Modified weighted centroid algorithm for indoor and outdoor positioning using wireless sensors network

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A B S T R A C T

Positioning, either outdoor or indoor, has been one of the most attractive fields for researchers to study and they apply different approaches in order to allocate a moving object. Some positioning approaches use Received Signal Strength (RSSI) in order to determine the location such as Fingerprinting, and Weighted Centroid Localization (WCL). On the other hand, some approaches use signal travelling time such as Time of Arrival (TOA) and Time Difference of Arrival (TDOA). However, the accuracy is still low due to the effect of RSSI to moving objects. This paper shows how to allocate a blind node in a wireless sensor network (WSN) using the proposed WCL approach and shows how the enhancement of the algorithm made better accuracy with mean square error, MSE, of 64.5 cm for indoor positioning and 123.0 cm for outdoor positioning. One of previous WCL approaches reached accuracy with an error of as low as 15.0 cm but in simulation, and others used different approaches with MSE of 80.0 cm and another as high as 2.6 m.

1. Introduction

Most researchers manipulate RSSI for positioning. Other techniques like TOA or TDOA are studied by some researchers however their approaches are hard to be implemented practically and done mostly in simulation. Even though RSSI is less accurate but it is the most applicable to be implemented in real environment due to the implementation difficulties that time-related techniques require such as time synchronization between network nodes (Henniges, 2012). This paper uses RSSI for positioning in WSN which is using Zigbee technology and there are other approaches that use WiFi technology for indoor positioning as in Alshami et al. (2014, 2017).

Using RSSI for positioning in WSN is also the main approach for most researchers but researchers should take in mind that RSSI readings in WSN is not as strong and accurate in other technologies due to the low bandwidth that WSN has, so RSSI might still be efficient enough for positioning in WSN as long this point is taken in consideration. Not just horizontal distances could affect RSSI measurements; also vertical distances could affect

the readings. Habaebi et al. (2014) had some experiments on RSSI in WSN and in their results found that RSSI measurements in indoor environment for 3D positioning at 1 m show the best results, whereas the 1.6m height was the worst. They concluded that external factors could affect RSSI measurements such as the obstacles between the receiver and the transmitter, such as people moving around and the antenna of both of them (Alshami et al., 2016). Approaches that used RSSI are different and the goal of each is to minimize the MSE as low as possible. Chen et al. (2012) reached and MSE of 2.6 m and back in that time it was good, and the researchers continued enhancing the accuracy and that is why we can notice that recent approaches reaches an MSE less than 1.0 m as we can find with Baccar and Bouallegue (2016).

As most of many other positioning algorithms, WCL uses RSSI in order to calculate estimated position. The principle of the traditional centroid localization algorithm is that if a blind node is in the range of a reference node then it has to be in its range forming a circle which its center is the coordinates of that reference node. And if the blind node is in the range of more than one reference nod then it has to be forming a circle with each one and by that a potential position are is created within the intersection of all formed circles. WCL, as with Wang and Zheng (2014), works the same way but enhanced by the idea of having a weight for each reference node. This weight reflects the contribution

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of each reference node to the localization process. Its basic fundamental is to use the relation between the RSSI value and how it got affected by the distance between the blind node and the reference node. Assuming the RSSI of each reference node as a radius of a circle centered by the coordinates of the reference node and the blind node.

2. Positioning

Many positioning approached uses different technologies. For a big scale outdoor positioning GPS is the optimal choice but for indoor positioning many methods could be used such as WiFi, as in Alshami et al. (2017) which used fingerprinting to estimate positions or WSN which this paper is implementing using the work flow shown in Fig. 1.
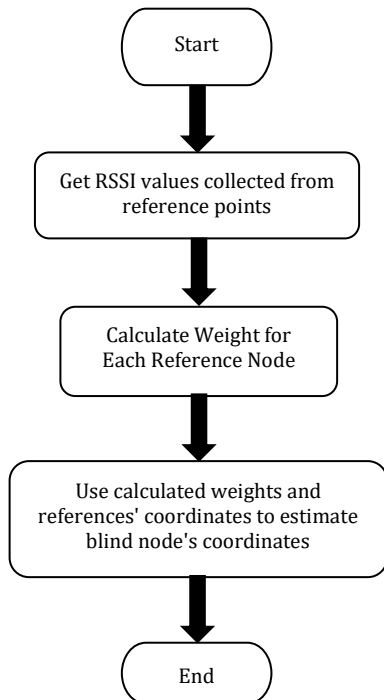

Fig. 1: Modified WCL work flow

In general, most of these approaches use reference nodes in order to estimate the position of a blind node. In this paper, a minimum of four nodes should be used three as reference nodes and one as the blind node to be positioned. The technique used is called trilateration which calculate the position of a blind node by estimating its location from each reference node. As RSSI could indicate the distance between the reference node and the blind node, all RSSI values for each reference node will be used as weight in our WCL algorithm.

2.1. WCL algorithm

The idea of WCL algorithm is based on the relation between the RSSI of a blind node to each reference node and the distance between it and each of them. RSSI values increases by the increase in distance and that could be considered as a good factor to calculate the weight that affect the distance

calculation between the blind node and each one of the reference nodes. According to Wang and Zheng (2014), the weight could be calculated from the following:

$$\begin{cases} x = \dfrac{w_1 * x_1 + w_2 * x_2 + w_3 * x_3 + \cdots + w_n * x_n}{w_1 + w_2 + w_3 + \cdots w_n} \\ y = \dfrac{w_1 * y_1 + w_2 * y_2 + w_3 * y_3 + \cdots + w_n * y_n}{w_1 + w_2 + w_3 + \cdots w_n} \end{cases} \tag{1}$$

$$w_i = \frac{RSSI_i}{RSSI_1 + RSSI_2 + RSSI_3 + \cdots + RSSI_n} \tag{2}$$
$$i \in (1,2,3,\ldots,n)$$

where i is the reference node number, w is the calculated weight. As RSSI increases by distance, applying (1) will lead to decrease the actual contribution of the nearest reference node to the blind node in the localization process and at the same time increase the contribution of the farthest one and in order to reflex that then the actual weight could be as the following:

$$w_i = \frac{RSSI_1 + RSSI_2 + RSSI_3 + \cdots + RSSI_n}{RSSI_i} \tag{3}$$

Because RSSI value does not start from 0 and because reference points should be in higher location of the surrounding to avoid obstacles as much as possible, experimental results show that RSSI value is in the range of [47-52], so a reasonable estimated value M that normalize the RSSI values should be taken in consideration in order to get better accuracy. In this experiment M is estimated by 50. So, applying that on (3) then w would be as the following:

$$w_i = \frac{RSSI_1 + RSSI_2 + RSSI_3 + \cdots + RSSI_n - (M * i)}{RSSI_i - M} \tag{4}$$

As w is the weight that will be used to estimate the coordinates, then the weight of each reference node most be a fraction of the total weight of all reference nodes, but as (4) is actually an inverted ratio then each w_i will not be a fraction of total summation of wi for all i in [1 - n] any more. In order to solve this, simply, we can just calculate the ratio of each w_i to the total summation of all of them and the result will be the new value of the weight as in the following:

$$w_{ii} = \frac{w_i}{w_1 + w_2 + w_3 + \cdots + w_i} \tag{5}$$

where w_{ii} is the final calculated weight for all reference nodes with coordinates (x_i, y_i), i is the number of each reference node. Applying (5) on (1) will give us the estimated (x,y) for the blind node and this algorithm should be implemented by the java application that shows the layout map with the estimated position of the blind node.

3. Results and analysis

The algorithm was implemented for a predetermined position in an indoor environment using normal WCL algorithm as in (3), and then

using the shifted weight approach as in (4), and with shifted and inverted weight as in (5). Finally, and to check other possible approaches, the inverted weight was implemented without shifting. Fig. 2 shows that normal WCL makes good result but with the lowest accuracy and the shifted inverted weight is the best accuracy of them.

Fig. 2: Different approaches of WCL

After making sure that inverted shifted weight approach is the best to be use, the experiment was conducted for indoor environment and the calculated result were as in Table 1.

Table 1: Indoor experiment result

Actual		Estimated		Diff^2		MSE (cm)
X	Y	x	y	X_{Diff}^2	Y_{Diff}^2	
120	120	169	129	2401	81	49.8
180	120	187	205	49	7225	85.3
240	120	194	165	2116	2025	64.4
300	120	285	208	225	7744	89.3
360	120	312	145	2304	625	54.1
420	120	395	145	625	625	35.4
480	120	524	139	1936	361	47.9
540	120	562	147	484	729	34.8
600	120	578	150	484	900	37.2
660	120	595	182	4225	3844	89.8
720	120	649	167	5041	2209	85.1
780	120	712	143	4624	529	71.8
120	240	155	207	1225	1089	48.1
180	240	233	191	2809	2401	72.2
240	240	173	294	4489	2916	86.1
300	240	340	228	1600	144	41.8
360	240	331	260	841	400	35.2
420	240	395	213	625	729	36.8
480	240	443	275	1369	1225	50.9
540	240	533	170	49	4900	70.3
600	240	557	187	1849	2809	68.2
660	240	589	159	5041	6561	107.7
720	240	685	158	1225	6724	89.2
780	240	708	177	5184	3969	95.7

From the results in Table 1 and using the known equation to calculate accuracy as explained in Ou et al. (2015), the accuracy formula to estimate Mean Square Error, MSE, is:

$$MSE = \frac{\sum_{i=0}^{n} \sqrt{(X_{Act.} - X_{Est.})^2 + (Y_{Act.} - Y_{Est.})^2}}{N} \qquad (6)$$

Then MSE would equal 67.5cm. Applying the same approach for outdoor environment the results were as in Table 2.

By applying (6) from the above results, we found that the accuracy MSE for positioning in outdoor environment would be 123.0 cm which is also a very

good result for positioning in wireless sensors networks using WCL.

Table 2. Outdoor experiment result

Actual		Estimated		Diff^2		MSE (cm)
X	Y	x	y	X_{Diff}^2	Y_{Diff}^2	
5	300	40	320	1225	400	40.3
5	420	130	380	15625	1600	131.2
200	300	250	480	2500	32400	186.8
200	420	180	350	400	4900	72.8
400	300	280	320	14400	400	121.7
400	420	420	540	400	14400	121.7
600	300	480	420	14400	14400	169.7
600	420	520	490	6400	4900	106.3
100	150	160	230	3600	6400	100.0
300	200	330	320	900	14400	123.7
100	600	120	470	400	16900	131.5
300	600	420	480	14400	14400	169.7

4. Conclusion

The modified algorithm of WCL has shown good results with good accuracy. The experiment shown how the accuracy increased by doing inversion in the algorithm and also by making shift in the RSSI values used in the algorithm. The best accuracy was when we used both inversion and shifting. This new technique is used in WSN which is a Zigbee network and applying it with other approaches that uses WCL with WiFi or other technologies might give the same results and could be proven in future work. The WCL algorithm can be applied with any Internet of things (IoT) applications for Indoor positioning with low cost and power consumption but with high accuracy.

Acknowledgement

References

Alshami IH, Ahmad NA, and Sahibuddin S (2014). Dynamic WLAN fingerprinting RadioMap for adapted indoor positioning model. In: Fujita H and Selamat A (Eds.), Intelligent software methodologies, tools and techniques, SoMeT 2014. Communications in Computer and Information Science: 513. Springer, Cham. https://doi.org/10.1007/978-3-319-17530-0_9

Alshami IH, Ahmad NA, Sahibuddin S, and Firdaus F (2017). Adaptive indoor positioning model based on WLAN-fingerprinting for dynamic and multi-floor environments. Sensors, 17(8): 1789-1818.

Alshami IH, Ahmad NA, Sahibuddin S, and Yusof YM (2016). The effect of people presence on WLAN RSS is governed by influence distance. In the 3rd International Conference on Computer and Information Sciences, IEEE, Kuala Lumpur, Malaysia: 197-202. https://doi.org/10.1109/ICCOINS.2016.7783214

Baccar N and Bouallegue R (2016). Interval type 2 fuzzy localization for wireless sensor networks. EURASIP Journal on Advances in Signal Processing, 2016(1): 42-55.

Chen Q, Liu H, Yu M, and Guo H (2012). RSSI ranging model and 3D indoor positioning with ZigBee network. In the IEEE/ION Position Location and Navigation Symposium, IEEE, Myrtle

Beach, SC, USA: 1233-1239. https://doi.org/10.1109/PLANS.2012.6236979

Habaebi MH, Khamis RO, Zyoud A, and Islam MR (2014). RSS based localization techniques for ZigBee wireless sensor network. In the International Conference on Computer and Communication Engineering, IEEE, Kuala Lumpur, Malaysia: 72-75. https://doi.org/10.1109/ICCCE.2014.32

Henniges R (2012). Current approaches of Wi-Fi positioning. In the SERVICE-CENTRIC NETWORKING - SEMINAR WS2011/2012, IEEE, TU-Berlin, Germany: 1-8.

Ou X, Wu X, He X, Chen Z, and Yu QA (2015). An improved node localization based on adaptive iterated unscented Kalman filter for WSN. In the 10th Conference on Industrial Electronics and Applications, IEEE, Auckland, New Zealand: 393-398. https://doi.org/10.1109/ICIEA.2015.7334145

Wang ZM and Zheng Y (2014). The study of the weighted centroid localization algorithm based on RSSI. In the International Conference on Wireless Communication and Sensor Network, IEEE, Wuhan, China: 276-279. https://doi.org/10.1109/WCSN.2014.63