A Novel Distance Estimation Algorithm for Bluetooth Devices Using RSSI

Junhua Huang, Song Chai*, Nan Yang and Liang Liu

The fourth part of the ring road No.16, Wuhou District, Chengdu, Sichuan, China
*Corresponding author

Abstract—**A lot of proximity related Bluetooth applications, such as Bluetooth indoor positioning/navigation and proximity detection, has emerged on market by using Received Signal Strength Index(RSSI). One of the key technology in these application is to estimate distance between Bluetooth devices. In this paper, a distance estimation algorithm is proposed for Bluetooth devices. The RSSI values are first processed using median filter, and then converted to distance values. Finally, Kalman filtering is applied to further reduce noise. Our experiments show that our algorithm has average accuracy of 0.1~0.4m.**

Keywords-bluetooth, distance estimation; RSSI, median filter; Kalman fitler

I. INTRODUCTION

In recent years, Bluetooth Low Energy(LE) has being widely used in short-range wireless communication[1]. Bluetooth LE allows designers to inquire Received Signal Strength Index (RSSI), which indicates radio signal power level received by antenna[2], and it enables a blooming market of proximity related application, such as indoor positioning[3], indoor navigation[4], indoor tracking[5], proximity detection[6] and so on.

The key problem in such proximity related Bluetooth applications is to calculated distance between Bluetooth devices, known as distance estimation[7], and most distance estimation algorithm for Bluetooth devices are implemented based on RSSI.

In our paper, a novel distance estimation algorithm is proposed for Bluetooth device. First, the received RSSI values are filtered using median filter to eliminate any outliers. Then the processed RSSI are converted to distance values. Finally, further noise reduction is performed by applying Kalman filter.

The rest of this paper is organized as follow: Section 2 discuss some related work in proximity based Bluetooth applications; our algorithm is proposed in Section 3; Section 4 shows the experiment results; Section 5 concludes the paper.

II. RELATED WORK

By inquiring RSSI in Bluetooth LE, various proximity related Bluetooth applications are proposed in recent years. An indoor positioning system is proposed in [3], which uses Euclidean distance correction algorithm to calibrate distance estimation. In [4], a positioning and navigation system is proposed for indoor scenario using Bluetooth devices. The location of Bluetooth device is determined by calculating distance between current device and surrounding Bluetooth devices, and navigation is implemented using grid following

method. A Bluetooth pedestrian indoor tracking system is proposed in [5]. The system uses Bayesian filter to predict further movement, and results in an 80cm accuracy.

III. PROPOSED ALGORITHM

A. Median Filter

RSSI received by Bluetooth device is corrupted due to severely multipath fading in indoor scenario[8], shown as blue line in Figure 1. Most RSSI values lie between -65 dB and -68dB with some outlier falling below -72dB. Thus these outliers must be removed before further process.
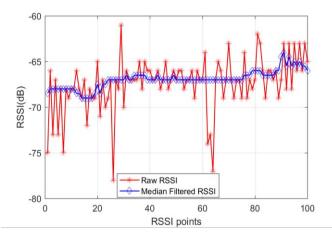

FIGURE I. RAW RSSI MEASURED AT 1M DISTANCE AND MEDIAN FILTERED RSSI

RSSI outliers are removed by using median filter [9] in our algorithm. Ten most recent RSSI values are collected as RSSI_raw, and sorted as RSSI_sorted. The

$$[RSSI\_sorted(5) + RSSI\_sorted(6)] \div 2$$

, namely median of RSSI_sorted, is rendered for future process, noted as RSSI_median. The result of median filtering is shown as blue line in Figure 1.

B. Distance Calculation

RSSI_median is then converted to distance value. During the conversion, the RSSI measured in 1m distance, known as the reference RSSI[10] (RSSI_refer), is needed. Then the distance is calculated using Equation 1, which is obtained by first measuring RSSI in varies distance, and then fitting the data into the experience formula.

$$distance = \begin{cases} 1.37 \times (\dfrac{RSSI\_median}{RSSI\_refer})^{6.854} - 0.372, RSSI\_median > RSSI\_refer \\ 0.979 \times (\dfrac{RSSI\_median}{RSSI\_refer})^{7.489} + 0.183, RSSI\_median > RSSI\_refer \end{cases}$$

$$(1)$$

C. Kalman Filtering

To further reduce noise in calculated distance in previous section, Kalman filter is applied to increase the accuracy of estimated distance[11]. The flow of Kalman filter is shown in Figure 2.

Initial A, H, r, p, q and d;

WHILE True DO

    Input $dist$;

    $d = A \times d$;

    $p = A \times A \times p + q$;

    $gain = \dfrac{p \times H}{p \times H \times H + r}$;

    $p = (1 - gain \times H) \times p$;
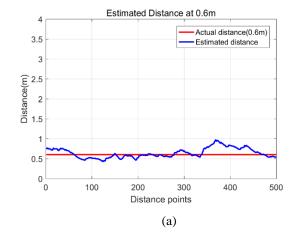
    $d = d + gain \times (dist - H \times d)$;
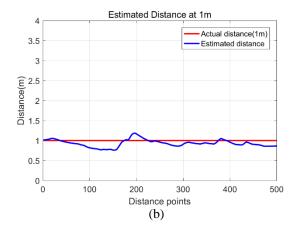
    Output d;

END WHILE
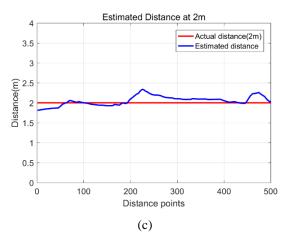

FIGURE II. FLOW OF KALMAN FILTER

IV. EXPERIMENT AND RESULT

In our experiment, the distance between two Bluetooth devices, which both are Texas Instrument CC2541 Development Board, is evaluated using our distance estimation algorithm. A new RSSI is observed every 0.1s, and the distance between two devices is evaluated every 0.1s too.

Figure 3 (a)~(d) shows the stationary distance estimation of 0.6m, 1m, 2m and 3m respectively. As observed in these figures, our algorithm has a solid performance within 2m distance, with average error of 0.1m. When increasing distance to 3m, as shown in Figure 3(d), the average error boost to 0.41m.
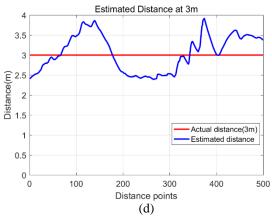

(a)

(b)

(c)

(d)

FIGURE III. STATIONARY RESULTS

Figure 4 shows the results of dynamic scenario, in which two Bluetooth devices moves away from 2m to 5m, and then move together from 5m to 2m with constant velocity. In figure 4, red line represents the actual distance and blue line is the estimated distance. As observed in this figure, estimated distance always follows actual distance with a lag of 5 points (0.5s), which is introduced in the median filtering stage.
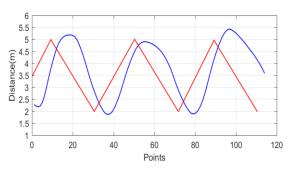
FIGURE IV. RESULTS OF DYNAMIC SCENARIO

V. Conclusion

A distance estimation algorithm is proposed for Bluetooth devices in this paper. The algorithm first uses median filter to remove RSSI outliers, and then converts RSSI to distance values. Finally, Kalman filtering is applied to further reduce noise. Experiment results show that our algorithm has average accuracy of 0.1~0.4m.

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