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A Bluetooth Location-based Indoor Positioning System for Asset Tracking in Warehouse

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Abstract - **In recent year, with the development of mobile device and wireless communication, the concept of Internet of things (IoT) emerges and extensive research and development of IoT application enables the real-time indoor localization for asset tracking through wireless sensor network. Many studies have focused on the positioning technology using Global Positioning System (GPS), Radio Frequency Identification (RFID) and ZigBee, but little attention has been paid on the industrial application of low-cost Bluetooth location-based indoor positioning system in asset localization. In this paper, a Bluetooth location-based indoor positioning system is proposed for warehouse asset tracking purpose to achieve a cost-effective asset management solution.**

Keywords – **Positioning technology, Bluetooth Low Energy Beacons, Asset tracking, Asset management, Internet of things**

I. INTRODUCTION

Asset management, especially in the area of warehouse asset tracking, has always been an important issue for manufacturing industry for many years. Manufacturing processes usually proceed with indoor environment and involved tons of assets which are stored in the buildings. However, traditional asset management relies on manual records that are not updated in real-time basis. Nowadays, Internet of things (IoT) drives innovations and development on building interconnection between objects to allow real-time information exchange of these objects through context-centric wireless network. The ubiquitous communication network connecting tiny sensors and mobile devices contribute to a wide spread of application in different domains [1]. Therefore, asset management integrated with IoT network provides real-time localization which can avoid unnecessary human effort to locate the asset and benefit to manufacturing industry.

Typical localization approaches such as Radio Frequency Identification (RFID), Global Positioning System (GPS) and ZigBee are commonly used in estimating information of object distance and have different limitations in applications. Beacon is a tiny device with a simpler infrastructure that supports Bluetooth Low Energy (BLE) which provides higher precision of location information for indoor positioning and lower power consumption compared to GPS [2] and ZigBee [3] respectively. However, many studies have focused on positioning technology using GPS, RFID and ZigBee rather than the industrial application of this kind of low-Bluetooth location based indoor positioning system for asset management.

Bluetooth technology was originally designed as an inexpensive wireless communication to facilitate data exchange for different classes of portable devices [4]. There are mainly four types of Bluetooth parameters that are related to signal strength for localization purpose including Received Signal Strength Indicator (RSSI), Link Quality Indicator (LQI), TX power level and RX power level. RSSI-based positioning algorithm is widely adopted for indoor localization because it does not require active connection [5] and its positioning algorithms is based on the Power Law Model [6]. It is also suggested to use a fusion approach of RSSI and LQI for localization in indoor environment with 25% increase in accuracy [7]. RSSI values can be influenced by multipath effect and the fading effect in the indoor environment. Therefore, Signal filters are usually applied in data processing stage to reduce the noise and minimize the error of RSSI measurement.

To explore a cost-effective asset management solution, this project aims to study and develop a Bluetooth location based system for real-time asset localization in the view of accuracy and cost-effective aspect. In order to facilitate system design improvement, factors such as interference from environment, topology and TX power which have significant impact on the accuracy of RSSI measurement are highlighted in this paper. This study also aims to investigate and propose the effective filtering algorithm for the proposed system to reduce the variation of RSSI values. Thus, higher accuracy in distance estimation from Beacons to receiver can be achieved. Besides, the topology of reference nodes required for positioning is also studied because the system relies heavily on the Beacons with known coordinates. Furthermore, metal attenuation effect and the effect of multiple Beacons at nearby location are also studied.

II. METHODOLOGY

A. *System Framework*

The proposed Bluetooth location-based indoor positioning system which consists of different component including the Beacons, Bluetooth signal receiver, data processing unit, software, Wi-Fi-network, database and the application is illustrated in Fig. 1. Beacons are placed on the target object and broadcast the Bluetooth signal. The BLE module on Raspberry Pi 3 model acts as the Bluetooth signal receiver and receive the data packet. Compared to other programming languages like C++ and Java, Python was chosen due to its simple syntax and highly compatibility with Raspberry Pi under Linux environment to reduce the time for program development. The Python program in Raspberry Pi decodes the data in binary format to hex format. Raspberry Pi identifies the target beacon by Universally Unique Identifier (UUID) and generates the RSSI values for further determination for distance. RSSI values are stored in the memory card in the Raspberry Pi and sent to the database via Wi-Fi network. The application retrieves the RSSI values from the database and convert to distance. After obtaining the estimated object distance from the Raspberry Pi in the four corners, the co-ordinates of the target object can be estimated by trilateration method. Raspberry Pi can be remote accessed from other computer on the same local network via the Secure Shell (SSH) and share file by installing samba web server.

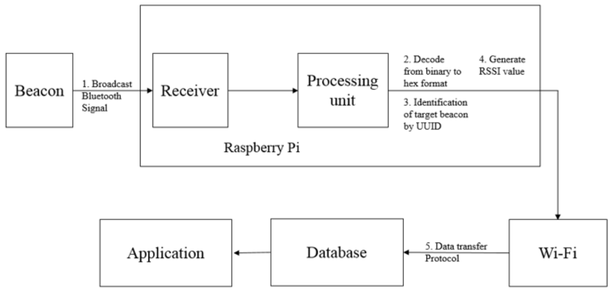

Fig.1. System Framework of the proposed Indoor Positioning System

Python version 3.4 is used with the installation of Bluez 5.23 and PyBluez 0.22 for Bluetooth signal scanning under Linux environment. Calibration for Python program was carried out to adjust the parameter and ensure the efficiency of each scan. Number of received data, name of device, timestamp, total process time, TX power, RSSI values, UUID, major and minor of Beacon are generated as output from program. After several adjustments, the parameter is finalized at 20 Bluetooth signals in a single scan.

B. *Sensor Topology*

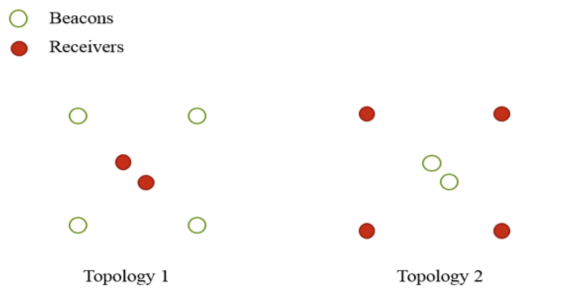

Fig.2. Possible Topology for Indoor Positioning System

There are two possible topologies for the Bluetooth Indoor positioning system as shown in Fig. 2. In topology 1, Beacons are placed at the four corners while receivers are installed on the target object to be traced. In topology 2, receivers are placed at corners and beacons are placed on the target object. Topology 2 is more appropriate for the system in asset tracking aspect because Beacons have longer lifetime due to low power consumption and fixed power supply.

C. *RSSI Filters Applied in Signal Processing*

In this study, effectiveness of different types of filters are studied and compared by standard deviation and R-squared value. First of all, median filter takes median values of all the received RSSI values in the time series and its observed sequence is expressed in below equation:

$$med = \begin{cases} x_{n+1} & v = 2n+1 \\ \frac{1}{2}\left(x_{(n)} + x_{(n+1)}\right) & v = 2n \end{cases} \quad (1)$$

, where x_n is the nth order in the sequence.

Second, moving average filter sum up the recent RSSI values and total is divided by pre-defined moving average interval which is 5 in this project as shown in the equation as follow:

$$RSSI_{t+1} = \frac{RSSI_t + RSSI_{t-1} + \cdots + RSSI_{t-i+1}}{i} \quad (2)$$

, where $RSSI_{t+1}$ is the estimated RSSI value, i is the moving average interval for $i \geq 2$.

For Kalman filter, it is applied in the signal processing to smooth out the RSSI value. Equation for computation of Kalman gain is:

$$K_k = P_k H^T (H P_k H^T + R)^{-1} \quad (3)$$

$$K_k = P_{k-1}(P_{k-1} + R)^{-1} \quad (4)$$

, where K_k is the Kalman gain, P_k is the measurement error, P_{k-1} is the measurement error in previous state, H is the measurement matrix and R is process noise. Standard deviation for RSSI values were calculated to determine the measurement error and initial error in estimation in the first run. Assuming H is a unit matrix equals to 1 for stationery objects in equation (3), the Kalman gain can be simplified as equation (4). Assume that P_k is equal to R, initial Kalman Gain is 0.5 and value continue to update along the measurement with update of error in estimation, the equation for new estimated RSSI value is:

$$x_k = x_{k-1} + K_k(z_k - x_k - 1) \quad (5)$$

, where x_k is estimation for new RSSI value, x_{k-1} is the estimation for old RSSI value, K_k is the Kalman gain, z_k is the current RSSI reading. Thus, the equation for error in estimation will be:

$$P_k = (1 - K_k)P_{k-1} \quad (6)$$

After studying different filters, Kalman-LULU filter is newly proposed which consists of two tiers: Kalman filter and LULU smoother. After obtaining the output from Kalman filter, RSSI values are further smoothed by LULU smother. LULU smoother is the non-linear filter to smooth the values by establishing the upper and lower operators to smooth the outliners within the upper and lower boundaries. Lower and upper operators are expressed in equation (7) and (8) while LULU smoother is expressed in equation (9):

$$L_n = \max(\min(x_{i-n},\ldots x_i)\ldots\min(x_i\ldots x_{i+n})) \quad (7)$$

$$U_n = \min(\max(x_{i-n},\ldots x_i)\ldots\max(x_i\ldots x_{i+n})) \quad (8)$$

$$(W_j x)_i = \begin{cases} x_i & if\ x_i \in [(P_{lj}x)_i, (P_{uj}x)_i] \\ (P_{lj}x)_i & if\ x_i < (P_{lj}x)_i \\ (P_{uj}x)_i & if\ x_i > (P_{uj}x)_i \end{cases} \quad (9)$$

, where W is the winsorised smoother, $P_{lj}x$=Ln and $P_{uj}x$=Un. LULU smoother creates moving upper boundary and lower boundary along the series. Next RSSI observation are assigned to the value of upper and lower boundaries if it exceeds upper and lower boundaries.

D. Calibration

In order to formulate the relationship between RSSI and distance, calibration process is preliminary and essential step for the implementation of the indoor positioning system. The calibration workflow is illustrated below:

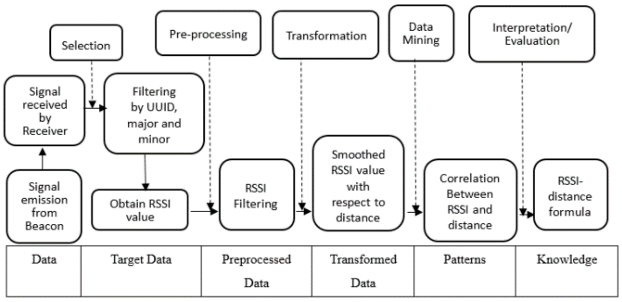

Fig. 3 Calibration Workflow interpreted in KDD process

In this experiment, the Beacons are placed in 24 different positions with a distance of 0.5m for the first 10m to study the effect of RSSI readings at different distance. After first 10m, the beacon was placed at 11m, 13.5m, 16m, 18.5m and 21m to observe if there is any change in average RSSI value. The sample size is 500 RSSI values at each position and advertisement rate of Bluetooth signal for Beacon is fixed at 100ms. After processing, the correlation between RSSI and Beacon distance can be deduced in which the pattern is obtained in the KDD process. With the aid of linear regression method, formula of RSSI values against distance can be deduced in the final stage which is knowledge retrieved from the entire calibration process. Effective range can also be determined if there is no change in RSSI values with increase in distance on particular point. The distance beyond that particular point should be considered as out of effective range. Responsiveness is measured by recording the process time between each received signal. The shorter process time required to receive each Bluetooth signal implies higher responsiveness. Since the trilateration requires the RSSI values from three receivers, the application may require buffering time to collect all RSSI values for distance estimation and then to perform trilateration.

E. Positioning algorithm

It is assumed that the signal strength of EM wave propagate in all direction are identical, so that the coordinates of target object (x_a,y_a) and receiver (x_a,y_a) can be calculated by trilateration. Location of Beacon can be determined by receiver with known coordinates (x_i,y_i) when RSSI value converted to distance (d_i) between signal receiver and Beacon. Fig. 5 illustrates the object localization process by trilateration and only three receivers with shortest estimated distance are selected to perform trilateration. Based on Fig. 4, d_1, d_2 and d_3 are chosen to procees trilateration because the shorter estimated distance is converted by higher RSSI values which implies a stronger signal received by receivers. If one of the receivers malfunctions, the remaining receiver can still estimate the object location by trilateration.

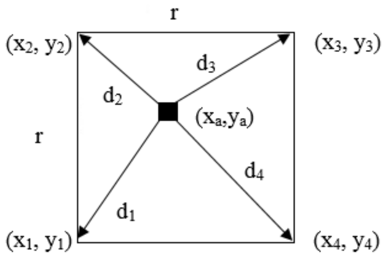

Fig. 4 Estimated Location of Beacon and Receiver

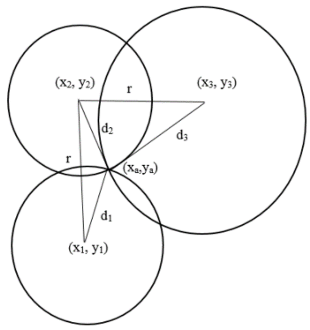

Fig. 5 Object Distance Estimated by Trilateration

From the following equation,

$$(x_a - x_1)^2 + (y_a - y_1)^2 = {d_1}^2 \quad (10)$$

$$(x_a - x_2)^2 + (y_a - y_2)^2 = {d_2}^2 \quad (11)$$

$$(x_a - x_3)^2 + (y_a - y_3)^2 = {d_3}^2 \quad (12)$$

Equations (13) and (14) can help estimate coordinates of Beacons (x_a,y_a) with pre-defined receiver location after putting x_1=0, y_1=0, x_2=0, y_2=r and subtract equations (11) from (10).

$$y_a = \frac{d_1^2 - d_2^2 + r^2}{2r} \quad (13); \quad x_a = \frac{{d_2}^2 - {d_3}^2 + r^2}{2r} \quad (14)$$

F. Accuracy Analysis

Five coordinates (2, 5), (5, 3.5), (7, 0.5), (6, 2.5), (1, 7.5) are chosen for test cases. A hundred RSSI observations are collected for each receiver and the average RSSI values for each receiver are calculated. The RSSI values are sorted by descending order and the three highest RSSI values are proceed by the trilateration. The root mean square error (RMSE) between the estimated coordinate and actual coordinate are compared to find out the accuracy level at different coordinates.

G. Study of Shielding Effect by Metal

A receiver is placed at 50 cm at the left-hand side of the metal strip and the Beacon is placed at 50 cm at the right-hand side of the metal strip. The total distance between Beacon and receiver is 1 meter. The metal strip blocks the direct straight path between Beacon and receiver. The experiment setup is illustrated in Fig. 6. The RSSI values collected are compared with the RSSI value collected in calibration to observe if there is change in RSSI values that may be arising from shielding effect and reflection. The experimental results are interpreted by average error.

Fig. 6 Beacon Placed in 1m away from Receiver Shielded by Metal Strip

H. Assumptions

Several assumptions are made before experiment developed. Firstly, all Beacons and Raspberry Pi are identical. Secondly, the correlation of RSSI values and distance follows the Powel Model Law at all distance intervals. Thirdly, the RSSI values generated from the driver of the receivers is consistent at all distance interval. Also, there is no invisible external interference during the calibration process. At last, all measurement errors are arising from process noise of the system.

III. EXPERIMENTAL SETUP AND RESULT ANALYSIS

The specification of proposed indoor positioning system is described in Table I. Power bank is served as power supply due to its flexibility for this experiment. However, Raspberry Pi should be connected to fixed power supply to maintain its sustainability in actual operation.

TABLE I. SPECIFICATION OF THE PROPOSED SYSTEM

System Specification	
Beacon	Advertisement rate: 100 ms
	TX power: 0 dBm
	Bluetooth: 4.1 classic, BLE
Receiver	Raspberry Pi 3 model B
Network	10/100 Ethernet, 2.4GHz 802.11n wireless
Storage	16 GB Micro SD card
Power Supply	Power Bank
	DC 5.1 V, Output 2.4 A, 10050 mA

In this experiment, 500 RSSI values were obtained from different object distance to see whether there is any correlation between RSSI value and actual Beacon distance in these intervals. First of all, TX power level is set at -8 dBm, 0dBm, 10 dBm to investigate which TX Power provides the longest effective range for the proposed system. From the results, TX power of 0 dBm shows linear correlation between RSSI values and actual distance up to 9.5m. Thus, 0 dBm TX power is the optimal TX power level and effective range is set as 9.5m to conduct other test for the proposed system.

Then, the correlation between RSSI value and actual distance is examined in this experiment. Without using any filter, it is observed that the RSSI reading have a wide range in the measurement and the standard deviation is very large comparing with the value of the difference of mean RSSI between each interval. Therefore, non-filter results are not desirable for positioning as the fluctuation of RSSI values may have negative impact on accuracy which may lead to ambiguity in distance estimation. Besides, the results are also unsatisfactory after applying median filter, moving average filter and Kalman filter because of decrease or insignificant improvement in R-squared value. However, the proposed Kalman-LULU filter shows the strongest correlation among the tested filters which provides a more reliable linear relationship of the deduced equations for distance estimation.

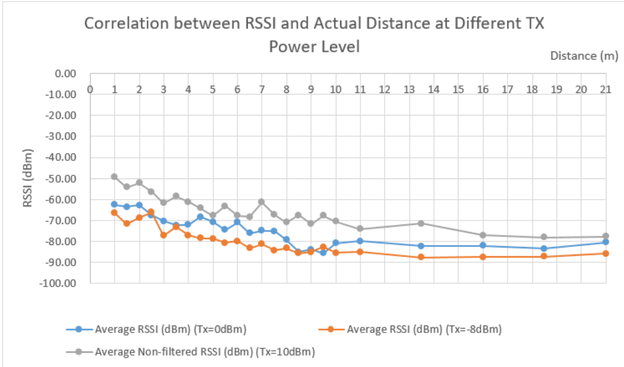

Fig. 7 Correlation between RSSI and Actual Distance at Different TX power level

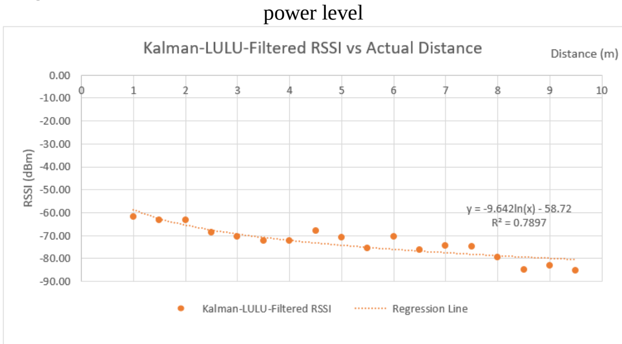

Fig. 8 Kalman-LULU Filtered RSSI vs Actual Distance

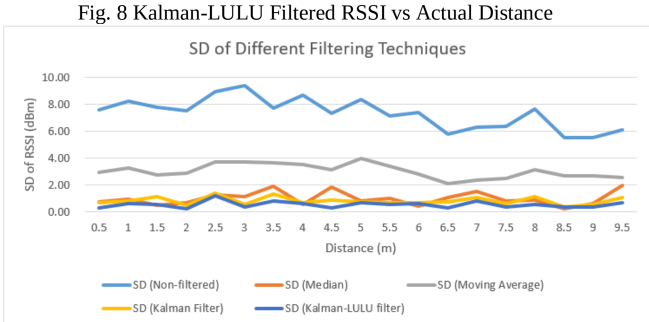

Fig. 9 Standard Deviation of different filtering techniques

Fig. 9 describes the difference in standard deviation before and after applying different filtering techniques. It is obvious that the proposed hybrid approach, Kalman-LULU filter have the least standard deviation at all distance intervals.

Responsiveness of Indoor Positioning System is also investigated in this study. It is found that process time reaches peak value when distance of Beacon is located at 5m and 8.5m. From Fig. 10, the linear relationship between the process time and the distance of Beacon cannot be deduced. The only conclusion can be drawn is the average process time is less than 3.5s which can be used to determine the refresh rate of proposed system to reduce the chance of not receiving RSSI values simultaneously.

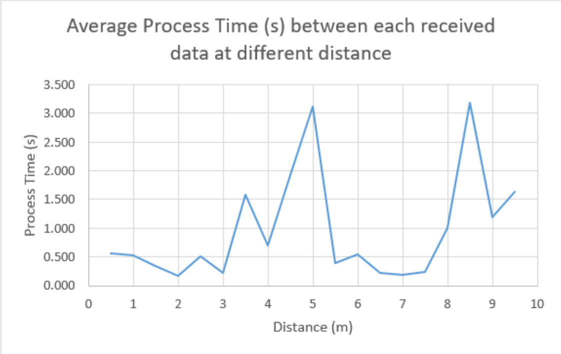

Fig. 10 Average Process Time between each received data at different distance

Metal attenuation effect at 1m with Kalman Filter is also one of the focus of this study. From the results, the initial filtered RSSI values are higher than that of presence of metal which indicated a stronger signal strength in absence of metal in path of signal transmission. After continuously iteration by Kalman filter, the RSSI values quickly coverage and achieve stable results.

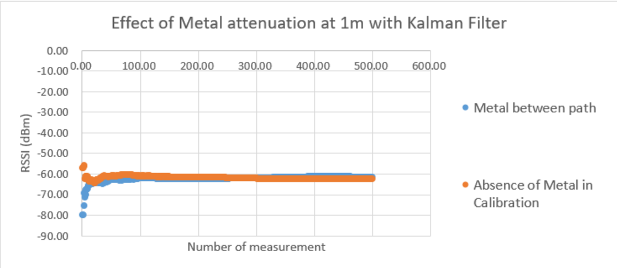

Fig. 11 Metal attenuation effect at 1m with Kalman Filter

There is an unexpected finding that nearby Beacons have additional effect on RSSI value to target Beacon which may be caused by constructive phase in EM wave propagation at the particular time instance. The receiver requires extra time to synchronize the transmitter and receiver for inquiry scan if multiple Beacons are used.

Finally, the summarized trilateration results of five test cases with Beacons placed at different locations are shown in Table II. It is found that the average root mean square error of proposed Kalman-LULU filter is the least among all filters. The overall performance of newly proposed filter achieves 22.42% error when comparing with effective range. It also reduces approximately 30% error when comparing with non-filter results.

TABLE II. SUMMARY OF TRILATERATION RESULTS

Filter	**Average RMS Error**	**% Error to Effective Range**	**% of improvement compare with non-filter**
Non-filtered	3.06	32.22%	N/A
Median	2.46	25.90%	19.64%
Moving Average	2.52	26.54%	17.63%
Kalman	2.19	23.07%	28.42%
Kalman-LULU	2.13	22.42%	30.42%

IV. CONCLUSION

This study aims to propose a Bluetooth location-based indoor positioning system for asset tracking purpose in warehouse environment. Performance metrics are defined and studied throughout the experiments. By applying the newly proposed filter, Kalman-LULU filter, in signal processing stage, helps increase the accuracy of the system and reduce noise in fast pace. The effective range of proposed system is up to 9.5m with TX power equals to 0dBm and the average process time should not exceed 3.5s within the tolerance level of real-time application. It is also suggested that the receiver should be placed at a height far away from the metal shelf to avoid metal attenuation effect. Since there is no existing method to identify each alternative path caused by multipath effect, the proposed system is first introduced and equipped with enhanced data filtering and processing techniques to minimize the noise in Bluetooth signal for a more accurate distance estimation. This paper could provide useful insights in manufacturing industry to facilitate the application of cost-efficient Bluetooth Location-based indoor positioning system. The future work should focus on Beacons with the aid of other sensor such as magnetic sensor for distance evaluation and take environmental factors into consideration to achieve higher level of precision.

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