

Received Signal Strength Indicator Based Localization of Bluetooth Devices Using Trilateration: An Improved Method for the Visually Impaired People

Muhammad Irfan Aziz, Thomas Owens, Uzair Khaleeq uz Zaman

Abstract—The instantaneous and spatial localization for visually impaired people in dynamically changing environments with unexpected hazards and obstacles, is the most demanding and challenging issue faced by the navigation systems today. Since Bluetooth cannot utilize techniques like Time Difference of Arrival (TDOA) and Time of Arrival (TOA), it uses received signal strength indicator (RSSI) to measure Receive Signal Strength (RSS). The measurements using RSSI can be improved significantly by improving the existing methodologies related to RSSI. Therefore, the current paper focuses on proposing an improved method using trilateration for localization of Bluetooth devices for visually impaired people. To validate the method, class 2 Bluetooth devices were used along with the development of a software. Experiments were then conducted to obtain surface plots that showed the signal interferences and other environmental effects. Finally, the results obtained show the surface plots for all Bluetooth modules used along with the strong and weak points depicted as per the color codes in red, yellow and blue. It was concluded that the suggested improved method of measuring RSS using trilateration helped to not only measure signal strength affectively but also highlighted how the signal strength can be influenced by atmospheric conditions such as noise, reflections, etc.

Keywords—Bluetooth, indoor/outdoor localization, received signal strength indicator, visually impaired.

I. INTRODUCTION

THE navigation from one place to another is an essential daily life activity and requirement. The critical role played by vision is widely acknowledged by most people, but visually impaired people face immense difficulty in detecting the visual information. It is estimated that a population of 253 million people in the world live with vision impairment. Among these, 217 million have moderate to severe vision impairment while 36 million are totally blind [1]. Normally, a mixture of declarative and route knowledge is used for navigation by the blind which is learnt by participation in

orientation and mobility (O&M) sessions [2]. But due to unexpected hazards and obstacles in dynamically changing environments, time saving, adaptable, cost- and user-friendly localization and location-based services (LBS) are the need of today [3], [4].

The global positioning system (GPS) has been used quite extensively over the years for outdoor environments but it deteriorates considerably indoors or near high rise structures due to technical constraints such as shadowing and multi-path disturbances [5], [6]. Therefore, other techniques such as TOA, TDOA and RSS have been used extensively in literature for localization of LBS. But since, narrow band signals such as Bluetooth cannot efficiently utilize TDOA or TOA, RSSI to measure RSS, has been found to be more reliable as it caters for the environmental interference [7], [8]. As the location of a node is very important in a sensor network, triangulation, trilateration and multilateration have been used extensively as positioning methods. Angles are used for positioning in triangulation while distances are employed in trilateration. Multilateration uses TDOA.

Bluetooth transmitters, if installed at regular intervals, transmit pre-recorded voice messages and can provide information about users' current position and nearby points of interests [9]. This kind of localization is a not a novel idea but due to the limitations of the original Bluetooth specification, this approach has not been widely used [10]. The Bluetooth-based localization devices can also connect several other devices to Personal Area Networks (PANs) thereby reducing the positioning error [11]. In addition, the available services of Bluetooth and their discovery are relatively simple which allow smoother communications as compared to Ethernet based Wi-Fi networks. This paper, therefore, proposes a RSSI based improved methodology using trilateration for localization of Bluetooth devices for the visually impaired people. To validate the method, class 2 Bluetooth devices (Blue Giga WT-12) were used. National Instruments LabView was used to develop the required software. Experiments were then conducted to generate surface plots of Bluetooth modules that can show the signal interferences and other environmental effects.

This paper is organized as follows: Section II presents the theoretical background for this work; Section III presents the proposed improved methodology; Section IV describes the implementation and conduct of practical experiments, and

Muhammad Irfan Aziz is with the College of Aeronautical Engineering, National University of Sciences and Technology, Risalpur, Pakistan (Corresponding author, phone: +92-333-5185755, e-mail: iirfan.aziz@cae.nust.edu.pk).

Thomas Owens is Department of Electronic and Computer Engineering, Brunel University, Kingston Lane, Uxbridge, Middlesex UB8, 3PH, West London, United Kingdom (e-mail: thomas.owens@brunel.ac.uk).

Uzair Khaleeq uz Zaman is with Laboratoire de Conception Fabrication Commande, Ecole Nationale Supérieure d'Arts et Métiers, Metz, France (e-mail: uzair-kahleeq-uz.zaman@ensam.eu).

finally, Section V discusses the results and the conclusions drawn.

II. BACKGROUND

A. Techniques to find Direction of Arrival (DOA)

In multiple signal sources, DOA is very important. Various methods are discussed in literature to find it. To minimize the effects of ground reflection, multiple signal classification (MUSIC) algorithm has been used extensively by calibrating commercial electromagnetic compatibility (EMC) antennas [12] and understanding the physical meaning of the presence of noise and other adverse effects [13]. Beamspace et al. [14] used Estimation method of Signal Parameters via Rotational Invariance Technique (ESPRIT) to utilize a self-initiating MUSIC based direction finder (DF) in an Acoustic Particle Velocity-Field. DOA can also be found using an Adcock DF (ADF) [15].

B. RSSI

RSSI is a 'distance-dependent' complex function that is easily interfered with by noisy wireless channels. A Radio Frequency (RF) fingerprint of the region is constructed by systems that utilize RSSI as demonstrated by Ibrahim and Youssef [16] who developed 'Cellsense' using a combination of deterministic and probabilistic techniques. It also implies that trilateration and fingerprinting are two basic techniques used in many indoor positioning systems (IPSS). A model made specifically for RSSI fingerprints was proposed by Danis and Cemgil. To give location aware services, RSSI schemes are being used widely almost everywhere in WLAN [17]. Moreover, finding the maximum value for RSSI is imperative in localization and was found by Sahu et al. [18] who suggested that as the terrain changed from plain to uneven, the fluctuations in RSSI values increased, and to determine the sensor position, the point of intersection of the perpendiculars that pass through the maximum RSSI point, was calculated. Frequency Modulation (FM) and Wi-Fi vectors for RSSI were also combined to check the effect on localization accuracy by Chen et al. [19].

C. Bluetooth, RSSI and LBS

For different indoor environments, Bluepass was developed by Diaz et al. [20]. Different characteristics of Bluetooth such as RSSI, link quality (LQ), transmit power level, etc., were evaluated by Hossain and Soh [21] who further concluded that a combination of LQ and RSSI is a viable option for localization purposes. Moreover, Feldmann et al. [22] utilized the golden receiver power rank (GRPR) to ascertain that to obtain functional approximation of the distance between a receiver and a transmitter, only positive values of RSSI should be used. Altini et al. [23] also described a region-based localization method to secure accurate location services without triangulation to handle the situations in which more than three Bluetooth base stations are involved. Furthermore, Li and Wang [24] found the required location by identifying the point of intersection of all the three circles corresponding to three Bluetooth transmitters. In reference to the visually

impaired, Bohonos et al. [25] used an implementation on a mock setup to demonstrate how Bluetooth can be used as an aid for the blind when crossing a road intersection. Lastly, Liu et al. [26] improved the overall reliability and accuracy of the system by coupling fluorescent light communication (FLC) with Bluetooth and radio frequency identification (RFID) tags installed at different locations.

III. PROPOSED METHODOLOGY

In this paper, a different approach was adopted from that available in literature for trilateration. Conventionally, trilateration measures the distances between two points and then solves for the desired results using geometry of circles, spheres and/or triangles. In the methodology proposed, instead of finding the circles of power, the normal to line connecting the circles was determined. If we assume that the object of interest is transmitting an RF signal which can be heard by at least three different receivers, then depending upon the power received by each of them, trilateration can be done, as shown in Fig. 1.

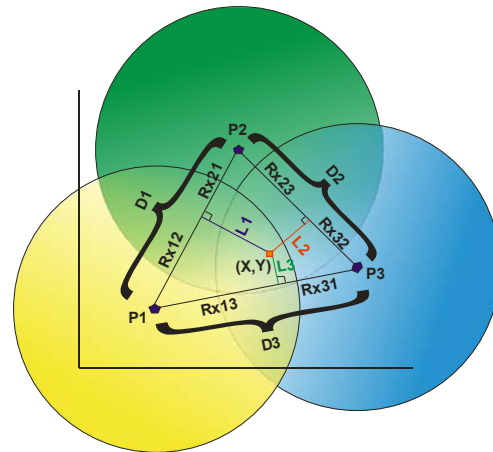


Fig. 1 Overlapping areas of three receivers depending upon theoretical RSSI

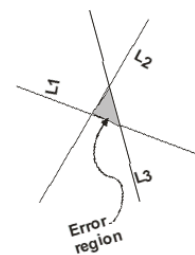


Fig. 2 Error region depicting position of actual target

Fig. 1 shows three unique receivers: P1, P2 and P3, marked by their area of listening as yellow, green and blue, respectively. The object of interest (A), for which trilateration is intended, is at point (X, Y). Since the coordinates of P1, P2 and P3 are fixed and known, the distances between them (i.e., D1, D2 and D3) are also known. P1, P2 and P3 make a

triangle and three perpendiculars are drawn from each side of the triangle to the location of 'A'. These perpendiculars are L1, L2 and L3, respectively, and each divide lines D1, D2 and D3 in such a way that $D1 = R_{x12} + R_{x21}$, $D2 = R_{x23} + R_{x32}$; and $D3 = R_{x13} + R_{x31}$. If equations of lines L1, L2 and L3 are found, the error-region or probable location of 'A' can be known, as shown in Fig. 2.

Since RSSI is a direct gauge of the distance, i.e., $P \propto \frac{1}{R^2}$, the relationship between receivers P1 and P2 can be depicted by (1):

$$\frac{P_{RSSI-1}}{P_{RSSI-2}} = \left(\frac{R_{x21}}{R_{x12}} \right)^2 \quad (1)$$

where P_{RSSI-1} and P_{RSSI-2} are the received powers at P1 and P2, respectively. (1) can be re-written as shown in (2):

$$R_{x12} = \frac{D_1}{\left[1 + \sqrt{\frac{P_{RSSI-1}}{P_{RSSI-2}}} \right]} \quad (2)$$

Similarly, R_{x23} , R_{x31} , and remaining distances can be found. Considering the crossing points of L1(x_{D1}, y_{D1}) on D1, L2(x_{D2}, y_{D2}) on D2 and L3(x_{D3}, y_{D3}) on D3, the final equations of L1, L2 and L3 can be known as shown in (3)-(5), respectively.

$$y_{L1} = \left(\frac{x_1 - x_2}{y_2 - y_1} \right) x_{L1} + \left((y_2 - y_1) \left(\frac{R_{x12}}{D_1} \right) - \left(\frac{x_1 - x_2}{y_2 - y_1} \right) (x_2 - x_1) \left(\frac{R_{x12}}{D_1} \right) \right) \quad (3)$$

$$y_{L2} = \left(\frac{x_2 - x_3}{y_3 - y_2} \right) x_{L2} + \left((y_3 - y_2) \left(\frac{R_{x23}}{D_2} \right) - \left(\frac{x_2 - x_3}{y_3 - y_2} \right) (x_3 - x_2) \left(\frac{R_{x23}}{D_2} \right) \right) \quad (4)$$

$$y_{L3} = \left(\frac{x_3 - x_1}{y_1 - y_3} \right) x_{L3} + \left((y_1 - y_3) \left(\frac{R_{x31}}{D_3} \right) - \left(\frac{x_3 - x_1}{y_1 - y_3} \right) (x_1 - x_3) \left(\frac{R_{x31}}{D_3} \right) \right) \quad (5)$$

The solution of the above lines (their intersection with each other) will result in the error triangle. The area inside the triangle is the probable location of the transmitter.

IV. IMPLEMENTATION AND EXPERIMENTS

A. Implementation

To implement the improved method of trilateration explained in Section III, a Bluetooth module (Blue Giga WT-12) was used which was a class 2 Bluetooth device with a range of 10 meters and a built-in chip antenna. The module was coupled with an evaluation board which was used as an inquiry generator for all the Bluetooth receivers. A graphical user interface (GUI) was then developed using National Instruments LabView for calculating RSSI. The GUI was designed in such a way that it could record all the values from the register of the Bluetooth Module after the Inquiry cycle. In addition to this, MAC addresses of all the Bluetooth modules along with their location on the 15 x 15 grid could also be

entered before the start of the tests. The inquiry cycle was run 25 times at each spot, whose coordinates were manually changed after each run.

B. Experiments

A grid of 15 x 15 feet was used on which five Bluetooth modules were placed, as shown in Fig. 3. These modules acted as receivers whose calibration was already carried out. The inquiry module (WT-12 Evaluation Board connected to the Laptop) was placed at each grid point starting from (2,0), (4,0) and so on till (14,0) and then it was moved to (0,2), (2,2) and so on up to (15,2) and this process continued until all the 81-grid points were covered except (0,0), (15,0) and (0,15) and (15,15) since they were occupied by the four receiver modules with the fifth one at (7.5,7.5). At each point 25 inquiry recordings were made for each receiver.

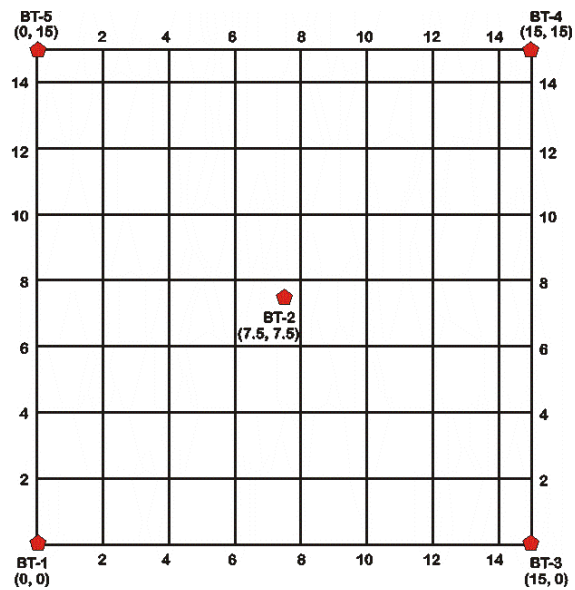
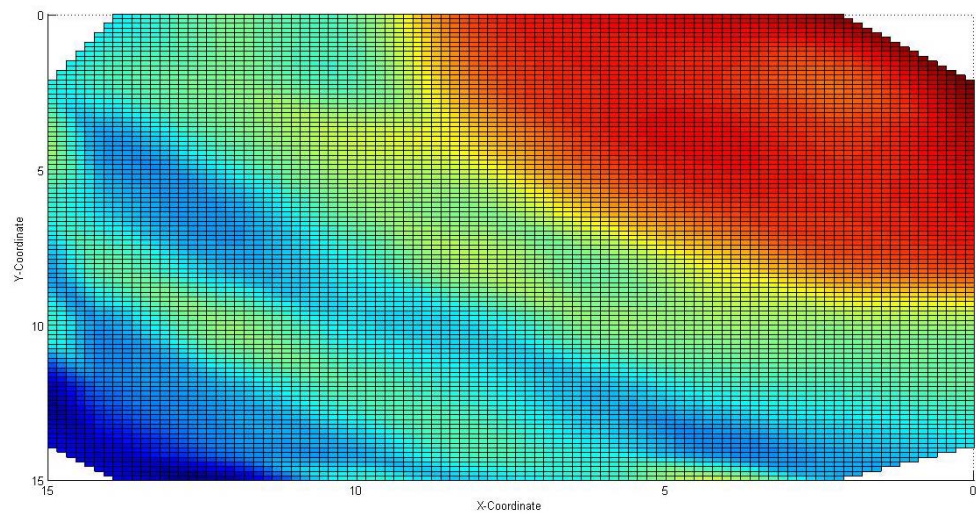


Fig. 3 A 15x15 grid for RSSI experiment

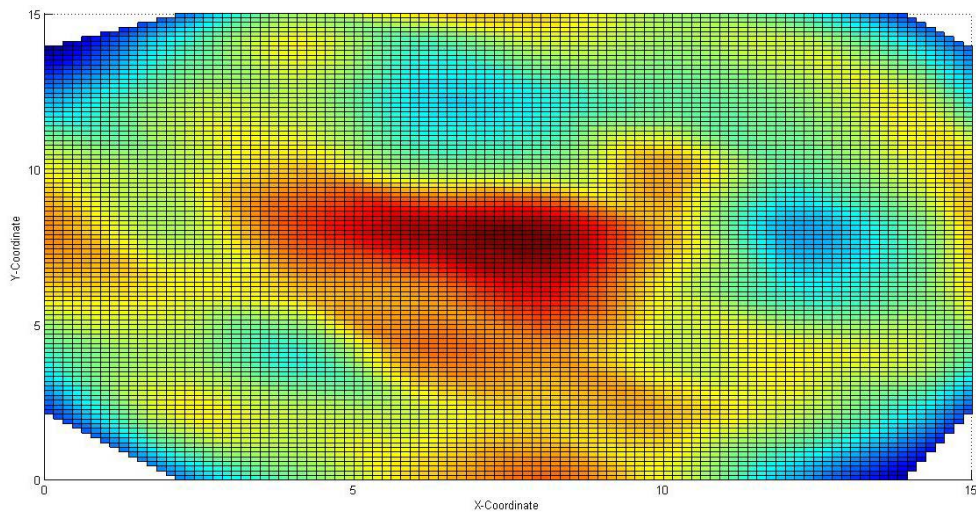
V. RESULTS AND CONCLUSIONS

A. Results

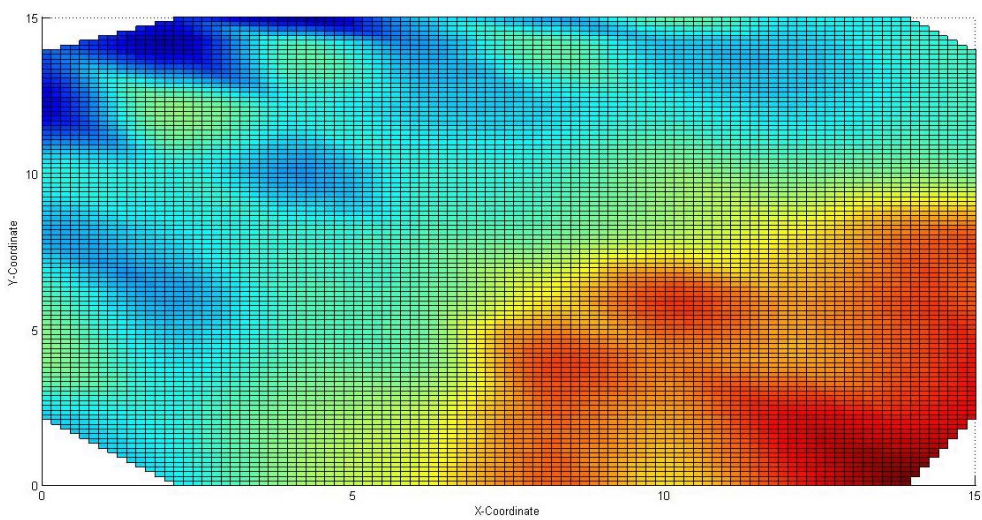
Surface plots of all the five Bluetooth modules are shown in Fig. 4. In each surface plot, strong and weak points of the Bluetooth signal strength are shown. The red area depicts the strongest signal strength whereas blue area shows the weakest signal strength whereas, the yellow region shows signal strength somewhere in between these two extremes. In ideal cases, the transition from red to yellow to blue should be smooth, with the transmitter closer to the receiver there should be a lot of red and once the transmitter is moved further away, the surface plot should show more blue. But in practice it is not the case due to many reasons like atmospheric conditions, environmental noise, multipath fading, reflections, etc. These factors affect the actual signal being received at the receiver end, which could make calculations much more complicated.



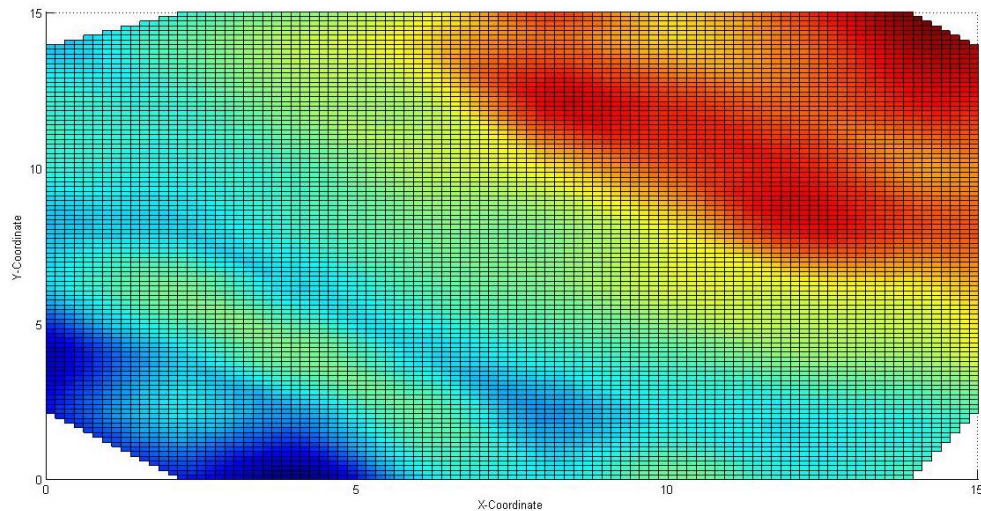
(a)



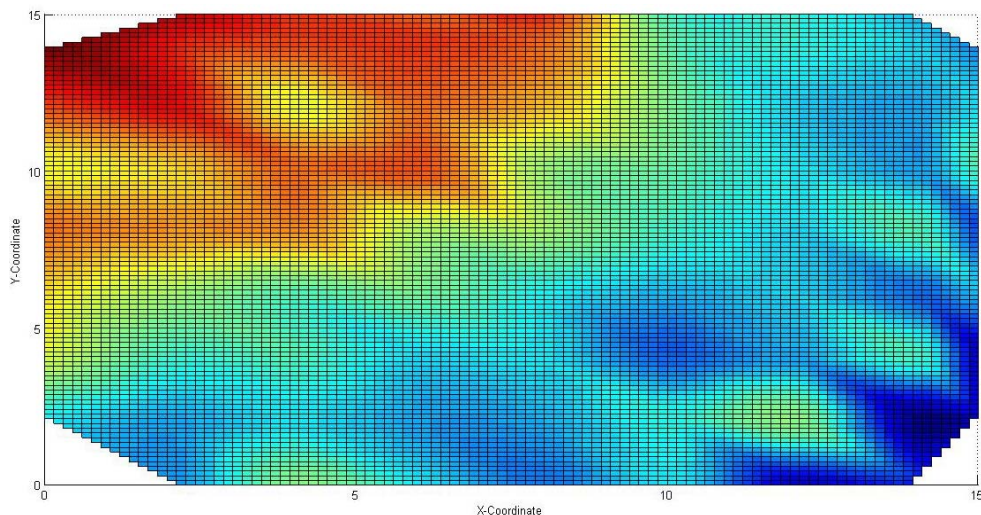
(b)



(c)



(d)



(e)

Fig. 4 Surface plot of Bluetooth modules as seen from TOP (a) BT-1 (b) BT-2 (c) BT-3 (d) BT-4 (e) BT-5

B. Conclusions

Localization for visually impaired people both in the indoor and outdoor environments is the need of today. Various methods of localization were discussed in this paper and it was found that the RSSI of Bluetooth systems can be further improved by improving the existing methodologies. This paper, similarly, proposed an improved method of measuring RSSI using trilateration for localization of Bluetooth devices for visually impaired people. To validate the method, class 2 Bluetooth devices were used along with an evaluation board. A software was also developed in National Instruments LabView. For the experimental part, five Bluetooth modules were placed on a grid of 15 x 15 feet which acted as receivers whose calibration was already carried out. Surface plots of all the five Bluetooth modules were then generated. In each surface plot, strong and weak points of the Bluetooth were

shown. It was also highlighted how many environmental conditions like, atmospheric conditions, environmental noise, multipath fading, reflections, etc., can change the required outputs by affecting the actual signal being received at the receiver end.

REFERENCES

- [1] World Health Organization. (2018) Visual impairment and blindness. (Online) Available: <http://www.who.int/mediacentre/factsheets/fs282/en/>
- [2] R. G. Golledge, J. M. Loomis, R. L. Klatzky A. Flury, and X. L. Yang, "Designing a personal guidance system to aid navigation without sight: progress on the GIS component," *International Journal of Geographical Information Systems*, vol. 5(4), pp. 373-395, 1991.
- [3] S. Halde and A. Ghosal, "Mobility-assisted localization techniques in wireless sensor networks: issues, challenges and approaches," *Cooperative Robots and Sensor Networks*, pp. 43-64, 2014.
- [4] F. Pflaum, S. Erhardt, R. Weigel, and A. Koelpin, "RSSI-based localization with minimal infrastructure using multivariate statistic

- techniques,” in *Proc. of IEEE Topical Conference on Wireless Sensors and Sensor Networks*, 2017, p. 69-72.
- [5] R. Kowalik and S. Kwasniewski, “Navigator: A Talking GPS Receiver for the Blind,” *Lecture Notes in Computer Science, Computers Helping People with Special Needs*, vol. 3118, pp. 446-449, 2004.
- [6] J. Loomis, R. Golledge, and R. Klatzky, “GPS-based navigation systems for the visually impaired,” in *Fundamentals of Wearable Computers and Augmented Reality*, W. Barfield and T. Caudell Eds, pp. 429-446, 2001.
- [7] Q. Wang, I. Balasingham, M. Zhang, and X. Huang, “Improving RSS-Based Ranging in LOS-NLOS Scenario Using GMMs,” *IEEE Communications Letters*, vol. 15(10), pp. 1065–1067, 2011.
- [8] Z. Farid, R. Nordin, and M. Ismail, “Recent advances in wireless indoor localization techniques and system,” *Journal of Computer Networks and Communications*, doi: 10.1155/2013/185138, 2013.
- [9] Dabrowski A, Kardys P, Marciniak T (2005) Bluetooth technology applications dedicated to supporting blind and hearing as well as speech handicapped people. In *ELMAR 47th International Symposium*: 295–298.
- [10] Kriz P, Maly F, Kozel T (2016) Improving indoor localization using Bluetooth low energy beacons. *Mobile Information Systems*, doi: 10.1155/2016/2083094.
- [11] Altini M, Brunelli D, Farella E, Benini L (2010) Bluetooth indoor localization with multiple neural networks. *5th IEEE International Symposium on Wireless Pervasive Computing*, doi: 10.1109/ISWPC.2010.5483748.
- [12] H. Chen and K. Lin, “An improved method for free-space antenna-factor measurement by using the MUSIC algorithm,” *IEEE Transactions on Electromagnetic Compatibility*, vol. 53(2), pp. 274–282, 2011.
- [13] K. Agarwal and X. Chen, “Applicability of MUSIC-type imaging in two-dimensional electromagnetic inverse problems,” *IEEE Transactions on Antennas Propagation*, vol. 56(10), pp. 3217–3223, 2008.
- [14] V. Beamspace, K. T. Wong, and M. D. Zoltowski, “Self-initiating MUSIC-based direction finding in underwater acoustic particle,” *IEEE Journal of Oceanic Engineering*, vol. 25(2), pp. 262–273, 2000.
- [15] S. Henault, Y. M. M. Antar, S. Rajan, R. Inkol, and S. Wang, “Impact of mutual coupling on wideband Adcock direction finders,” *Canadian conference on Electrical and Computer Engineering*, doi: 10.1109/CCECE.2008.4564755, 2008.
- [16] M. Ibrahim and M. Youssef, “CellSense: An accurate energy-efficient GSM positioning system,” *IEEE Transactions on Vehicular Technology*, vol. 61(1), pp. 286–296, 2012.
- [17] K. Wu, J. Xiao, S. Member, Y. Yi, and D. Chen, “CSI-based indoor localization,” *IEEE Transactions on Parallel and Distributed Systems*, vol. 24(7), pp. 1300–1309, 2013.
- [18] P. K. Sahu, E. H. K. Wu, and J. Sahoo, “DuRT: Dual RSSI trend-based localization for wireless sensor networks,” *IEEE Sensors Journal*, vol. 13(8), pp. 3115–3123, 2013.
- [19] Y. Chen, D. Lymberopoulos, J. Liu, B. Priyantha, “Indoor localization using FM signals,” *IEEE Transactions on Mobile Computing*, vol. 12(8), pp. 1502–1517, 2013.
- [20] J. J. M. Diaz, R. D. A. Mau, R. B. Soares, E. F. Nakamura, and C. M. S. Figueiredo, “Bluepass: an indoor Bluetooth-based localization system for mobile applications,” *IEEE Symposium on Computers and Communications*, doi: 10.1109/ISCC.2010.5546506, 2010.
- [21] A. K. M. M. Hossain and W. S. Soh, “A comprehensive study of bluetooth signal parameters for localization,” *IEEE 18th International Symposium on Personal, Indoor and Mobile Radio Communications*, doi: 10.1109/PIMRC.2007.4394215, 2007.
- [22] S. Feldmann, K. Kyamakya, A. Zapater, and Z. Lue, “An indoor Bluetooth-based positioning system: concept, implementation and experimental evaluation,” in *International Conference on Wireless Networks*, pp. 109–113, 2003.
- [23] M. Altini, D. Brunelli, E. Farella, and L. Benini, “Bluetooth indoor localization with multiple neural networks,” *5th IEEE International Symposium on Wireless Pervasive Computing*, doi: 10.1109/ISWPC.2010.5483748, 2010.
- [24] D. Li and J. Wang, “Research of indoor local positioning based on Bluetooth technology,” in *5th International Conference on Wireless Communications, Networking and Mobile Computing*, doi: 10.1109/WICOM.2009.5302300, 2009.
- [25] S. Bohonos, A. Lee, A. Malik, C. Thai, and R. Manduchi, “Universal real-time navigational assistance (URNA): an urban bluetooth beacon for the blind,” in *Proc. of the 1st ACM SIGMOBILE international workshop on Systems and networking support for healthcare and assisted living environments*, pp. 83–88, 2007.
- [26] X. Liu, H. Makino, S. Kobayashi, and Y. Maeda, “Design of an Indoor Self-Positioning System for the Visually Impaired-Simulation with RFID and Bluetooth in a Visible Light Communication System,” in *Engineering in Medicine and Biology Society, EMBS, 29th Annual International Conference of the IEEE*, pp. 1655–1658, 2007.