EFFECTS OF SAMPLING PERIODS ON THE COMMUNICATION RELIABILITY AND THE ESTIMATION ACCURACY OF AN RSSI-BASED INDOOR LOCALIZATION SYSTEM

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Received: June 14, 2019; Revised: August 03, 2019; Accepted: August 17, 2019

Abstract

In this paper, the experimental study of a received signal strength indicator (RSSI)-based indoor localization system is presented. The major contribution of our paper is twofold. First, how the sampling period set for the reference nodes affects the communication reliability and the estimation accuracy of the target localization system is investigated. Second, the optimal sampling period for the reference nodes is determined, and it also applied for the test in the case of a mobile target scenario. Experiments using low-cost low-power 2.4 GHz wireless nodes developed by our research team have been carried out in an office environment. Experimental results demonstrate that the sampling period set for the reference nodes significantly affects the communication reliability of the localization system as indicated by the level of the packet delivery ratio. It also affects the estimation accuracy of the mobile target localization as indicated by the estimated position determined by the trilateration method. Consequently, the optimal sampling period is the period which can achieve both the communication reliability and the estimation accuracy of the RSSI-based indoor localization system.

Keywords: Sampling period, RSSI-based localization, mobile target, indoor, experiment

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Introduction

Localization is one of the important subjects in wireless networks because position information is useful for deployment, coordination, and routing (Cheng *et al.*, 2012). Furthermore, position information can be used in several applications, such as human tracking in buildings (Patwari *et al.*, 2005; Liu *et al.*, 2007), patient and equipment tracking in hospitals (Redondi *et al.*, 2013), mobile robot tracking (Severino *et al.*, 2007), worker tracking in construction sites (Wang *et al.*, 2010; Luo *et al*., 2011), the guidance of firemen inside buildings and the people inside airports, and automated control of devices (Yeh *et al.*, 2010; Boorawong *et al.*, 2013). Thus, one of the fundamental challenges in wireless networks is the localization problem.

Localization techniques introduced in the research literature are often performed by using the information of time of arrival (TOA), time of difference of arrival (TDOA), angle of arrival (AOA), RSSI, and a hybrid of them (Liu *et al.*, 2007; Yang and Shao, 2015). Here, the TOA and the TDOA techniques with including the global position system (GPS) need the complicated timing and synchronization, which makes complexity and cost expensive. The GPS is also not suitable for indoor environments (Wang and Yang, 2011). For the AOA technique, the need of extra hardware and the need of a minimal distance among the receivers result in disadvantages in terms of cost and size of wireless nodes (Boukerche, 2008). Therefore, RSSI-based indoor localization is more widely used than those techniques. The main advantage of the use of RSSI information is that most wireless devices have RSSI circuits built into them. Hence, no additional hardware is required to reduce the cost and the complexity of the system (Goldoni *et al.*, 2008; Zanca *et al.*, 2008).

To estimate an unknown target position in an RSSI-based indoor localization system, a number of reference nodes stationary at the known locations broadcast a packet, namely the beacon packet, to a target node for every predefined sampling period. Upon receiving the beacon packet, the target node reads the RSSI value provided by its radio circuit. The RSSI value is then converted to the distance value using the radio propagation model, and finally, by applying localization methods, an unknown target position can be estimated. Here, the well-known trilateration method is widely used to estimate the unknown target position, since its algorithm is simple, and it can also provide accurate position estimates (Goldoni *et al.*, 2008; Zanca *et al.*, 2008).

According to the research literature, the RSSI-based indoor localization system using the trilateration method was applied and studied as follows. In (Goldoni *et al.*, 2008) and (Rattanalert *et al.*, 2015), an experimental comparison of RSSI- based localization methods including the trilateration method in low- power wireless sensor networks was presented. In Zanca *et al* (2008), a robust experimental study of the trilateration method for indoor wireless sensor networks was also tested. The studies in (Goldoni *et al.*, 2008; Zanca *et al.*, 2008; Rattanalert *et al.*, 2015) were concluded that the RSSI-based trilateration method provided good accuracy and computational complexity, when a small numbers of reference nodes were used for position estimation. In (Booranawong *et al.*, 2018), the reduction of RSSI signal variation for the trilateration method was presented and investigated through the simulation study. Results showed that, using the method in (Booranawong *et al*., 2018), the position estimation was significantly improved. Finally, in (Kianoush *et al*., 2012), the multilateration localization method was used to track a moving target inside a faculty building. Experimental results showed that it was able to track a target path with good accuracy and low computational impact. However, for all research works presented above, the exploration of how the predefined sampling period set for the reference nodes affects the communication reliability as well as the estimation accuracy of the localization system is not focused and included in the scope of those works. Here, the unreliability and the inaccuracy of the localization system can lead to poor decisions, and cannot support some applications at all.

According to the research gaps presented above, in this paper, effects of the sampling periods of the reference nodes on the communication reliability and the estimation accuracy of the RSSI-based indoor localization system is investigated. The optimal sampling period for the reference nodes is determined, and it also tested in the case of a mobile target scenario. By the experimental results using a low-cost low-power 2.4 GHz wireless technology, we show that the optimal sampling period is the period which can achieve both the reliability and the estimation accuracy of the RSSI-based localization system.

The structure of this paper is as follows. Section 2 explains the RSSI- based indoor localization system. Section 3 presents the experiment. Section 4 provides results with discussion. Finally, we conclude this paper in Section 5.

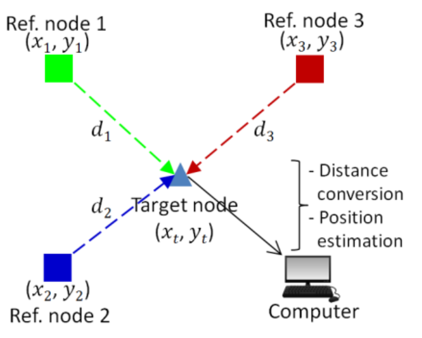

Figure 1. The RSSI-based localization system introduced in this work

An RSSI-based Localization System

The RSSI- based localization system presented in this work is illustrated in Figure 1. There are one target node to be estimated its position (the target node connected to a computer as the processing center via a wire connection) and three reference nodes stationary at the known positions x_i and y_i; (x_i, y_i), (x_2, y_2), and (x_3, y_3), respectively. To estimate the target position, there are three processes. The first process is the RSSI measurement and collection. The second process is the RSSI to distance conversion using the path-loss equation. Finally, the third process is the position estimation using the trilateration method. They are explained here.

In the first process, each reference node generates a packet, namely the beacon packet, and then broadcasts the beacon packet to the target node for every predefined sampling period. Upon receiving the beacon packet, the target node reads the RSSI value provided by its radio circuit and also transfers the RSSI reading to the computer. Here, to study how the sampling period set for the reference nodes affects the communication reliability and the estimation accuracy of the localization system, we intend to vary the sampling period of the reference node with different levels. It will vary from low to high levels which will be defined in Section 3.

The second process begins after the computer receives the RSSI value. The RSSI value can be converted to the distance value using the path-loss equation which describes the relationship between the measured RSSI value and the corresponding distance value in the test field. The path-loss equation (Goldoni *et al.*, 2010; Luo *et al.*, 2011) is presented by (1) and (2), where $RSSI_d$ is the mean RSSI value (in dBm) at distance d (i.e. the distance between the transmitter and the receiver), $RSSI_{d_0}$ is the mean RSSI value (in dBm) at the reference distance from the transmitter (d_0), and α is the path-loss exponent. It is the rate at which the received signal strength decreases along with distance. $RSSI_{d_0}$ and α can be determined in the test field by collecting the RSSI data in which the distances from the transmitter to the receiver is known. The setting of such parameters is again described in Section 3.

$$RSSI_d = RSSI_{d_0} - \left[10 \times \alpha \times log_{10}\left(\frac{d}{d_0}\right)\right] \quad (1)$$

$$d = 10^{\frac{RSSI_{d_0} - RSSI_d}{10 \times \alpha}}; \text{where } d_0 = 1 \quad (2)$$

After the RSSI value is converted to the distance value, and the computer receives all distance values from all reference nodes (i.e. d_1, d_2, and d_3 in Figure. 1), the third process immediately performs. *Here*, the trilateration localization method is applied to estimate the unknown target position. We intend to select such a commonly used method because its algorithm is simple, and its computational complexity is low as referred by the mathematical operation. Thus, the trilateration method (i.e. the final form) is easy to implement on hardware platforms. Also, it can provide accurate position estimates, as investigated by the works in (Goldoni *et al.*, 2008; Zanca *et al.*, 2008; Luo *et al.*, 2011; Rattanalert *et al.*, 2015). The basis of the trilateration method is the calculation of the intersection point of three circles with radius d_1, d_2, and d_3. The intersection point as the unknown target position (x_{est}, y_{est}) can be determined by using the simple circle equations as expressed in (3) to (5). *More detail of the trilateration method can be found in* (Savvides *et al*., 2002; Goldoni *et al.*, 2008; Zanca *et al.*, 2008; Luo *et al*., 2011; Rattanalert *et al.*, 2015; Booranawong *et al.*, 2019).

$$(x_{est} - x_1)^2 + (y_{est} - y_1)^2 = d_1^2 \quad (3)$$

$$(x_{est} - x_2)^2 + (y_{est} - y_2)^2 = d_2^2 \quad (4)$$

$$(x_{est} - x_3)^2 + (y_{est} - y_3)^2 = d_3^2 \quad (5)$$

We note that to determine the intersection point (x_{est}, y_{est}), we also provide the solving of the Equations (3) to (5), as expressed by (6) to (14) below.

: From (3), (4), and (5)

$$x_{est}^2 - 2x_{est}x_1 + x_1^2 + y_{est}^2 - 2y_{est}y_1 + y_1^2 = d_1^2 \quad (6)$$

$$x_{est}^2 - 2x_{est}x_2 + x_2^2 + y_{est}^2 - 2y_{est}y_2 + y_2^2 = d_2^2 \quad (7)$$

$$x_{est}^2 - 2x_{est}x_3 + x_3^2 + y_{est}^2 - 2y_{est}y_3 + y_3^2 = d_3^2 \quad (8)$$

: (6) – (7)

$$(x_2 - x_1)x_{est} + (y_2 - y_1)y_{est} = \frac{1}{2}(d_1^2 - d_2^2 - x_1^2 + x_2^2 - y_1^2 + y_2^2) \quad (9)$$

: (7) – (8)

$$(x_3 - x_2)x_{est} + (y_3 - y_2)y_{est} = \frac{1}{2}(d_2^2 - d_3^2 - x_2^2 + x_3^2 - y_2^2 + y_3^2) \quad (10)$$

: From (9) and (10)

$$a_{11}x_{est} + a_{12}y_{est} = b_1 \quad (11)$$

$$a_{21}x_{est} + a_{22}y_{est} = b_2 \quad (12)$$

Where $a_{11} = (x_2 - x_1)$, $a_{12} = (y_2 - y_1)$, $a_{21} = (x_3 - x_2)$, $a_{22} = (y_3 - y_2)$, $b_1 = \frac{1}{2}(d_1^2 - d_2^2 - x_1^2 + x_2^2 - y_1^2 + y_2^2)$, and $b_2 = \frac{1}{2}(d_2^2 - d_3^2 - x_2^2 + x_3^2 - y_2^2 + y_3^2)$

$$x_{est} = \frac{a_{22}b_1 - a_{12}b_2}{a_{11}a_{22} - a_{12}a_{21}} \quad (13)$$

$$y_{est} = \frac{a_{21}b_1 - a_{11}b_2}{a_{12}a_{21} - a_{11}a_{22}} \quad (14)$$

Experiments

To investigate how the sampling period set for the reference nodes affects the communication reliability and the estimation accuracy of the target localization, experiments are described here. We provide two tests: fixed target and mobile target scenarios. For both tests, experiments are carried out in an office room at the Faculty of Engineering, Prince of Songkla University, Thailand, as demonstrated in Figures 2 and 3. Here, the dimension of the test field is equal to 4.90×6.90 m. Three reference nodes are placed in the area at (x_1 = 4.45 m, y_1 = 4.70 m), (x_2 = 1.50 m, y_2 = 6.50 m), and (x_3 = 1.00 m, y_3 = 3.69 m), respectively. The target node is placed at the position (x_t = 3.70 m, y_t = 1.10 m) for the fixed target test, and it starts at the position (x_t = 2.30 m, y_t = 1.35 m) for the mobile target test.

In the experiment, the target node can directly transfer the measured RSSI data to the computer via wire communications. The target node communicates with the computer via an RS232 serial port interface. The real-time RSSI data and the estimated positions by the trilateration method can be displayed on the

LabVIEW program. We note that there are six processes implemented on LabVIEW including, device scanning, RSSI reading, RSSI separation from each device, position estimation by the trilateration, data display and recoding, and statistics calculation, as shown in Figure 4.

In our experiments, the LPC2103F microcontroller interfacing with the CC2500 RF transceiver (Instrument 2019) developed by our research team is used as the wireless node, as shown in Figure 5 (Rattanalert *et al.*, 2015). The CC2500 RF transceiver is communicated with the LPC2103F microcontroller via a serial peripheral interface (SPI) (Yang, 2011; Jindamaneepon *et al.*, 2016). The CC2500 is a low-cost 2.4 GHz radio module designed for very low power wireless applications. It has the maximum data rate of 500 kbps. The CC2500 can support various radio channels as operating in the frequency range of 2.4 GHz to 2.4835 GHz. Therefore, in this work, we aim to configure the radio channels of the wireless nodes differently from the radio channels of WLAN devices to avoid radio signal interference (Booranawong, Jindapetch, and Saito, 2018). Here, before deploying the wireless nodes. We

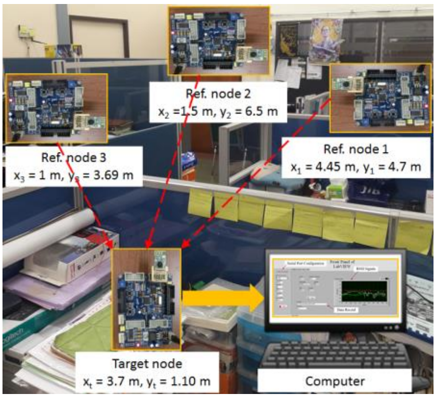

Figure 2. Fixed target scenario

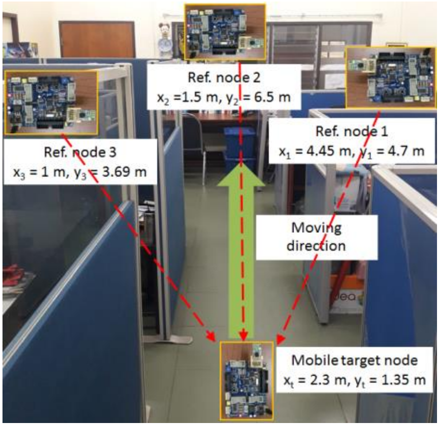

Figure 3. Mobile target scenario

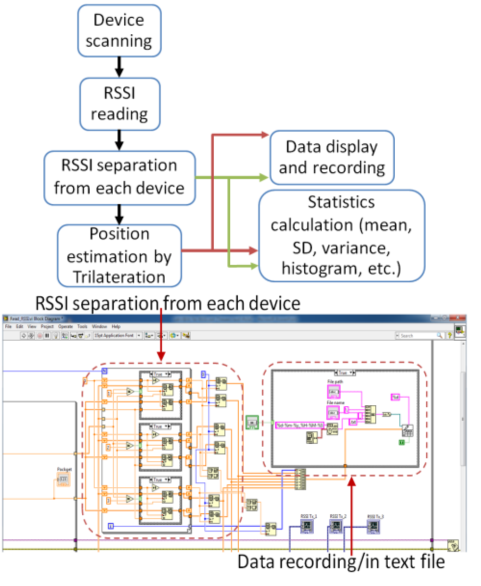

Figure 4. (a) The process on LabVIEW and (b) an example of RSSI separation and data recording functions

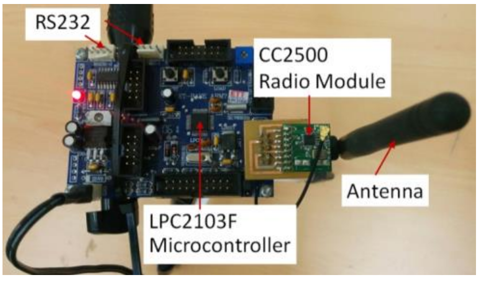

Figure 5. Wireless node (with an external antenna) developed by our research team

used the Wi-Fi analyzer (software app.) on our mobile phone to monitor the wireless signals which are available in the test area. Thus, all Wi-Fi channels and the signal strength (in dBm) can be seen. In addition, in the CC2500, the RSSI value in dBm ($RSSI_{dBm}$) can be read using (15), where $RSSI_{offset}$ is the offset value corresponding to the data rate. $RSSI_{offset}$ is 72, since the data rate is set to 500 kbps in this work.

$$RSSI_{dBm} = \begin{cases} \left[\frac{RSSI_{dec}-256}{2}\right] - RSSI_{offset}, RSSI_{dec} \geq 128 \\ \left[\frac{RSSI_{dec}}{2}\right] - RSSI_{offset}, RSSI_{dec} < 128 \end{cases} \quad (15)$$

We define that, in the first test (i.e. fixed target scenario), the sampling period of the reference node is varied in six levels: 1, 10, 50, 100, 200, and 400 ms, respectively. For each test, each reference node sends 500 beacon packets to the target node, and each test is repeated five times. In addition, the packet delivery ratio as the ratio of the total number of packets received at the target node to the total number of packets sent by the reference node is collected to measure the communication reliability or the success rate of packet transmission. For in the second test (i.e. mobile target scenario), the target node moves from the start position (x_t = 2.30 m, y_t = 1.35 m) to the position (x_t = 2.30 m, y_t = 6.00 m) with the speed of 2 m/s approximately (i.e. walking speed). In such a test, the sampling period is set to 100 ms, and 400 ms, respectively, and the estimated position by the trilateration method is also provided.

As mentioned in Section 2, the measured RSSI value collected from the test filed can be converted to the distance values using the path-loss equation as expressed in (1) and (2). To find the path-loss equation for the test field in Figures 2 and 3, in the beginning, we use one transmitter node and one receiver node to collect the RSSI data at five different distances: 1, 2, 3, 4, and 5 m, respectively. We move the devices from 1 m to 5 m far from each other with steps of 1 m steps. At each distance, the receiver node collects 3,000 RSSI samples. By applying the linear curve fitting to the plot of the average RSSI value in dBm versus the distance in meters (logarithmic scale), the path-loss equation can be determined. By our experiment, the parameters $RSSI_{d_0}$ and α in (1) and (2) are -49.970 and 3.372, respectively.

Results and Discussion

In fixed target scenario, the number of received packets and the average total number of received packets (from all reference nodes) collected at the target node when the sampling period is set to 1, 10, 50, 100, 200, 300, and 400 ms, are shown in Figures 6 and 7, respectively. The packet delivery ratio is also provided in Figure 8. We note that, since in each test, each reference node sends 500 beacon packets to the target node, the total number of received packets will be 1,500 if there is no packet loss in the networks.

The experimental results in Figures 6 to 8 indicate that the sampling period set for the reference node significantly affects the communication reliability of the system. The success rate of packet transmission increases when the sampling period is set to the bigger value. Here, from the results, using a very small sampling period, like 1 ms, the packet delivery ratio (i.e. 37.32%) is quite low, while using the high sampling period, like 400 ms, the packet delivery ratio reaches 99.36%. Using a small sampling period, not only the packet collision and the radio signal interference are occurred in the network, but also the reference node uses more amount of energy consumption to perform the task. However, using a high sampling period, although the packet delivery ratio can be improved, but the system may require more times for processing. For this case, there is a trade-off between the communication reliability and the communication latency. By this reason, the optimal sampling period is the period that can satisfy both reliability and the latency perspectives. Here, from the experimental results in Figures 6 to 8, we found that the optimal sampling period is 100 ms, since it achieves both requirements.

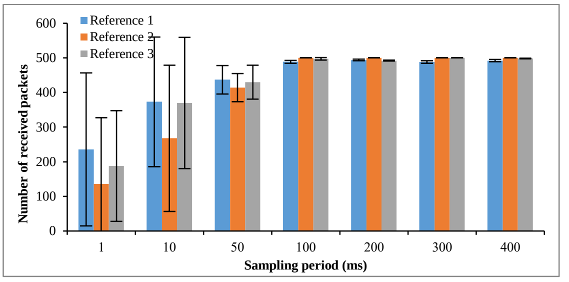

Figure 6. Number of received packets collected at the target node vs. sampling periods

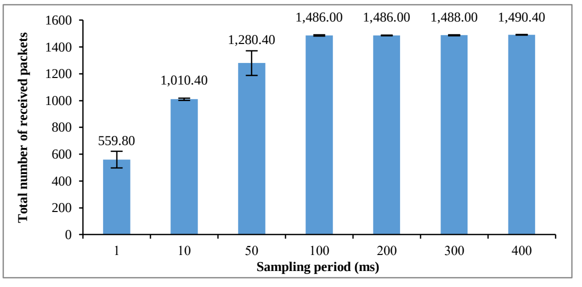

Figure 7. Average total number of received packets (from all reference nodes) collected at the target node vs. sampling periods

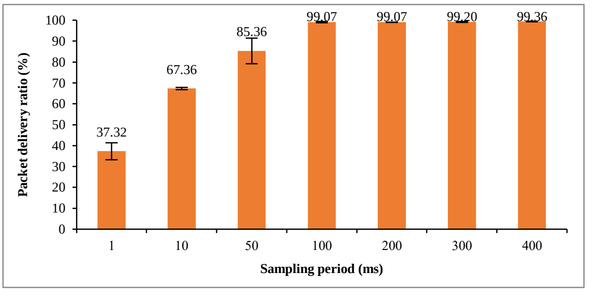

Figure 8 The packet delivery ratio vs. sampling periods

For in mobile target scenario (i.e. from Figure 3), the estimated position determined by the trilateration method, when the sampling period of the reference node is set to 100 ms and 400 ms, is presented in Figure 9. We note that the estimated points shown in Figure 9 are the average result from every 50 samples. Here, the experimental results indicate that, using the sampling period of 100 ms, the estimated position (i.e. a blue line) is closer the actual walking direction (i.e. a dash-dot black line; the start position (x_t = 2.30 m, y_t = 1.35 m) to the end position (x_t = 2.30 m, y_t = 6.00 m) than the case using the sampling period of 400 s (i.e. a red line). As mentioned before, the sampling period of 400 ms requires more time than the case of the sampling of 100 ms to perform the task, although the energy consumption is lower. In this case, the sampling period of 400 cannot be appropriately used for this test. The results by this case indicate that the setting of the optimal sampling period for the reference node should be considered for mobile target tracking scenario.

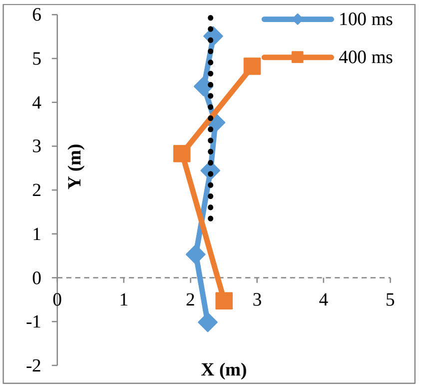

Figure 9. The estimated position determined by the trilateration method, when the sampling period of the reference node is set to 100 ms and 400 ms, respectively

Conclusions

The experimental study of an RSSI-based indoor localization system is presented in this paper. How the sampling period set for the reference nodes affects the communication reliability and the position estimation accuracy of the localization system is investigated. Experimental results using a low-cost low-power 2.4 GHz wireless network indicate that the optimal sampling period set for the reference node significantly affects the communication reliability of the system as well as the estimation accuracy of the mobile target localization. The optimal sampling period is the period which can satisfy both the communication reliability and the estimation accuracy of the localization system.

In future work, since in this work, to first prove the concept of how the sampling period set for the reference nodes affects the communication reliability and the estimation accuracy of the localization system, only one moving pattern of the mobile target is tested. However, the different patterns (like L or loop patterns) should be considered and tested to confirm the optimal sampling period for the indoor localization system. In addition, since in our test scenario, the speed of the mobile target is set at 2 m/s, approximately, the experimental results are verified only for this case. However, effects of different speeds of the mobile target on the performances of indoor localization system should also be taken into account.

Acknowledgement

This work was supported by the Faculty of Engineering, Prince of Songkla University, Thailand.

References

Booranawong, A. Jindapetch, N. and Saito, H. (2018). A system for detection and tracking of human movements using RSSI signals. IEEE Sensors J., 18(6):2531-2544.

Booranawong, A. Sengchuai, K. and Jindapetch N. (2019). Implementation and test of an RSSI-based indoor target localization system: Human movement effects on the accuracy, Measurement., 133:370-382.

Booranawong, A. Sopajarn, J. Sittiruk, T. and Jindapetch N. (2018). Reduction of RSSI variations for indoor position estimation in wireless sensor networks, Engineering and Applied Science Research., 45(3):212-220.

Booranawong, A. Teerapabkajorndet, W. and Limsakul, C. (2013). Energy consumption and control response evaluations of AODV routing in WSANs for building-temperature control. Sensors., 13(7): 8303-8330.

Boukerche, A. (2008). Algorithms and protocols for wireless and mobile ad hoc networks, John Wiley & Sons.

Cheng, L., Wu, C., Zhang, Y., Wu, H., Li, M., and Maple, C. (2012). A survey of localization in wireless sensor network. International Journal of Distributed Sensor Networks., 2012:1-12.

Goldoni, E. Savioli, A. Risi, M. and Gamba, P. (2010). Experimental analysis of RSSI-based indoor localization with IEEE 802.15.4. In: Proceedings of the European Wireless Conference., :71-77.

Instrument, T. CC2500 Datasheet. http://www.ti.com.cn/cn/lit/ds/swrs040c/swrs040c.pdf (2018) Accessed 8 April 2019.

Jindamaneepon, W. Rattanalert, B. Sengchuai, K. Booranawong, A. and Jindapetch, N. (2016). A novel FPGA-based multi-channel multi-interface wireless node: implementation and preliminary test. Advanced Computer and Communication Engineering Technology, Lecture Notes in Electrical Engineering., :1163-1173.

Kianoush, S., Goldoni, E., Savioli, A., Gamba, P. (2012). Low-complexity localization and tracking in hybrid wireless sensor networks. ISRN Sensor Networks., 2012:1–7.

Liu, H. Darabi, H. Banerjee, P. and Liu, J. (2007). Survey of wireless indoor positioning techniques and systems. IEEE Transactions on System, Man, and Cybernetics- Part C: Applications and Reviews., 37(6):1067-1080.

Luo, X. Brien, W.J. and Julien, C.L. (2011). Comparative evaluation of received signal-strength index (RSSI) based indoor localization techniques for construction jobsites. Advanced Engineering Informatics., 5(2): 355-363.

Patwari, N., Ash, J.N., Kyperountas, S., Hero, A.O., Moses III, R.L., and Correal, N.S. (2008). Locating the nodes: cooperative localization in wireless sensor networks. IEEE Signal Processing Magazine., 22(4): 54-69.

Rattanalert, B. Jindamaneepon, W. Sengchuai, K. Booranawong, A. and Jindapetch, N. (2015). Problem investigation of min-max method for RSSI based indoor localization. In: Proceedings of the 12th International Conference on Electrical Engineering/ Electronics, Computer, Telecommunications and Information Technology., p. 1-5.

Redondi, A., Chirico, M., Borsani, Cesana, M., and Tagliasacchi, M. (2013). An integrated system based on wireless senor networks for patient monitoring. Localization and tracking, Ad- Hoc Networks., 11:29-53.

Savvides, A. Park, H. and Srivastava, M. (2002). The bits and flops of the N-hop multilateration primitive for node localization problems. In: Proceedings of the First ACM International Workshop on Wireless Sensor Networks and Application., p. 112-121.

Severino, R. (2007). Engineering a search and rescue application with a wireless sensor network-based localization mechanism. IEEE International Symposium on a World of Wireless, Mobile and Multimedia Networks (WoWMoM 2007)., p. 1-4.

Wang, G., Yang, K. (2011). A new approach to sensor node localization using RSS measurements in wireless sensor networks. IEEE Transactions on Wireless Communications., 10(5):1,389–1,395.

Wang, Y. Huang, L. and Yang, W. (2010). A novel real-time coal miner localization and tracking system based on self-organized sensor networks. EURASIP J. Wireless Commu. Net., p. 1-14.

Yang, C., Shao, H.R. WiFi-based indoor positioning. IEEE Communications Magazine., 53(3):150-157.

Yang, L.D. (2011). Implementation of a wireless sensor network with EZ430-RF2500 development tools and MSP430FG4618/F2013 experimenter boards from Texas instruments. Master thesis, the Department of Electrical & Computer Engineering, Louisiana State University and Agricultural and Mechanical College.

Yeh, L.W. Lu, C.Y. Kou, C.W. Tseng, Y.C. and Yi, C.W. (2010). Autonomous light control by wireless sensor and actuator networks. IEEE Sensor J., 10(6):1,029-1,041.

Zanca, G. Zorzi, F. Zanella, A. and Zorzi, M. (2008). Experimental comparison of RSSI-based localization algorithms for indoor wireless sensor networks. In: Proceedings of the Workshop on Real-word Wireless Sensor Networks., p. 1-5.