

D2D Distance Measurement using Kalman Filter Algorithm for Distance-based Service in an Office Environment

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Abstract— The device-to-device (D2D) distance-based service is affected by distance between the D2D devices. Thus, the wireless distance measurement between devices is an indispensable technology in D2D applications. When mobile devices use the distance between D2D devices in the D2D application, the distance should be measured easily and accurately. Several methods can be used to measure the distance between D2D devices. The RSSI system can be used to estimate the D2D distance easily and inexpensively because most D2D devices can estimate the received signal strength. However, estimating the distance using a RSSI is difficult due to inaccuracies. We tested the relationship between distance and a Bluetooth RSSI to look into the inaccuracy of the RSSI in an office environment. Through the results of this test, we realize that the D2D distance is hard to be classified due to the inaccuracy of Bluetooth RSSI. Therefore, filtering algorithm should be applied to reduce the inaccuracy of the Bluetooth RSSI. Nowadays, Kalman filter is widely used in many research fields and shows good performance. Thus, we use the Kalman filter to increase the accuracy of Bluetooth RSSI. To evaluate the effectiveness of the Kalman filter algorithm, we tested the D2D distance measurement in an office environment. The result of this test indicates that the Kalman filter reduces the inaccuracy of Bluetooth RSSI significantly. In addition, we describe wireless body area network (WBAN) region classification using Bluetooth RSSI and Kalman filter in an office environment.

Keywords— Device to Device (D2D), Distance, Kalman filter, Wireless signal, Wireless personal area network

I. INTRODUCTION

The distance based service means that the service is dependent with distance between devices. For example, the devices nearby from a user device are classified to several regions according to the distance from the user device. The Near field communication (NFC) region is about within 20 cm, WBAN region is about within 1~2 m, WPAN region is about within 10 m, and WLAN region is about within 100 m. For each region, different services can be applied. The privacy service can be activated between D2D devices in NFC and WBAN regions, the group service can be activated between D2D devices in WPAN region, and the public service can be activated between D2D devices in WLAN region. To support

distance-based services between D2D devices, the distance between D2D devices should be estimated easily and accurately.



Figure 1. D2D distance for distance-based service.

Several methods, such as the received signal strength indication (RSSI), time of arrival (ToA) [1], and time difference of arrival (TDoA) [2]-[5], can be used to estimate the distance between D2D devices. The ToA system needs precisely synchronized devices and the TDoA system needs extra hardware increasing the cost. An RSSI can be used to estimate the distance between D2D devices using the received signal strength from another device easily and inexpensively [6]-[8]. However, it is hard to measure the distance using an RSSI because of noises, obstacles [9]. The distance estimation using this method may therefore incur inaccuracies. Nevertheless, RSSI can become the most used technology of distance estimation due to its low cost [10]. These reasons, we propose the D2D distance measurement using Kalman filter algorithm to reduce the inaccuracy of the distance estimation using the RSSI. Using the Kalman filter algorithm, the distance measurement accuracy between D2D devices is increased significantly.

The outline of this paper is as follows. Section II we describe Kalman filter algorithm for the D2D distance measurement, and the experimental results are then provided in section III. Finally, some concluding remarks are given in section IV.

II. KALMAN FILTER ALGORITHM FOR D2D DISTANCE MEASUREMENT

The Bluetooth RSSI is used to measure the D2D distance because it is widely used in a lot of mobile devices nowadays. To see the inaccuracy of Bluetooth RSSI, we tested the relationship between D2D distance and Bluetooth RSSI in an office environment.

A. Relationship between D2D Distance and Bluetooth RSSI

A tablet PC was used to measure the Bluetooth RSSI from a notebook PC in an office environment. It measured 200 samples at 3m apart from the notebook PC. The result of this test is shown Fig. 2. The average RSSI values from 0 to 6m are -60.59, -60.83, -67.09, -76.77, -70.18, -73.82, and -76.2 dBm, respectively. The standard deviation (SD) values are 3.48, 1.64, 4.92, 5.64, 4.46, 3.9, and 4.32 dBm, respectively. The measurement range (MR) values, which are the difference between maximum and minimum value at each distance, are 20, 11, 26, 28, 22, 20, and 24 dBm. The mean values of the standard deviation and measurement range are 4.05 and 21.57 dBm, respectively. As shown the result, it is hard to classify the D2D distance between devices when RSSI raw data is used. Thus, for classifying the D2D distance, the filtering algorithm should be used to reduce the measurement error.

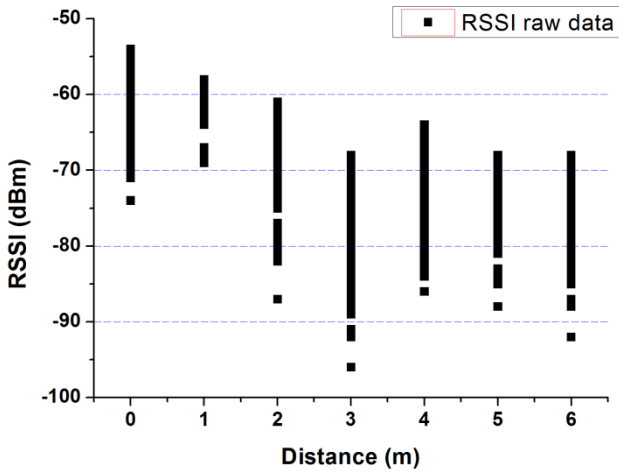


Figure 2. The relationship between D2D distance and Bluetooth RSSI in an office environment.

B. Kalman Filter Algorithm

The Kalman filter addresses the general problem of trying to estimate the state of a discrete-time controlled process that is governed by the linear stochastic difference equation. The process model and measurement model is shown in (1) and (2), respectively.

$$x_{k+1} = Ax_k + w_k \quad (1)$$

$$z_k = Hx_k + v_k \quad (2)$$

where w_k is the process noise and v_k is the measurement noise.

They are assumed to be independent, white, and with normal probability distributions as shown below.

$$p(w) \sim N(0, Q)$$

$$p(v) \sim N(0, R)$$

The Kalman filter algorithm is shown in Fig. 3. The state and the error covariance project ahead in step 1 and step 2, respectively. The Kalman gain is computed in step 3. The estimation value ($\hat{x}_k$) is updated with the measurement value (z_k) in step 4. Finally, the error covariance is updated in step 5.

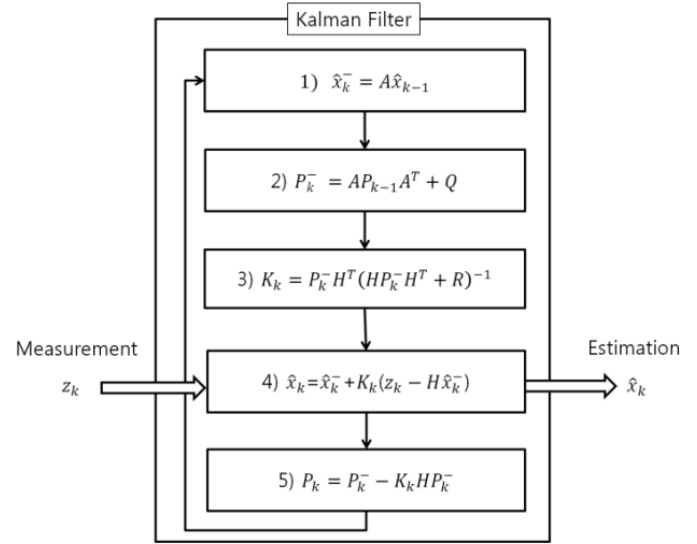


Figure 3. The Kalman filter algorithm

The error covariance and the Kalman gain are big when Q value is big as seen the step 2 and step 3 in Fig. 3. Therefore, if Q value is big, the estimation value is more affected by the measurement value. The Kalman gain is small when R value is big as seen the step 3 in Fig. 3. Therefore, if R value is big, the estimation value is less affected by the measurement value. The bigger R value and the smaller Q value, the less affected the estimation value by the measurement value.

III. EXPERIMENTAL RESULTS

To see the effectiveness of Kalman filter algorithm, we compared the Bluetooth RSSI at 2 m in an office environment. As shown in Fig. 4, the RSSI deviation is too large when the raw Bluetooth RSSI data are used. The measurement range value is 26 dBm. The average RSSI is -67.09 dBm and the standard deviation is 4.92 dBm. When the Kalman filter algorithm is used, the minimum RSSI value and maximum RSSI value are -72.8 dBm and -63.5 dBm, respectively. The measurement range value, 9.3 dBm, is reduced significantly. The average RSSI is -67.06 dBm and the standard deviation is 1.42 dBm. The measurement range value and the standard deviation of the Kalman filter data are 16.7 dBm and 3.5 dBm smaller than those of the raw RSSI data, respectively.

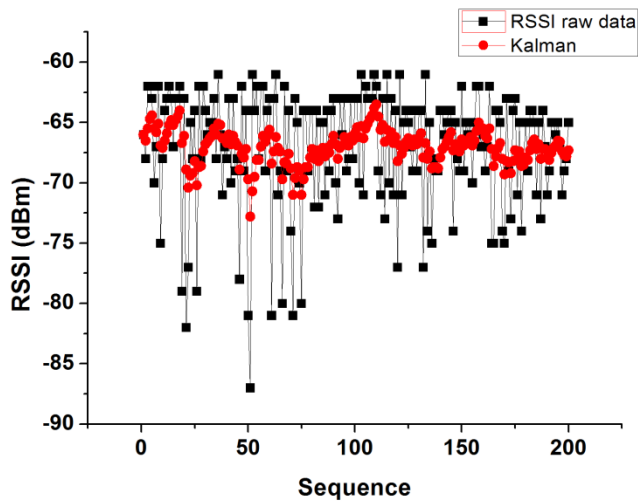


Figure 4. Raw Bluetooth RSSI data and Kalman filter data at 2 m in an office environment.

The results of Kalman filter data are compared with those of raw RSSI data at all distances, from 0 to 6 m, in the office environment as shown in Fig 5. The average RSSI values from 0 to 6 m are -60.72, -60.83, -67.06, -76.66, -70.2, -73.86, and -76.27 dBm, respectively. The standard deviation values from 0 to 6 m are 1.73, 0.48, 1.42, 2.77, 1.66, 1.41, and 1.64 dBm, respectively. The measurement range values are 8.1, 2.3, 9.3, 12.6, 8.2, 7.3, and 10.2 dBm. The mean values of the standard deviation and measurement range are 1.64 and 8.29 dBm, respectively.

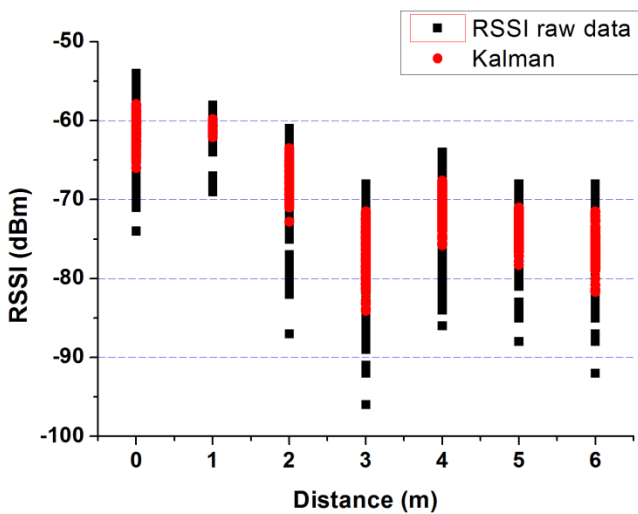


Figure 5. Measurement range comparison in an office environment.

At each distance, the standard deviation and measurement range are reduced when the Kalman filter algorithm is used as shown Table I. The reduced standard deviation values from 0 to 6 m are 1.75, 1.16, 3.5, 2.87, 2.8, 2.49, and 2.68 dBm, respectively. The reduced measurement range values are 11.9, 8.7, 16.7, 15.4, 13.8, 12.7, and 13.8 dBm. The reduced average values of the standard deviation and measurement range are 2.46 and 13.3 dBm, respectively.

TABLE 1. THE RESULT COMPARISON BETWEEN RAW RSSI AND KALMAN FILTER DATA

Distance (m)	Raw RSSI (dBm)		Kalman Filter (dBm)		Reduced Value (dBm)	
	SD	MR	SD	MR	SD	MR
0	3.48	20	1.73	8.1	1.75	11.9
1	1.64	11	0.48	2.3	1.16	8.7
2	4.92	26	1.42	9.3	3.5	16.7
3	5.64	28	2.77	12.6	2.87	15.4
4	4.46	22	1.66	8.2	2.8	13.8
5	3.90	20	1.41	7.3	2.49	12.7
6	4.32	24	1.64	10.2	2.68	13.8
Average	4.05	21.6	1.59	8.3	2.46	13.3

From these results, it is proven that the measurement errors from RSSI are reduced about 50% using the Kalman filter algorithm.

There is a partition between 1 and 2 m from notebook PC. Therefore, the WBAN region is 1 m from the notebook PC in this environment. There is an overlap region, 13dBm, between WBAN area and outside of WBAN area when raw RSSI data is used. Thus, it is hard to classify WBAN region using the raw RSSI data. However, there is a small overlap region, 2.5dBm, between WBAN area and outside of WBAN area when the Kalman filter data is used. Therefore, When the Kalman filter algorithm is used to estimate distance between D2D devices, the WBAN region can be classified more clearly.

IV. CONCLUSION

The RSSI system can be used to estimate the D2D distance easily and inexpensively because most D2D devices can estimate the received signal strength. However, estimating the distance using a RSSI is difficult due to inaccuracies. Through the relationship test between distance and the Bluetooth RSSI, we realize that the D2D distance is hard to be classified due to the inaccuracy of Bluetooth RSSI. Therefore, filtering algorithm should be applied to reduce the inaccuracy of the Bluetooth RSSI. Therefore, this paper described a Kalman filter algorithm using Bluetooth RSSI for distance-based service between D2D devices.

To evaluate the effectiveness of the Kalman filter algorithm, we tested the D2D distance measurement in an office environment. The results of this test indicate that the Kalman filter reduces the inaccuracy of Bluetooth RSSI significantly. That is, the reduced average values of the standard deviation and measurement range are 2.46 and 13.3 dBm, respectively. Therefore, when the Kalman filter algorithm is used to estimate distance between D2D devices in an office environment, the WBAN region can be classified more clearly.

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