP4	AP5
-22	-20	-21	-20	-22

Table 11. Measured Distance from each AP

	AP1	AP2	AP3	AP4	AP5
Measured distances	12.59m	15.85m	1.78m	14.13m	3.98m

Table 11 shows the results of calculating distance by using the RSSI values of the APs at the measurement positions. The quadrant of the topology is selected by the smallest value of the measured distances. The three selected APs are AP3, AP5, and AP1. In this case, the position is placed between quadrants 3 and 4. So a large error is observed.

Table 12. Quadrants and Error Rate

	Quadrant	Error rate
Real location	4	0m
Assumed location	4	0.44m
Calcualted location	3 or 4	1.65m

Table 12 shows when a decision for the quadrant is wrong; then, the error rate become bigger at the calculated position. If the same quadrant is decided as an estimated position, then the calculated position may have less of a distance error. In the experiment, because of the different quadrants of the measurement location, the calculated position has larger errors.

4.2 Positioning using Laser Sensor and Compass Sensor

An experiment was carried out based on the layout in Figure 7. The scale of the room layout is provided. The compass sensor used was NTrex's NT-Mag6352, and the laser sensor was LULSED LIGHT's LIDAR-Lite. To track the position of mobile nodes, a geomagnetic sensor is first used to get a bearing angle, and then, a laser sensor gets distance in one direction. At least two directions for distance may be needed to decide a position, compared with the room layout information.

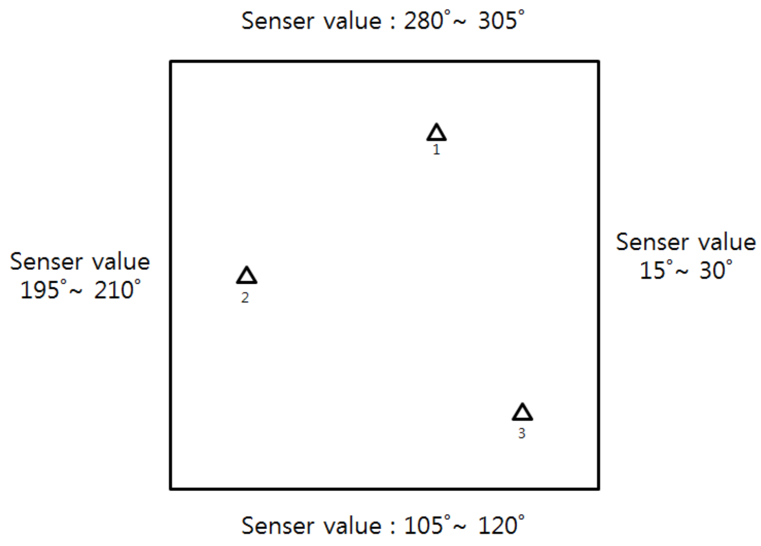

Figure 7. Three Arbitrary Positions in a 6m x 6m Layout

Figure 7 shows three arbitrary mobile object positions used in the experiments.

Table 13. Bearing Value and Distance Value at the Position

Location	Bearing value	Distance	Bearing value	Distance
1	292°	1.02m	202°	3.56m
2	305°	3.03m	205°	1.01m
3	288°	5.07M	198°	5.03m

Table 13 shows some results that were measured as the distance values and the bearing angles at the three arbitrary positions. The distance values were measured several times from the target wall to the mobile object by rotating the object in 10° directions. The final distance in azimuth is determined by selecting the shortest value of the measured values.

Table 14. Positioning Error between Actual Position and the Measured Position

Location	Actual distance		Measurement distance		Error rate
	Width	Height	Width	Height	
1	3.5m	1m	3.56m	1.02m	6.32cm
2	1m	3m	1.01m	3.03m	3.16cm
3	5m	5m	5.03m	5.07m	7.61cm

Table 14 shows positioning errors between actual positions and the measured positions.

The positioning error by using the laser sensor and the geomagnetic sensor is very low. The error is less than 10cm.

5. Proposed Hybrid Indoor Positioning System

A hybrid method for tracking indoor location is proposed. Figure 8 shows an example environment. The followings are prerequisites. A blueprint that shows the precise scales and bearing angles of the room layout is needed. Some Wi-Fi APs are located in designated positions. The mobile object decides roughly a room by Wi-Fi signals using the layout, and then an accurate position is decided using a compass sensor and a laser sensor by scaling the distances from the wall. By accumulating the real-time positioning data, the system can work as an indoor navigation or security system.

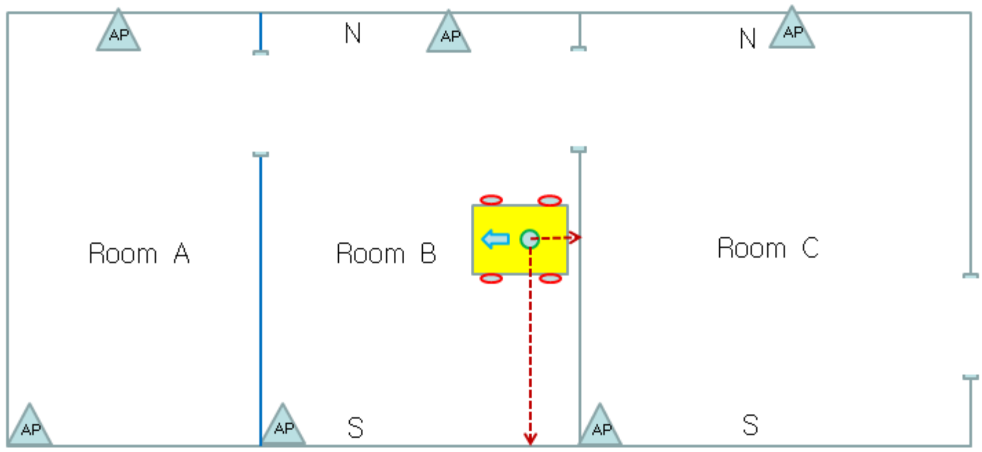

Figure 8. An Example of the Hybrid Indoor Positioning

6. Conclusions

Indoor location tracking by using Wi-Fi RSSI signal strengths is studied. The signal strength of wireless is not always corresponding, especially longer than 5m, to the propagation distance. In order to increase the accuracy of the location estimation, triangle quadrants of the rectangle is introduced to predict precisely where the mobile object is located.

In order to reduce the position errors and to avoid selection of wrong quadrants, some additional methods are needed. Some of candidate additional techniques are considered to improve accuracy. But it has also errors due to the surrounding environment. The RSSI based method is not sufficient to improve positioning accuracy. The need for introducing ToF(Time of Flight) to replace the RSSI in the Wi-Fi environment is increased.

The effect of sampling frequency in an arbitrary position is additionally studied. To increase correctness for deciding correct location, some epochal positioning methods for location of mobile object must be studied. As a method, laser sensor and geomagnetic sensor are introduced.

By combining Wi-Fi and other sensors like laser sensor and geomagnetic sensor, more efficient and accurate indoor positioning can be achieved.

Acknowledgements

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