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Research Article

Advanced Smoothing Approach of RSSI and LQI for Indoor Localization System

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Ubiquitous indoor environments often contain substantial amounts of metal and other similar reflective materials that affect the propagation of radio frequency signals in important ways, causing severe multipath effects, including noise and interference, when measuring the signal strength between sender and receiver. To minimize the noise level, this study proposes advanced fusion filter (AFF) and improved fusion filter (IFF) using received signal strength indicator (RSSI) and link quality indicator (LQI) by using feedback filter. The aim of this research was to provide a low cost, simple technique based on RSSI and LQI values, provided by ZigBee module without considering needs to change the system according to specific indoor environments. The proposed technique could efficiently decrease huge amount of noise level from the original signal. To check the performance of the proposed technique, this study applied median filter and Savitzky-Golay filter to compare the performance of AFF and IFF. Further, the statistical analysis technique of cross-correlation method was used to check the similarity between original signal and filtered signal. The simulation results demonstrate the efficiency of the proposed RF-based indoor location determination.

1. Introduction

Indoor localization systems have gained a significant attention in recent years due to their ease of deployment, low cost, and potential applications in several areas. Global positioning system (GPS) is a satellite navigation system that provides autonomous geospatial positioning with global coverage successful for outdoor positioning and applications [1]. However, the positioning within indoor environments is not feasible with GPS as it generally requires a direct view to several satellites, resulting in limited performance for indoor environments. Consequently, development of non-GPS-based solutions is of great interest for indoor use based on existing signals and hardware, as well as new systems and sensor modalities. There are numbers of existing indoor positioning systems which utilize a variety of sensing technologies and system architectures. Generally, indoor localization uses many different sensors such as infrared (IR), ultrasound, or radio frequency (RF).

Received signal strength indicator (RSSI) is affected by the distance between the nodes but there are few other factors that affect the radio signal propagation and hence the RSSI value that is perceived by a node. These factors include (but are not limited to) interference from other signal sources, reflection, diffraction, and presence and nature of objects in the path of the radio-wave. There are three main problems that the RF based indoor localization systems need to overcome: the signal reflection of the obstacles that supposes multipath contributions in the RF location system sensors; the signal attenuation when passing through the obstacles placed between the RF sources and the sensors [2, 3]; and, finally, the noise level that may seriously affect the system performance, especially the accuracy for the transmitter (Tx) location determination. Based on indoor localization systems design, it will be influenced by various application requirements such as location network scalability, energy efficiency, and location accuracy. Also various indoor fading effects are the main cause of the localization error [4]. The fading effects can be divided into the slow and the fast fading. Slow fading is caused by the environment, such as the radio block or shadow fading. Conversely, fast fading is temporary or random effect, such as interference, random noise, and the multipath effects. These work together, making it hard to predict the distance using RSSI value and thus introduce large localization error. Therefore, the main purpose of this study is to reduce noise from the measured RSSI values by applying the filtering technique to reduce the noise and sudden picks from the actual signals.

This study presents the evaluation of a RSS-based indoor localization method using a ZigBee-based sensor network. The aim of this paper is to achieve an efficient localization algorithm via integration of previous proposals [5–13]. In this paper, the proposed protocol intends to improve the existing algorithms using RSSI and link quality indicator (LQI) values. The localization systems presented in this study are based on the RSSI as a strength indicator and LQI as a quality indicator of a received packet and can also be used to estimate a distance from a node to reference points. This scheme can find out the location of the object by measuring the RSSI and LQI according to distance. Based on this information, a person can be tracked and broadly located.

This study consists of five Sections. Section 2 reveals the background of RSSI and LQI and previous works based on RSSI in indoor environment. Section 3 provides the methodologies of "advanced smoothing approach of RSSI and LQI for indoor localization system" and its probability of returning to the correct location and also describes the analysis results obtained from the model of location system. Section 4 shows the experimental performance. Finally, Section 5 gives the conclusion drawn from this study.

2. Related Work and Background

There are many algorithms from previous studies using different sensing approaches to solve the localization problem. The reason for this rich pool of different approaches is partly because wireless sensor network (WSN) can be used for numerous scenarios in a diverse range of environments. It logically follows that each environment comes with its own physical characteristics, requiring special handling. These localization techniques vary according to different characteristics such as accuracy, scalability, range, power consumption, and cost. Different sensors provide different range of accuracy from centimeters to room level. One of these is the physical means used for localization, for example, through the RF attenuation in the electromagnetic (EM) waves [4, 9, 10, 14] or the time required to cover the distance between transmitter and receiver (ultra-wideband). If using ultrasonic pulses, one could also use the time of arrival or time difference between the arrivals of the waves [15]. This can even be extended to audible frequency sounds [16]. The methods that use RSSI for localization are called distance measurement, fingerprinting, and angle measurement. These techniques are based on the specific behavior of radio signals in a given environment, including reflections and fading, rather than on the theoretical strength-distance relation. Cricket [15] is an indoor location system, which utilizes RF and ultrasound using static transmitters and mobile receptors. On the other hand, the Dolphin system [17], developed at the University of Tokyo, utilizes RF and ultrasound to create a peer-to-peer system providing coordinate based positioning. The Dolphin team has created a system which can propagate to locations with 10–15 cm of accuracy from four stationary reference nodes. Infrared has been popularly used for containment-based location systems [18]. Infrared location system is not as accurate in strong sunlight and under fluorescent tube lighting as both of these are sources of infrared light. In this paper, RSSI and LQI are used as two major parameters in wireless sensor network. The proposed protocol intends to improve the existing algorithms using RSSI and LQI values. The localization systems presented in this report are based on the RSSI as a strength indicator and LQI as a quality indicator of received packets; they can also be used to estimate a distance from a node to reference points. This scheme can determine the location of the object by measuring the RSSI and LQI according to distance. Based on this information, a person can be tracked and generally located.

2.1. RSSI and LQI. RSSI and LQI are two properties related to radio signal. These two indicators do not require prior information regarding the communication protocol and can be observed by collecting the signal data from receiver. There are many papers in the literature using RSS information for location estimation [11, 19, 20]. The popularity of RSS is due to the fact that it requires no additional hardware and almost every node in the network has the ability to analyze the strength of a received message. In order to estimate distances based on RSS samples taken from a given channel (i.e., communication environment), some model of the channel must be developed that adequately describes the environment. Theoretical models have an advantage in their ability to reproduce a channel for comparison between various localization scenarios, resulting in an accurate measure of relative performance.

A majority of the existing methods leverage the existence of IEEE 802.11 base stations with powerful radios that transmit powers of approximately 100 mW per base station. Such radios are in a different class from the low power IEEE 802.15.4 compliant radios that typically transmit at low power levels ranging from 52 mW to 29 mW. The wide availability of more IEEE 802.15.4 radios has revived the interest for signal strength-based localization in sensor network. Despite the rapidly increasing popularity of IEEE 802.15.4 radios and signal strength localization, there is a lack of detailed characterization of the fundamental factors contributing to large signal strength variation. The analysis of RSSI values is needed to understand the underlying features of location-dependent RSSI patterns and location fingerprints. RSSI can be defined as the ratio of received power P_R to the reference power P_{Ref} typically taken as 1 mW [12]. In [12], RSSI is defined as

$$\text{RSSI} = 10\log\left(\frac{P_{\text{RX}}}{P_{\text{Ref}}}\right), \tag{1}$$

and P_{RX} is defined as

$$P_{\text{RX}} = P_{\text{TX}} \times G_{\text{TX}} \times G_{\text{RX}} \left(\frac{\lambda}{4\pi d}\right)^2, \tag{2}$$

where P_{TX} is the transmission power of sender; P_{RX} is the remaining power of wave at receiver; G_{TX} is the gain of transmitter; G_{RX} is the gain of receiver; λ is the wave length; d is the distance between sender and receiver.

In embedded devices, the RSS is converted to RSSI which is defined as the ratio of the received power to the reference power (P_{Ref}). Typically, the reference power represents an absolute value of P_{Ref} which equals 1 mW. One of the characteristics of RSSI is that the received signal strength will decrease with increased distance as shown in the equation below:

$$\mathrm{RSSI} = \left(10n\log_{10}d + A\right), \tag{3}$$

where n is the signal propagation constant, also named propagation exponent; d is the distance from sender; A is the received signal strength at a distance of one meter.

The LQI is an indication of the quality of the data packets received by the receiver. The LQI can be used as a measure of the signal quality. It is also a measure of the total energy of the received signal. The ratio of the desired signal energy to the total in-band noise energy (the signal-to-noise ratio, or SNR) is another way to judge the signal quality. As a general rule, higher SNR translates to lower chance of error in the packet. Therefore, a signal with high SNR is considered a high-quality signal. The link quality can also be judged using both the signal energy and the signal-to-noise ratio.

The LQI measurement is performed for each received packet and must have at least eight unique levels. It is reported to the MAC layer and is available to the network (NWK) and the APL layers for any type of analysis. For example, the NWK layer can use the reported LQI levels of the devices in the network to decide which path to use to route a message. In general, the path that has the highest overall LQI has a better chance of delivering a message to the destination. The LQI is only one of the factors used in selecting a path to route a message. Other factors, such as routing energy efficiency considerations, can also influence the route selection. For example, a battery-powered device might be in an excellent location in terms of the link quality, but routing the messages frequently through this device will drain its battery much earlier than the rest of the devices in the same network.

LQI exhibits a very good correlation with packet loss and is therefore a much better link quality indicator. However, one of the contributions of the present work is to show that RSSI is a reasonable metric if it is processed correctly, and if interference can be distinguished from noise. Given that LQI is a superior metric, it should not be forgotten that it is only made available by 802.15.4 compliant devices. It therefore makes sense to use RSSI as much as possible.

Several studies have been conducted to improve the indoor localization performance using RSSI. In particular, it is difficult to implement an accurate localization performance because of the range errors being only a few meters in RSSI based fingerprint method. Also, because noises are easily included in the RSSI-based localization by disturbances such as multipath and electronic equipment, several filtering techniques have been proposed for reducing these noise problems [5, 7, 9–11, 13]. These methods reduce the noise and errors from actual signal by using the RSSI values, LQI values, and a fusion of RSSI and LQI values. These techniques represent the metric of the current quality of the received signal as well as the RSSI and provide filtering factor α value for noise elimination.

In order to measure a more accurate range, this paper proposes two new filtering techniques, advanced fusion filter (AFF) and improved fusion filter (IFF), which effectively eliminate the noises by providing exponential α value to the acquired data in consideration of the signal attenuation characteristics of the RSSI, which has a log distribution. The proposed method uses the feedback filter, which can provide different α value to the current value and previous averaged value according to the noise level included in the obtained signals, and it applies a fitted α value using an exponential function so as to be appropriate for the RSSI-based localization in the indoor environment.

This research measured the RSSI from 0 m to 10 m using two ZigBee-based wireless nodes in three different indoor environments: an open space environment, a half-open and half-closed space environment, and a closed space environment. It was verified that the proposed method enhanced the filtering performance so as to facilitate the development of the location based service (LBS) and could be used as an effective preprocessing step to implement the RSSI-based localization as well as improving the noise elimination performance when compared with the other existing methods.

For verifying the proposed filters performance, this study applied two different filters, the median filter and the Savitzky-Golay filter, to reduce noise from the measured RSSI value and compare the performance with the proposed AFF and IFF filters. Furthermore, this study applied cross-correlation technique to measure the similarity between the measured signal and filtered signal.

3. Methodologies

This chapter focuses on how this effective protocol was implemented and how the implementation issues were evaluated. In this section, the research focused on how to characterize and measure link quality in sensor networks deployed in utility environments. Experiments were conducted with Hybus nodes. To measure the radio link quality, two useful radio hardware link quality metrics were used: (i) LQI and (ii) RSSI. Specifically, RSSI was the estimate of the signal power and was calculated over 8 symbol periods, while LQI was viewed as chip error rate and was calculated over 8 symbols following the start frame delimiter (SFD). LQI values were usually between 110 and 50 and corresponded to maximum and minimum quality frames, respectively. The details of LQI metric were found in the IEEE 802.15.4 standard. The specific point in a system where position estimates are calculated is an important design parameter. In this scheme, the mobile device itself calculated the position based on its own measurements.

3.1. Selected Location System Architecture. The purpose of this study is to minimize the range errors for improving the RSSI based indoor localization performance and to verify this by experiments in the indoor environment. The experiments were conducted in three different environments, shown in Figure 1, which are Path 1: open space environment, Path 2: half-open and half-closed space environment, and Path 3: closed space environment. The RSSI was measured for a distance of 10 m by using the ZigBee device Hybus, Hmote 2430 [21].

It was decided to use a private and scalable system in this scheme. It featured an active base station that transmitted both RSSI and LQI signals. The mobile devices receive the signals, but they do not transmit anything themselves. The base station transmits the RSSI and LQI signals simultaneously. A mobile device measures a signal and is able to calculate the distance to the transmitter. By this scheme the location privacy of the user, who carries the mobile device, can be easily guaranteed because the mobile device does not send out any signals that might disclose its presence or its location. A further advantage of this architecture is its scalability to many mobile devices. Because the mobile devices do not transmit any signals, there can be an unlimited number of mobile devices in principle. Due to its privacy and scalability features, this architecture might be particularly suitable for large-scale professional location systems or systems in public spaces. Each mobile device calculates its own position, based on the received signals.

The RSSI and LQI of two nodes were measured at an interval of 0.5 m; the results are shown in Figures 2 and 3, which show the RSSI according to the distance measured in three locations, the x-axis representing the distance between the two nodes and the y-axis the obtained RSSI.

It was verified that the increasing signal strength became more similar to the form of a log model, and the decreasing signal strength was more distorted because of more noise. It was observed that although the signal strength was approximately −15 dBm and −70 dBm, on average, at the distances between the two nodes of 0 m and 10 m, respectively, as the signal strength decreased to less than −60 dBm, the graph became very irregular and many noises were mixed.

To correct the signals distorted by these noises, (3) was redefined as (4) by adding the scaling factor (s) to it; thus, the distance between the two nodes (d) was expressed as (5). This system used the scaling factor for the log model. As is known, for environmental change the log model also changes; hence, the scaling factor was used to find the accurate log model for a specific environment. Then the RSSI values were measured and compared with the log model:

$$\text{RSSI} = -10n\log_{10}(sd + 1) + A, \tag{4}$$

where s is the scaling factor

$$d = \frac{\left(10^{(\text{RSSI}-A)/-10n} - 1\right)}{s}. \tag{5}$$

Figure 3 shows the LQI, which represents the communication quality between the two nodes in the three paths, with the x-axis representing the distances between the nodes and the y-axis representing the obtained LQI values. It was verified that although the communication state was generally good in the range of the measured LQI values of approximately 100~107, as the distance between the two nodes increased, there was great variation in the LQI values, thereby gradually lowering the communication quality.

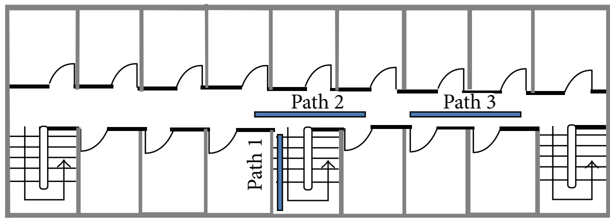

Figure 1: Experiment testbed.

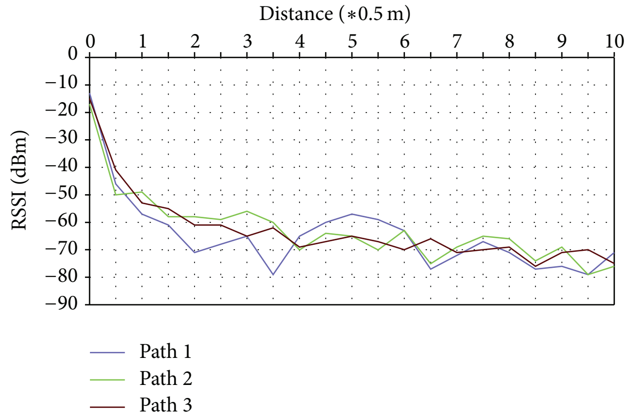

Figure 2: Measured rough RSSI in the three paths.

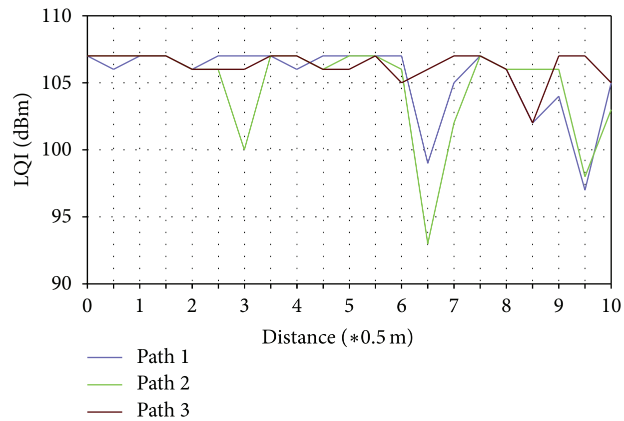

Figure 3: Measured rough LQI in the three paths.

3.2. System Implementation Using Filter. Wireless signals in the indoor environment include noises because they are easily distorted by various disturbances such as spatial structure, quality of the material, and electronic equipment; the range errors can be reduced by using several filters. A reduction of range errors is a very important process for accurate estimation of the locations of objects, which is the main objective of indoor localization.

Various filters can be used to smooth the RSSI value. Two common filters are simple averaging and feedback filters. Averaging is the most basic filter type, but it requires more data packets to be sent. Feedback filters use only a small part of the most recent RSSI value for each calculation. This requires less data but increases the latency when calculating a new position.

With an averaging filter, the average RSSI value is simply calculated by requiring a few packets from each reference node; each time the RSSI values are measured and calculated according to the equation below:

$$\overline{\mathrm{RSSI}} = \frac{1}{n}\sum_{i=0}^{i=n} \mathrm{RSSI}_i. \quad (6)$$

3.3. Feedback Filter. The feedback filters used for eliminating noise in various fields are the filters basically used in this study. If a filter approximation is used, it can be expressed as (7) where α represents the weighted value. In this equation, although the range of α value is 0-1, typically the variable a is 0.75 or above. RSSI_n represents the most recently measured value, and RSSI_{n-1} represents the previous averaged value. This approach ensures that a large difference in RSSI values will be smoothed:

$$\mathrm{RSSI}_{(\mathrm{smooth})} = \alpha \times \mathrm{RSSI}_n + (1-\alpha) \times \mathrm{RSSI}_{n-1}. \quad (7)$$

This means that the averaged RSSI value corresponding to the signal strength at distance depends on both the previous averaged value and the most recently measured value. As the value of a, which should be between zero and one, determines the degree of filtering, if a is chosen to be close to one, the new measurement barely plays a role in the calculation of the new average. If, on the other hand, the value of a is nearly zero, virtually no filtering is performed. An optimal filter, that is, the value for a, specific for this project will be determined in this section.

In this section, different filtering processes will be proposed. From the measured RSSI and LQI values, it was found that RSSI is a good indicator but LQI gives a better performance than RSSI over a long distance. From this measurement, it was decided to use LQI as a reference aid when the RSSI value is below some specific standard, so that smoothing can be done properly. With this experiment, the goal was to determine an optimal a value which would be used to filter the radio signal strengths. The goal was to have a filter that was able to remove the noise, that is, the peaks, from the raw data, but that would also preserve the typical signal behavior characteristics of both stillness and movement.

The first step in the signal analysis technique was done in order to understand the characteristics of the LQI and RSSI values on three types of environments. Although the effect of distance on received signal strength could be measured by the RSSI and the LQI provided by the radio, it was decided to use (7) to get the RSSI and LQI values. Equation (3) describes the basic model for RSSI, where the received signal strength decreases with increased distance. This system uses scaling factor for log model. It seems that the log model can also be changed for environmental change. So, for finding the accurate log model for a specific environment, the scaling factor was used (4). To determine the accurate distance, (5) was used, and to measure the signal attenuation factor, the following equation was used:

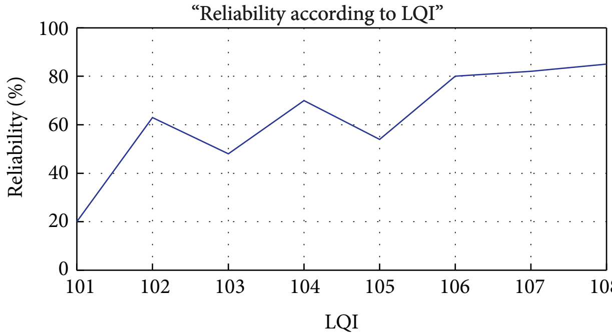

Figure 4: Reliability according to LQI in all three paths.

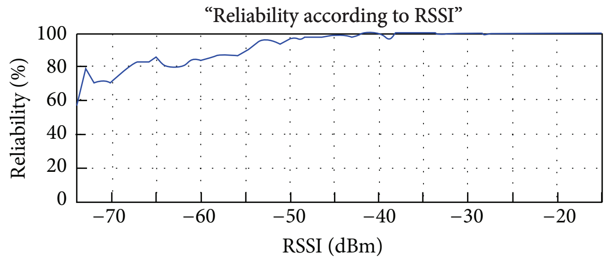

Figure 5: Reliability according to RSSI in all three paths.

$$N = \frac{\mathrm{RSSI} - A}{-10\log 10\,(sd + 1)}. \quad (8)$$

3.4. Reliability according to RSSI and LQI. Figures 4 and 5 show the reliability of the RSSI and LQI from all testbeds done to determine the LQI and RSSI reliability values. In Figure 4, it was found that LQI gave the best performance when the value was 108 in about 2-meter distances; then it showed 80% reliability. The results show that when the value was 100, it gave the lowest performance at about 8 meters. Since the measurement testbed was 10 meters, it was decided to determine the value below 10 meters. So, it was determined to make the reliability curve from 100 to 108 for LQI, with the reliability varying from 20% to 80%.

Figure 5 shows that RSSI gave its best performance when the value was −15 at about 0 meter and at that distance it gave 100% reliability. It was also found that when its value was −75, it gave its lowest performance at about 5 meters. So, the reliability curve for RSSI seemed to be between −15 and −75, where the reliability varied from 50% to 100%.

To find the proper RSSI threshold value, all the measured RSSI values were averaged; then that average RSSI value was set as an RSSI threshold value to filter the raw RSSI more smoothly. After determining the specific RSSI threshold value, it was decided to find a reliable LQI value for filtering process. The LQI threshold value was used to find the reliable LQI value.

After applying the filter, the program analyzed the behavior of the filtered signal strengths over distance. Based on that analysis, this study decided that the advanced fusion filter and improved fusion filter's filtering values performed better than the RSSI filter, the LQI filter, and the fusion filter.

3.5. Advanced Fusion Filter. The advanced fusion filter, which eliminates noises by using both LQI and RSSI filters, is illustrated in Figure 6. The noises of the obtained rough RSSI signals were primarily eliminated by the LQI filter as in (11), and these first resulting values were used as the input values to the RSSI filter. The second set of resulting values, showing the noises which were secondarily eliminated by the RSSI filter as in (12), were the final output of the advanced fusion filter. Similarly, the advanced fusion filter reduced the noise level by performing two filtering processes:

if (Present_LQI < $\mathrm{LQI}_{\mathrm{Threshold}}$)

$\alpha = 0$

else

$$\alpha = 0.8 - 0.6 \times \frac{108 - \mathrm{LQI}}{8},$$

$$\mathrm{RSSI}_{(\mathrm{smooth\_LQI})} = a \times \mathrm{RSSI}_n + (1-a) \times \mathrm{RSSI}_{n-1} \quad (9)$$

if ($\mathrm{RSSI}_{(\mathrm{smooth\_LQI})} < \mathrm{RSSI}_{\mathrm{Threshold}}$)

$\alpha = 0.1$

else

$$\alpha = 1 - 0.5 \times \frac{-15 - \mathrm{RSSI}}{60}, \quad (10)$$

$$\mathrm{RSSI}_{(\mathrm{smooth\_AF})} = a \times \mathrm{RSSI}_{(\mathrm{smooth\_LQI})} + (1-a) \times \mathrm{RSSI}_{n-1}. \quad (11)$$

3.6. Improved Fusion Filter. In order to improve the techniques described above, this study proposed another filtering method to reduce the range errors by effectively eliminating the noises in the rough RSSI signals. This research proposed the improved fusionfilter (IFF) that is more effective when compared with the previously mentioned LQI, RSSI, and fusion filters, as expressed as (14). In the proposed IFF using the feedback filter in which the determination of α values is a key, the α values are determined by using an exponential function to effectively reduce noises acquired from RSSI:

if (Present_RSSI < $\mathrm{RSSI}_{\mathrm{Threshold}}$) | (Present_LQI < $\mathrm{LQI}_{\mathrm{Threshold}}$)

$\alpha = 1 - 0.5 \times (-15 - \mathrm{RSSI}/60)$

else

$$\alpha = 0.8 - 0.6 \times \frac{108 - \mathrm{LQI}}{8}$$

$$\mathrm{RSSI}_{(\mathrm{smooth\_IF})} = a \times \mathrm{RSSI}_n + (1-a) \times \mathrm{RSSI}_{(\mathrm{smooth\_}n-1)}. \quad (12)$$

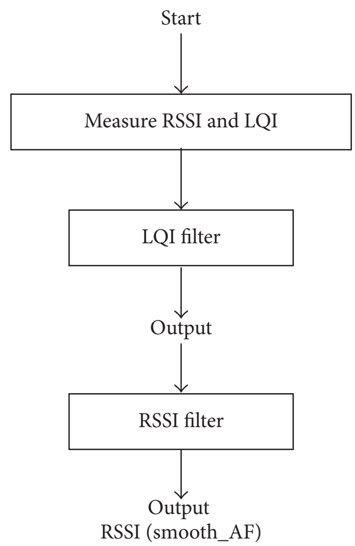

Figure 6: Filtering process of the advanced fusion filter.

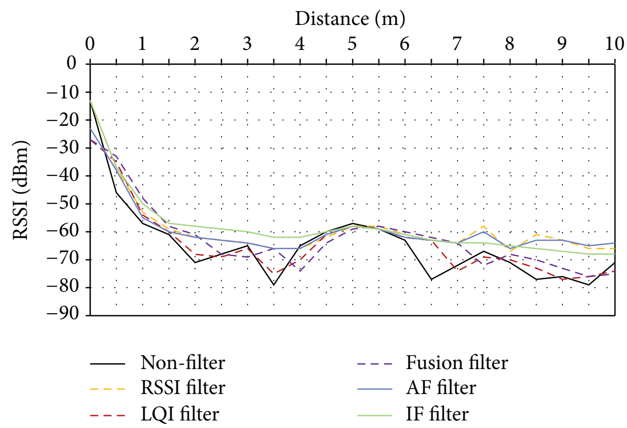

Figure 7: Smoothed RSSI values using all filters for open space environment.

This scheme intends, with respect to signal analysis, to filter the original signals in order to remove the noise. Sudden peaks and gaps in the signal strength are removed and the whole signal is smoothed, which eases the analysis process.

After applying the filter, the program analyzed the behavior of the filtered signal strengths over distance. Based on this analysis, this study decided that advanced fusion filter and improved fusion filter's filtering values perform better than RSSI filter, LQI filter, and fusion filter's filtering. Figures 7, 8, and 9 provide the results.

4. Experimental Performance

To verify the AFF and IFF performance for eliminating noise components, experiments were conducted in three locations of different spatial structures. The proposed AFF and IFF, which provided the different weights using the feedback filter with an exponential function, improved the noise elimination performance when compared with the existing LQI, RSSI,

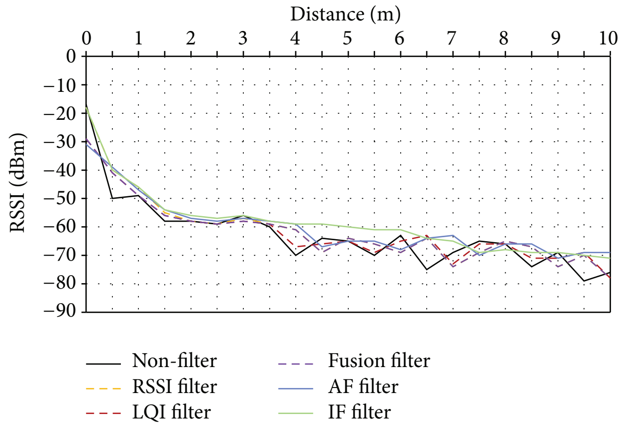

Figure 8: Smoothed RSSI values using all filters for half-open and half-closed space environment.

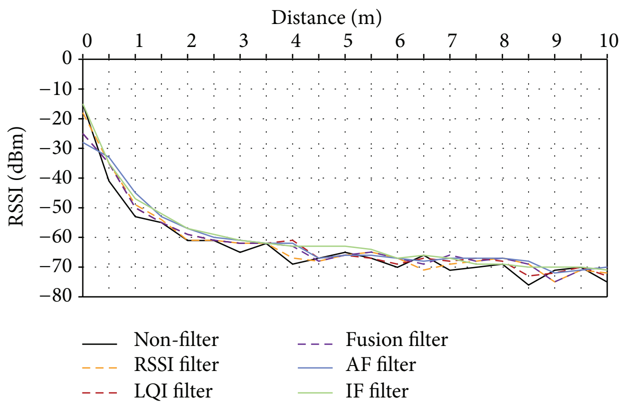

Figure 9: Smoothed RSSI values using all filters for closed space environment.

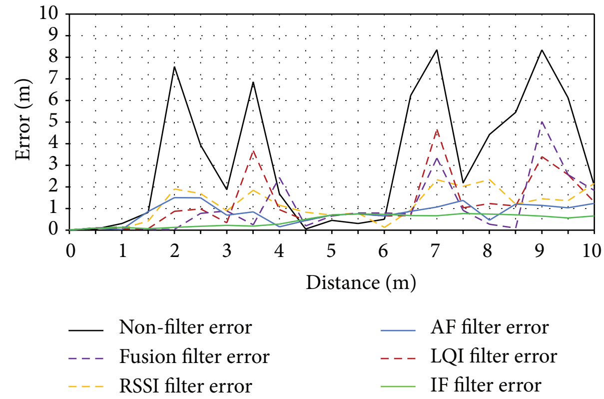

Figure 10: Performance results of various filters in open space environment.

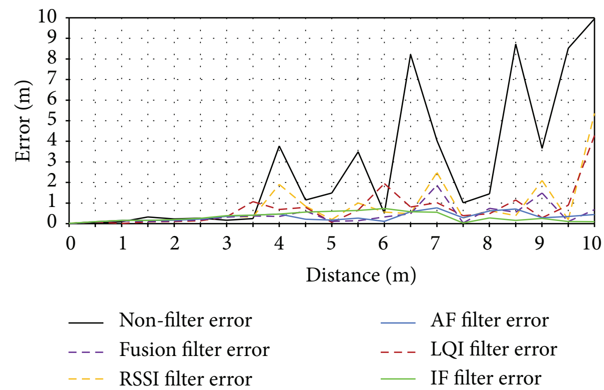

Figure 11: Performance results of various filters in half-open and half-closed space environment.

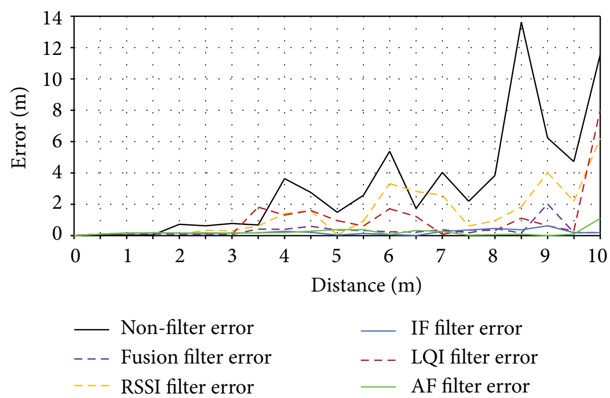

Figure 12: Performance results of various filters in closed space environment.

and fusion filters. Figure 9 compares the proposed AFF and IFF performance and those of the existing three filters, representing the errors in the estimated distances using the RSSI obtained according to the actual distances between the two nodes. Figure 11 shows results from the half-open section indoor environment; the noise levels appeared to rapidly increase because the stairs are located 5-6 m from the starting point. In that situation, the proposed AFF and IFF effectively reduced the noise levels. Similarly, as shown in Figures 10 and 12, it was verified that the AFF and IFF definitely reduced the noise level at the points where the noise levels rapidly increased. This implies that because the AFF and IFF have excellent noise elimination performance when estimating the range using the RSSI, they can be beneficially used as a preprocessing step in the indoor localization.

4.1. Performance Checking Using Median Filter and Savitzky-Golay Filter. To measure the performance of the proposed AFF and IFF filters compared with other standard filters, this study applied the median filter and Savitzky-Golay filter to the original signal. Median filters are nonlinear rank-order filters based on replacing each element of the source vector with the median value, taking over the fixed neighborhood (mask) of the processed element. These filters are extensively used in image and signal processing applications. Median filtering removes impulsive noise while keeping the signal blurring to a minimum. Even though it is well known that median filtering is useful for reducing random noise (especially when the noise amplitude probability density has large tails)

Table 1: Improvement rate comparison of the proposed AFF, IFF, and other filters.

Path	Filter name	Avg. error	Improvement rate	Max. error	Improvement rate
Open space environment	Non-filter	3.2168	0%	13.6349	0%
	RSSI filter	1.1592	63%	6.2049	54%
	LQI filter	1.2175	62%	8.0311	41%
	Fusion filter	1.0416	67%	2.0268	85%
	AF filter	0.7918	75%	1.0952	91%
	IF filter	0.4469	86%	0.6250	95%
	Median filter	1.7143	46%	9.0129	33%
	S-G filter	1.9075	40%	7.0286	48%
Half-open and half-closed space environment	Non-filter	2.7283	0%	9.9492	0%
	RSSI filter	0.8418	69%	5.3554	46%
	LQI filter	0.7255	73%	4.2761	57%
	Fusion filter	0.4177	84%	1.8660	81%
	AF filter	0.3236	88%	0.7662	92%
	IF filter	0.3189	88%	0.7304	93%
	Median filter	1.1429	58%	6.5971	34%
	S-G filter	1.6741	38%	5.6286	43%
Closed space environment	Non-filter	3.1803	0%	8.3472	0%
	RSSI filter	1.4412	55%	2.3432	71%
	LQI filter	0.9855	69%	4.6660	44%
	Fusion filter	0.3214	87%	5.0215	40%
	AF filter	0.2115	93%	1.5028	81%
	IF filter	0.2045	94%	0.7640	90%
	Median filter	1.1429	64%	5	41%
	S-G filter	1.1592	63%	2.8286	66%

and periodic patterns, theoretical results on its behavior are nonexistent in the literature [22]. The output of the median filter in the window centered at i is obtained by using the following equation:

$$Y_i = \text{Median}\left\{X_{i-M}, \ldots, X_{i-1}, X_{i+1}, \ldots, X_{i+M}\right\}. \tag{13}$$

Savitzky-Golay filters are a least-square smoothing filter which is based on least square polynomial approximation. Savitzky and Golay were interested in smoothing noisy data obtained from chemical spectrum analyzers, and they demonstrated that least square smoothing reduced noise while maintaining the shape and height of waveform peaks. In the Savitzky-Golay approach, each successive subset of $(2m+1)$ points is fitted by a polynomial of degree p $(p \le 2m)$ in the least-square sense. The dth $(0 \le d \le P)$ differentiation (zeroth differentiation = smoothing) of the original data at the midpoint is obtained by performing the differentiation on the fitted polynomial rather than on the original data. Finally, the running least-square polynomial fitting can be simply and automatically performed by convolving the entire input data with a digital filter of length $(2m + 1)$. The convolution coefficients can be obtained for all data points, all polynomial degrees, and all differentiation orders but with only an odd number of data sets [22]. The general filter equation of Savitzky-Golay filter is given by Press et al. [23]:

$$g_i = \sum_{n=-n_L}^{n_R} c_n f_i + n, \tag{14}$$

where g_i is the output of the Savitzky-Golay filter; n_L and n_R are the number of points used to the left and the right of the data point, respectively.

4.2. Improvement Rate of Average and Maximum Distance Error. For a detailed performance comparison, the average errors of respective filters and the improved rates of the filters versus no filter are listed in Table 1. It was verified that the proposed AFF and IFF, fusion, RSSI, and LQI filters were sequentially excellent in the noise elimination performance in three paths. The AFF and IFF effectively reduced the maximum error size as well as the average error size; particularly in Path 1 going up the stairs, AFF and IFF improved the performance by 94% and 93% in the average error and 94% and 90% in the maximum error, respectively. This verified that the AFF and IFF can be used more effectively in poor environments such as Path 1, which has possibly the most severe radio-wave disturbances among

Table 2: Cross-correlation comparison of the proposed AFF, IFF, and other filters.

Path	Filter name	Cross-correlation	Dissimilarity rate
Open space environment	RSSI filter	0.9246	7.54%
	LQI filter	0.8549	14.5%
	Fusion filter	0.9263	7.37%
	AF filter	0.9149	8.51%
	IF filter	0.9411	5.89%
	Median filter	0.9093	9.07%
	S-G filter	0.9323	6.77%
Half-open and half-closed space environment	RSSI filter	0.9209	7.91%
	LQI filter	0.9251	7.49%
	Fusion filter	0.8810	11.9%
	AF filter	0.8930	10.7%
	IF filter	0.9468	5.32%
	Median filter	0.9286	7.14%
	S-G filter	0.9296	7.04%
Closed space environment	RSSI filter	0.9769	2.31%
	LQI filter	0.9415	5.85%
	Fusion filter	0.9789	2.11%
	AF filter	0.9611	3.89%
	IF filter	0.9853	1.47%
	Median filter	0.9801	1.99%
	S-G filter	0.9145	8.55%

the three paths because of the inclined stairs and irregular left and right sections.

The average reduction of average distance error obtained by using the AFF and IFF filter was 85% and 89%, respectively. The average reduction of maximum distance error deduced by using the AFF and IFF filter was 89% and 91%, respectively.

4.3. Dissimilarity Rate Using Cross-Correlation. For more detailed performance comparison, cross-correlation technique between nonfiltered signal and filtered signal was studied. In signal processing, cross-correlation is a measure of similarity of two waveforms. Observing the level of correlation between the variations in the measured and reference signals enables the user to detect change in the signal. The cross-correlation between the newly fetched data with the reference data gave a coefficient value which informed the operator about the change or irregularities numerically. The coefficient value ranking from 0 to 1 can quantify the linear correlation between two signals, and the lower coefficient value can be an indicator of a change in the signal.

In probability theory and statistics, correlation is always used to include a standardizing factor in such a way that correlations have values between −1 and +1, and the term cross-correlation is used for referring to the correlation $\mathrm{corr}(X, Y)$ between two random variables X and Y, while the "correlation" of a random vector X is considered to be the correlation matrix (matrix of correlations) between the scalar elements of X.

Although the error reduction of AF filter and IF filter was better than other existing filters, Table 2 shows that the dissimilarity signal rate between nonfiltered values and IF filtered values was lower than other filters; this means an AF filter reduced error from the rough RSSI value but also lost some data. An IF filter reduced the error from the measured RSSI value as well as matched with the measured RSSI signal.

Table 2 shows that the dissimilarity rates of IF filter were the least among all the filters tested. The performance of the IF filter was stable in each path, but with other filters, the performance varied on different paths.

From the above discussion, it is clear that these new enhancement techniques give a significantly improved performance over other existing techniques.

5. Conclusion

Technology is developing rapidly and the increasing use of Internet is connecting people. There have been many forms of connections in cyberspace such as wired connection, wireless network, structured network, and ad hoc network. Life would be very different without any form of communication. Certainly security is a great concern in such beneficial technology. Security measures that provide confidentiality and integrity have been taken into account in the design of such technology. This work investigated the use of RF location systems for indoor domestic applications. Based on the assumption that low cost and minimal infrastructure are important for consumers, the concept of RF location system for integrated indoor location using RSSI and LQI provided by ZigBee module was introduced.

This study proposed an effective way of eliminating (deleted the) noises by using the RSSI, AF, and IF; different exponential weights were provided to the current value and the previous averaged value when measuring the range between the two nodes to identify the locations of objects in the indoor environment. To verify the proposed filter performance, experiments were conducted in three different paths, and the noise elimination performance was improved in all the paths. The proposed technique is flexible and can be applied in various wireless communications such as Wi-Fi, UWB, and RFID as well as ZigBee based on IEEE 802.15.4. The results imply that the AF and IF can be used as a preprocessing step that exhibits excellent noise elimination performance in various indoor LBSs using the RSSI and LQI. The experiment results showed that the proposed mathematical method can reduce the average error around 89%, and it is better than the other existing interference avoidance algorithms. As the speed of the moving object increased, the results showed that the error rate slightly increased, as expected. This technique has been found to work well in instances modeled on real world usage, thereby minimizing the effect of the error. The findings from this study would be helpful to design and implement a real-time location tracking system in indoor environment.

Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

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