Indonesian Journal of Electrical Engineering and Computer Science
Vol. 43, No. 2, August 2026, pp. 450~459
ISSN: 2502-4752, DOI: 10.11591/ijeecs.v43.i2.pp450-459

PID-based performance optimization of ultra-wideband microstrip patch antennas for indoor positioning systems

Fredelino A. Galleto Jr.[1,2], Aaron Don M. Africa[1], Bettina Gaille H. Dayrit[1], Gia Kyla S. Guevarra[1], Chrismon Elijah Q. Mansilungan[1], Michael Angelo M. Obciana[1], Mariah Venice A. Rodriguez[1], Keane Dwight A. Sulit[1]
[1]Department of Electronics and Computer Engineering, De La Salle University, Manila, Philippines
[2]Department of Electronics Engineering, University of Southern Mindanao, Cotabato, Philippines

Article Info

Article history:

Received Oct 4, 2024
Revised May 14, 2026
Accepted Jun 29 2026

Keywords:

Fuzzy logic
Indoor positioning system
Microstrip antenna
PID controllers
Rough set theory
UWB building systems

ABSTRACT

Ultra-wideband (UWB) technology has become a key enabler for high-accuracy indoor positioning systems (IPSs), where antenna performance directly influences localization accuracy, signal quality, and communication reliability. However, designing compact UWB microstrip patch antennas with wide bandwidth, low reflection loss, and stable radiation characteristics remains a significant challenge. This paper presents a PID-based performance optimization approach for UWB microstrip patch antennas to improve antenna characteristics for indoor positioning applications. The proposed methodology integrates MATLAB-based electromagnetic simulation with parameter optimization to refine antenna geometry while incorporating optimization concepts inspired by rough set theory and fuzzy logic to support efficient design parameter selection. Using MATLAB and the Parallel Computing Toolbox, the proposed approach significantly reduces computational complexity while accelerating the optimization process. Experimental results demonstrate substantial improvements in reflection coefficient (S11), voltage standing wave ratio (VSWR), radiation pattern, and antenna directivity, particularly around the target operating frequency of 10 GHz. Among the evaluated configurations, the optimized rectangular microstrip patch antenna consistently outperformed the triangular design in terms of impedance matching and radiation performance. The proposed optimization framework provides an effective and computationally efficient solution for enhancing UWB antenna performance, making it well suited for high-precision indoor positioning and next-generation wireless communication systems.

Corresponding Author:

Aaron Don M. Africa
Department of Electronics and Computer Engineering, De La Salle University
Manila, Philippines
Email: aaron.africa@dlsu.edu.ph

1. INTRODUCTION

Ultra-wideband (UWB) technology has emerged as a promising solution for high-accuracy indoor positioning systems (IPSs) because of its wide bandwidth, low transmission power, high data rate, and exceptional ranging accuracy. Unlike the global positioning system (GPS), whose performance deteriorates significantly in indoor environments due to signal attenuation and multipath propagation, UWB-based positioning systems can provide reliable localization in complex indoor scenarios, including smart buildings, industrial automation, healthcare facilities, warehouses, and emergency response operations [1]–[3].

Consequently, UWB technology has attracted considerable research interest as an enabling technology for next-generation indoor localization. Although various indoor positioning techniques based on radio frequency (RF), inertial navigation, vision, and acoustic sensing have been investigated, UWB remains one of the most effective solutions owing to its superior positioning precision, robustness against multipath interference, and high communication reliability. However, the overall performance of UWB-based IPSs is strongly influenced by antenna characteristics, including impedance matching, operating bandwidth, gain, radiation pattern, and directivity. Therefore, the design and performance optimization of UWB microstrip patch antennas have become essential for achieving accurate localization and reliable wireless communication in indoor environments.

RF systems like Wi-Fi, Bluetooth, and UWB are popular positioning technologies employed in various scenarios, including logistics, manufacturing, retail, smart cities, and healthcare [4]. UWB is particularly suitable for challenging environments like in-patient wards of hospitals, where the large number of rooms can impair UWB signal transmission and reception. Electromagnetic interference or noise can also block or reflect UWB signals, causing the multipath effect [5]. UWB also offers high accuracy in tracking the target in real-time, and the accuracy is at meter level [6]–[8]. These systems work hand in hand to calculate the location of the target in real time [9].

In general, integrating these diverse technologies lays the foundation for developing robust IPSs capable of addressing the multifaceted needs of various industries. These integrated systems are also robust because they provide precise and real-time tracking. Furthermore, it makes operations, in general, more efficient, as it increases productivity and encourages innovation.

UWB antennas can be used in various applications. Indoor environments present challenges like noise interference and inaccuracy. Fortunately, these challenges can be simulated using MATLAB. This software can simulate different scenarios in the environment of UWB systems [10]–[12]. UWB can be optimized for specific applications like tracking and indoor positioning. This optimization can address issues in the scalability and adaptability of the system. UWB antennas have emerged as necessary components in wireless communication, ushering in a system change between different applications, specifically in indoor environments [13], [14]. The UWB is recognized for its superior dependability and accuracy. These types of antennas have become essential in determining the direction of wireless communication technology.

Designing UWB antennas with optimal characteristics is a significant challenge, as they need to have broader bandwidth, characteristics that are well-featured, stable gain, and impedance matching over the operational bandwidth. UWB antennas have various applications in UWB communications, radar, sensing, and indoor localization [15], [16]. They are also crucial for fifth-generation (5G) communications, connecting many devices with high-speed data transmission and low latency. Operating easily in different broad spectrum of frequencies, UWB antennas excel in the transmission and reception of short-duration pulses of data [17]. This unique characteristic gives them a range of applications, from high-data-rate communications to the particulars of precise location tracking [18]. The functionalities of UWB antennas applied in IPSs are explored in this research. As technology continues to advance, it is crucial to grasp the design principles and functionalities of UWB antennas.

Common patch antenna designs for UWB applications in recent literature include diamond [19], [20], leaf-shaped bowtie [21], two-loop [22], log-periodic toothed trapezoidal [23], triangular [24], and Metasurfaced-based [25]. These antenna designs are small and compact, making them suitable for various mounting methods in indoor settings. Many of these antennas are only a few centimeters in size. The small size does provide a limitation when it comes to the gain of the antennas, with most antennas having a gain of 2 to 5 dBi. However, this can be easily mitigated by placing the antenna design in an array. This can be seen in the leaf-shaped bowtie array as it had an individual antenna gain close to 2.5 dBi, but it increased to 8 to 10 dBi when placed in an array. The ranges of these antenna designs may vary with the antenna power and design where the highest operational range is 55 m with the diamond patch antenna and the shortest distance being the triangular patch antenna of 1.46 m.

Aside from the self-produced antennas mentioned, commercial antennas also provide UWB functionality. Two models were commonly found, which are the Qorvo MDEK1001 [4] and the DWM1000 antenna module [26], [27]. The Qorvo has an operational range of 30 m around the antenna, a gain of 2.5 dBi, and a working frequency of 5.5 to 7.5 GHz. On the other hand, the DWM1000 has an operational range of 45 m during non-line-of-sight (NLOS) operation and 290 m during line-of-sight (LOS) operation. Moreover, it uses a center frequency of 5 GHz. Where both of the antennas also use the design of a patch antenna, with the DWM1000 specifically having an L-shaped antenna.

One prominent application of UWB antennas is indoor tracking, where multiple studies utilize UWB antennas along with software that can reduce errors in transmitting and receiving data. The usual setup of the tracking system is to have the UWB antenna transmitters to be in fixed locations in a room while there are receivers attached to the person or object that will be tracked [28]–[32]. The transmitters are usually referred to as “anchors,” while the receivers are “tags.” Multiple anchors are required to be placed in rooms in order to track the location of an object in a room more accurately. However, this would mean that larger indoor locations would require more anchors present. This is not only to compensate for the limited range of the anchors but also to account for the loss of signal through NLOS. A larger indoor environment would have more rooms present within them, and the walls of these rooms can block the signals from the anchors. This makes the anchors less accurate in tracking the tagged person or object through a wall. These tracking systems also monitor people or objects in real-time. UWB antennas are mostly favored in these applications because of the large bandwidth they provide, with the largest bandwidth used being 4.29 GHz. This large area for data storage allows the tracking of multiple persons or items at once. This large bandwidth also affects the speed of transmission between the anchors and tags. This is especially important for real-time tracking, as quicker location updates will provide a more accurate reading of the current location of the tag.

The utilization of rough set theory in optimization applications has been relevant in present studies. This also includes a fuzzy logic approach, as in the paper of Chaturvedi and Daniel (2020) [33], where they demonstrated improved network performance in wireless sensor networks by proposing a hybrid protocol that effectively enhances target coverage. Aside from wireless communication applications, fuzzy logic, and rough set theory have also been applied in i) processing large datasets without information loss [33], ii) generalized data reduction [34], and iii) enhancing student career selection with a hybridized distance measure, with case studies demonstrating their effectiveness [35].

Applications in proportional integral derivative (PID) control in IPS UWB building systems are also noteworthy in recent advance research. This system employs UWB technology to deliver high-precision indoor localization, enabling accurate tracking of objects and people across various sectors, including smart buildings, healthcare, logistics, and security. Studies on UWB-based IPS highlight its capabilities in achieving precise location accuracy, as seen in robotic platform tracking [36] and emergency response scenarios with sub-meter accuracy for static targets [37], 2) real-time tracking applications requiring high precision [38], and the use of global navigation satellite system (GNSS)-real-time kinematic (RTK) for rapid emergency deployment [37]. Fundamentally, these applications rely on UWB signals for indoor tracking.

The UWB antennas have a short range of detection, which is a limiting factor to their price-to-performance ratio. In order to accurately measure a person or object inside of a small room, multiple anchors are required to track them accurately. The greatest number of anchors used is eight in a single room [39]. This would make it expensive to track people or objects in a larger location, such as industrial buildings, as multiple anchor points are needed just to cover the area of the building. Therefore, a UWB antenna design that can increase the current operating range of present antenna designs is desirable.

This study aims to contribute significantly to this understanding by delving into the background of UWB antennas, illuminating their unique characteristics, and exploring potential innovations by honing in on the capabilities of UWB antennas; the research endeavors to uncover novel possibilities for augmenting wireless communication and positioning technologies across diverse applications, thereby shaping the future landscape of indoor wireless systems. This study aims to articulate and address these challenges, and the MATLAB software is used to simulate the complexities of the UWB antenna and propose innovative solutions to enhance their efficiency in wireless communication systems in the landscape of UWB technology. Also, this paper aims to design a UWB microstrip antenna in MATLAB, simulate the radiation pattern of the designed UWB microstrip antenna, obtain the reflection coefficient of the designed UWB microstrip antenna, obtain the VSWR of the designed UWB microstrip antenna, and verify if the bandwidth of the designed microstrip antenna is operating in the UWB spectrum.

The successful implementation of this research can revolutionize different sectors like radar systems, telecommunications, and the internet of things (IoT). Increasing the bandwidth within the spectrum of the UWB could lead to more reliable and faster data transfers. This research also contributes to the global trend of utilizing wireless technologies. The demand for high-speed communication persists, particularly in urban areas, and in this context, the UWB microstrip antenna will be valuable.

2. METHODS

This study proposes a systematic methodology for the design, simulation, and performance optimization of UWB microstrip patch antennas intended for IPS applications. The overall framework combines electromagnetic antenna modeling, simulation-based performance evaluation, and PID-based optimization to improve antenna characteristics while maintaining computational efficiency. The methodology consists of three main stages: i) antenna design and parameter configuration, ii) simulation and performance analysis, and iii) PID-based performance optimization.

In the first stage, the geometric parameters of the UWB microstrip patch antenna are determined based on the target operating frequency and substrate characteristics. The antenna dimensions, including the patch geometry, feed position, substrate thickness, dielectric constant, and ground plane configuration, are carefully selected to achieve wide impedance bandwidth, effective impedance matching, and stable radiation characteristics. Both rectangular and triangular microstrip patch antenna configurations are investigated to evaluate their suitability for indoor positioning applications.

The second stage involves electromagnetic simulation and performance evaluation using the MATLAB Antenna Toolbox integrated with the parallel computing toolbox. The simulated antenna models are analyzed using several key performance indicators, including the reflection coefficient (S11), VSWR, impedance bandwidth, radiation pattern, gain, and directivity. These parameters provide quantitative measures of antenna performance and serve as the basis for evaluating the effectiveness of the proposed optimization strategy.

In the final stage, a proportional–integral–derivative (PID)-based optimization approach is employed to iteratively adjust the antenna design parameters in order to achieve improved electromagnetic performance. The optimization process minimizes impedance mismatch while enhancing radiation efficiency and antenna gain across the desired UWB operating band. Simulation data generated during each optimization iteration are further analyzed to identify the optimal antenna configuration that satisfies the design objectives for IPSs.

The proposed methodological framework enables the systematic evaluation of antenna performance while providing an efficient optimization strategy for UWB antenna design. The resulting optimized antenna is expected to exhibit improved impedance matching, wider operational bandwidth, enhanced radiation characteristics, and higher directivity, thereby supporting reliable and accurate wireless communication for high-precision indoor positioning applications.

The flowchart of the MATLAB code for both patch antennas is depicted in Figure 1 at Appendix. Figure 1(a) shows the flow of the MATLAB code for the triangular patch microstrip antenna. The code starts with creating a MATLAB object for the triangular antenna. This object will store the properties of the antenna. Next, the parameters (center frequency and frequency range) for the said antenna are inputted. These are the working/operating frequencies for the antenna. The design() function was used to create the antenna object in accordance with the center frequency. Once the antenna object is created, the model of the antenna is displayed along with the radiation patterns, S-parameter, and VSWR plot. In order to create the most optimal antenna for UWB applications, the antenna's bandwidth must be maximized to achieve a minimum of 500 MHz bandwidth. As such, optimization is required. To do this, the parameters of the antenna to be optimized are its side, height, and feed offset. With this, lower and upper bounds of the parameters are also included so that MATLAB can adjust these parameters accordingly. Once this is done, the optimize() function is used with the antenna object, center frequency, objective (maximize bandwidth), and bounds were used as input. Also, the function canUseGPU() was used to enable parallel computing during the optimization computations to speed up the computations. Once the function is done running, it will output the optimized antenna object. With this, the optimized antenna model, along with its radiation patterns, S-parameter, VSWR, and current distribution plots, will be displayed.

As shown in Figure 1(b), the flow of the MATLAB code for the rectangular patch antenna is seen. The flow for the rectangular antenna is the same as the triangular antenna. The main difference would be the parameters adjusted for optimization, wherein the side, height, and feed offset are to be adjusted for the triangular antenna. While for the rectangular antenna, the length, width, and height of the antenna are adjusted for the optimization process. The objective of optimization is still the same, which is to maximize the bandwidth of the antenna. For comparing the two antennas, the radiation pattern, gain, bandwidth (from the S-parameter plot), and VSWR are the factors to be considered.

3. RESULTS AND DISCUSSION

An analysis of the data obtained from the MATLAB-based design process of the UWB microstrip antenna is discussed in this section. Several key observations can be drawn from the simulation results. The initial phase of the study brought to light a noteworthy challenge in the form of the time-consuming nature of simulating the UWB microstrip antenna design. This extended duration was primarily attributed to the considerable demands on computational resources. Recognizing this hindrance, the researchers strategically implemented a solution by leveraging the parallel computing toolbox. This toolbox, designed for parallel processing, played a pivotal role in significantly enhancing the efficiency and speed of the simulation process. By distributing the computational workload across multiple processors or cores simultaneously, the parallel computing toolbox effectively mitigated the resource-intensive nature of the simulation, resulting in a notable improvement in the overall runtime. The analysis of the initial design reveals that it operates within the UWB band, albeit not optimally. Examination of Figures 2 and 3 (rectangular patch) and Figures 4 and 5 (triangular patch) depicting the reflection coefficient and SWR versus frequency graphs indicates that the antenna primarily operates at approximately 10 GHz.

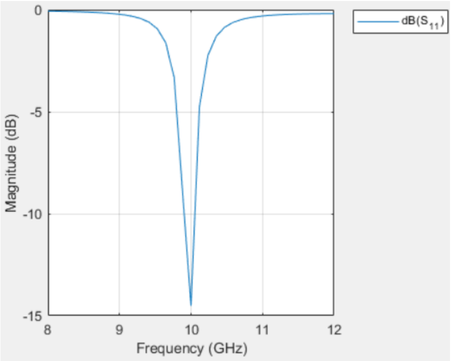

Figure 2. Reflection coefficient vs frequency graph of the rectangular patch microstrip antenna

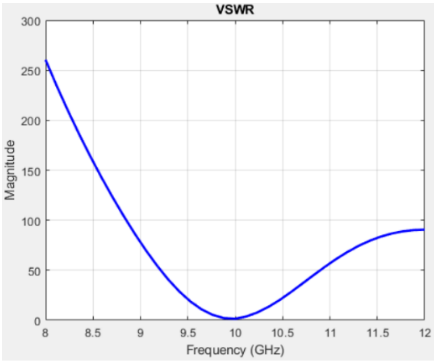

Figure 3. VSWR vs frequency graph of the rectangular patch microstrip antenna

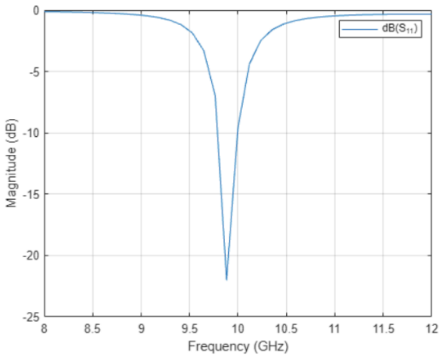

Figure 4. Reflection coefficient vs. frequency graph of the improved rectangular patch microstrip antenna

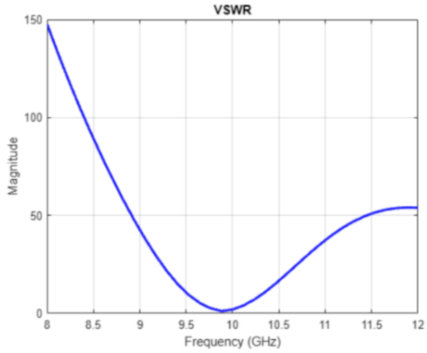

Figure 5. VSWR vs. frequency graph of the improved rectangular patch microstrip antenna

Subsequently, the optimized antenna design, developed using the MATLAB optimization script, demonstrated substantial performance improvements over the initial configuration. As illustrated in Figures 6 and 7 for the rectangular microstrip patch antenna and Figures 8 and 9 for the triangular configuration, the optimized designs achieved improved reflection coefficient (S11) characteristics and lower VSWR values across the target operating frequency range. These improvements indicate enhanced impedance matching between the antenna and the transmission line, thereby reducing signal reflections and increasing power transfer efficiency. The optimized antennas consistently operated around the target frequency of 10 GHz, satisfying the design requirements for UWB IPS applications. The radiation characteristics shown in Figure 10 (initial design) and Figure 11 (optimized design) further confirm the effectiveness of the optimization process. The optimized antenna exhibits a more stable and directional radiation pattern at the intended operating frequency, indicating improved electromagnetic performance and more efficient signal propagation.

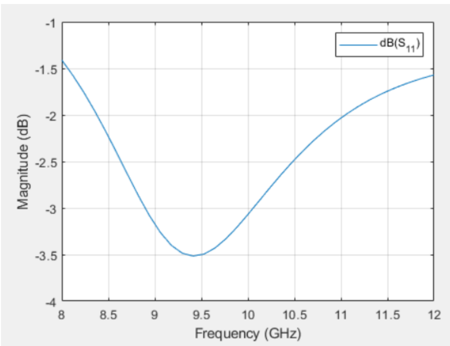

Figure 6. Reflection coefficient vs frequency graph of

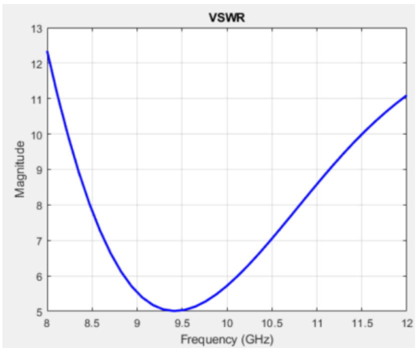

Figure 7. VSWR vs frequency graph of the

the triangular patch microstrip antenna

triangular patch microstrip antenna

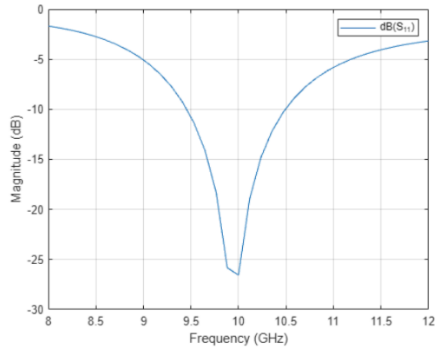

Figure 8. Reflection coefficient vs. frequency graph of the improved triangular patch microstrip antenna

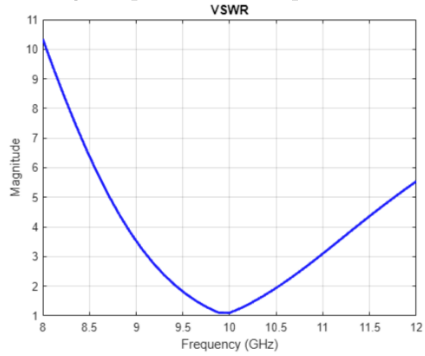

Figure 9. VSWR vs. frequency graph of the improved triangular patch microstrip antenna

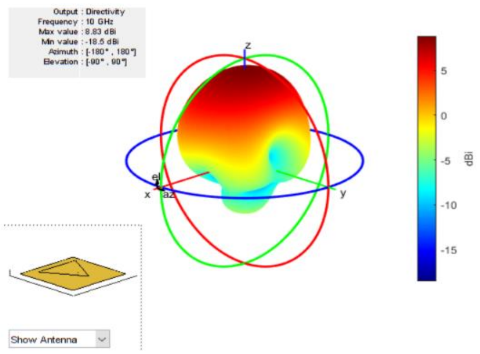

Figure 10. 3-D radiation pattern of triangular patch microstrip antenna

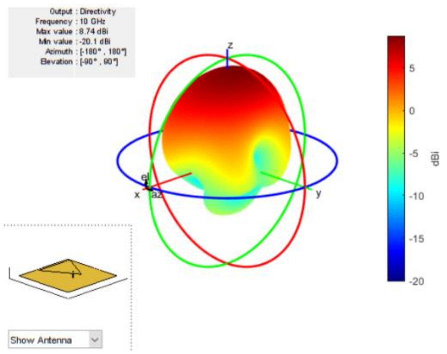

Figure 11. 3-D radiation pattern of improved triangular patch microstrip antenna

In addition to improved impedance characteristics, the optimization process also enhanced the antenna's radiation performance. Comparative analysis revealed that the optimized rectangular UWB microstrip patch antenna consistently outperformed the triangular configuration in terms of directivity and gain. Specifically, the rectangular antenna achieved a maximum gain of 10.1 dBi, whereas the triangular antenna exhibited gains ranging from approximately 8.74 dBi to 8.83 dBi. This improvement in antenna gain indicates a greater ability to concentrate radiated energy toward the desired direction, resulting in stronger signal transmission and improved coverage. Such characteristics are particularly important for IPSs, where localization accuracy and communication reliability depend heavily on antenna performance. Overall, the simulation results demonstrate that the proposed optimization strategy successfully enhances the key electromagnetic characteristics of the UWB microstrip patch antenna, making the optimized rectangular design a more suitable candidate for high-precision indoor positioning and next-generation wireless communication applications.

All in all, the most optimal design presented by the proponents, based on the data and results, is the improved design of the rectangular UWB microstrip patch antenna. This design is particularly well-suited for IPS applications due to its compact form factor, which aligns with the operating characteristics of a UWB antenna.

The findings can lead to several recommendations that could further improve our understanding and practical use of UWB microstrip antennas. Researchers might explore alternative simulation software to address the computational challenges encountered during simulation. This could enable a comparative analysis of different simulation software for UWB microstrip antenna performance. Future research efforts could focus on optimizing antenna design parameters such as patch shapes, dimensions, and substrate material to determine their effect on performance metrics.

4. CONCLUSION

This paper presented a PID-based performance optimization approach for UWB microstrip patch antennas intended for IPS applications. The proposed methodology combined electromagnetic simulation using MATLAB with a systematic optimization strategy to improve the antenna's impedance matching, radiation characteristics, and overall communication performance. The integration of the MATLAB Parallel Computing Toolbox significantly reduced simulation time and enhanced computational efficiency during the antenna optimization process. Simulation results demonstrated that the optimized rectangular UWB microstrip patch antenna achieved substantial improvements in key performance metrics, including the reflection coefficient (S11), VSWR, radiation pattern, and directivity at the target operating frequency of approximately 10 GHz. Comparative analysis further revealed that the optimized rectangular antenna consistently outperformed the triangular design, achieving a maximum gain of 10.1 dBi, compared with 8.74–8.83 dBi for the triangular configuration. These results confirm that the proposed optimization strategy effectively enhances antenna performance while satisfying the operational requirements of high-accuracy IPSs. Overall, the proposed PID-based optimization framework provides an effective and computationally efficient approach for designing high-performance UWB microstrip patch antennas suitable for next-generation indoor localization and wireless communication applications. Although the present study is based on electromagnetic simulations, future work will focus on fabricating and experimentally validating the optimized antenna under real-world indoor environments. Additional investigations will explore alternative patch geometries, substrate materials, feeding techniques, and advanced intelligent optimization methods to further improve antenna bandwidth, gain, radiation efficiency, and localization accuracy.

ACKNOWLEDGEMENTS

The authors gratefully acknowledge the financial and institutional support provided by the Department of Science and Technology – Engineering Research and Development for Technology (DOST–ERDT), which made this research possible.

APPENDIX

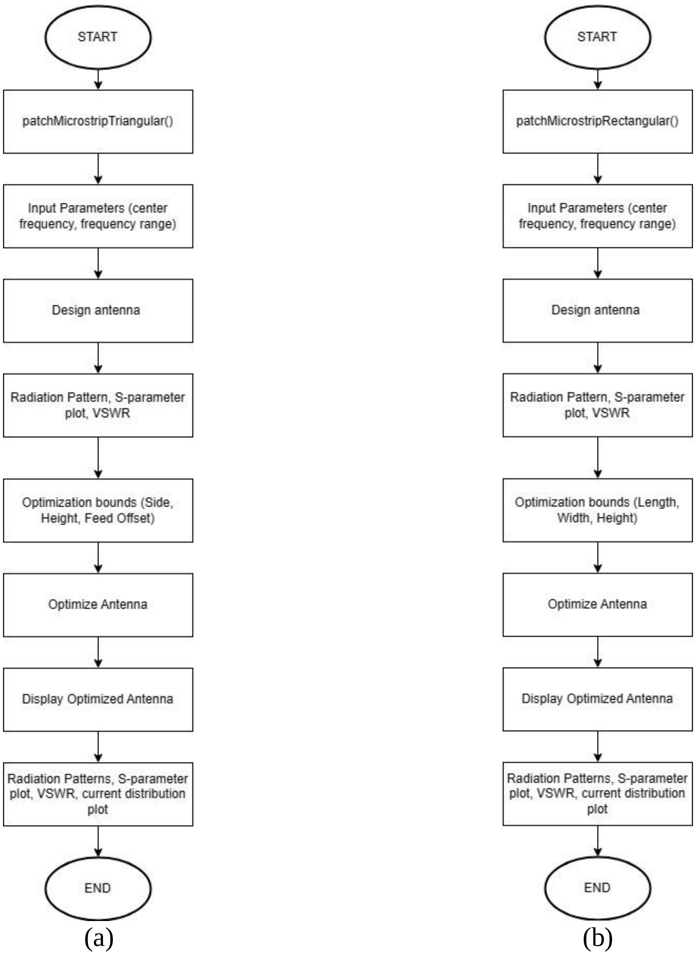

Figure 1. Flowchart of the MATLAB code for (a) triangular and (b) rectangular patch microstrip

REFERENCES

[1] S. J. Hayward, K. van Lopik, C. Hinde, and A. A. West, “A survey of indoor location technologies, techniques and applications in industry,” *Internet of Things (Netherlands)*, vol. 20, 2022, doi: 10.1016/j.iot.2022.100608.

[2] A. Waqar, I. Ahmad, D. Habibi, and Q. V. Phung, “Analysis of GPS and UWB positioning system for athlete tracking,” *Measurement: Sensors*, vol. 14, 2021, doi: 10.1016/j.measen.2020.100036.

[3] W. Ma, X. Fang, L. Liang, and J. Du, “Research on indoor positioning system algorithm based on UWB technology,” *Measurement: Sensors*, vol. 33, p. 101121, 2024, doi: 10.1016/j.measen.2024.101121.

[4] A. Volpi, L. Tebaldi, G. Matrella, R. Montanari, and E. Bottani, “Low-cost UWB based real-time locating system: development, lab test, industrial implementation and economic assessment,” *Sensors*, vol. 23, no. 3, 2023, doi: 10.3390/s23031124.

[5] D. Zhu, H. Wang, and J. Yue, “A multi-model vehicle integrated navigation algorithm based on EM estimation,” *Yi Qi Yi Biao Xue Bao/Chinese Journal of Scientific Instrument*, vol. 43, no. 7, pp. 239–246, 2022, doi: 10.19650/j.cnki.cjsi.J2209692.

[6] W. Suski, S. Banerjee, and A. Hoover, “Using a map of measurement noise to improve UWB indoor position tracking,” *IEEE Transactions on Instrumentation and Measurement*, vol. 62, no. 8, pp. 2228–2236, 2013, doi: 10.1109/TIM.2013.2256714.

[7] Y. Liu, L. Yang, and J. Li, “Robust UWB indoor position tracking using TDOA measurements,” *2018 IEEE 4th International Conference on Computer and Communications, ICCC 2018*, pp. 736–743, 2018, doi: 10.1109/CompComm.2018.8780881.

[8] M. C. Chen, Y. T. Cheng, and R. W. Chen, “A novel indoor positioning framework,” *CMES - Computer Modeling in Engineering and Sciences*, vol. 130, no. 3, pp. 1459–1477, 2022, doi: 10.32604/cmes.2022.015636.

[9] J. Blazek, J. Jiranek, and J. Bajer, “Indoor passive positioning technique using ultra wide band modules,” *ICMT 2019 - 7th International Conference on Military Technologies, Proceedings*, 2019, doi: 10.1109/MILTECHS.2019.8870099.

[10] G. Kumar and R. Kumar, “A survey on planar ultra-wideband antennas with band notch characteristics: Principle, design, and applications,” *AEU - International Journal of Electronics and Communications*, vol. 109, pp. 76–98, 2019, doi: 10.1016/j.aeue.2019.07.004.

[11] Y. Alnaiemy and N. Lajos, “Design and analysis of ultra-wide band (UWB) antennas based on metamaterial,” *2018 11th International Symposium on Communication Systems, Networks and Digital Signal Processing, CSNDSP 2018*, 2018, doi: 10.1109/CSNDSP.2018.8471835.

[12] M. Jayaram, S. Murugan, S. Mohandass, and B. M. Anjaneyulu, “Design and simulation of ultra-wideband antenna for wireless applications,” *Proceedings of the 2022 3rd International Conference on Communication, Computing and Industry 4.0, C2I4 2022*, 2022, doi: 10.1109/C2I456876.2022.10051580.

[13] S. Soni, M. Shrivastava, and A. Agwekar, “A detail concept and survey on ultra wide band (UWB) antennas,” *2nd International Conference on Data, Engineering and Applications, IDEA 2020*, 2020, doi: 10.1109/IDEA49133.2020.9170657.

[14] P. Kumar, M. M. M. Pai, and T. Ali, “Ultrawideband antenna in wireless communication: a review and current state of the art,” *Telecommunications and Radio Engineering (English translation of Elektrosvyaz and Radiotekhnika)*, vol. 79, no. 11, pp. 929–942, 2020, doi: 10.1615/TelecomRadEng.v79.i11.20.

[15] M. Y. Mohamed, A. M. Dini, M. M. Soliman, and A. Z. M. Imran, “Design of 2× 2 microstrip patch antenna array at 28 GHz for millimeter wave communication,” *2020 IEEE International Conference on Informatics, IoT, and Enabling Technologies, ICIoT 2020*, pp. 445–450, 2020, doi: 10.1109/ICIoT48696.2020.9089458.

[16] C. Wei and Q. Ge, “Indoor positioning and navigation model based on semantic grid,” *International Journal of Pattern Recognition and Artificial Intelligence*, vol. 36, no. 6, 2022, doi: 10.1142/S0218001422550096.

[17] H. Ş. Savcı, “A four element stringray-shaped MIMO antenna system for UWB applications,” *Micromachines*, vol. 14, no. 10, 2023, doi: 10.3390/mi14101944.

[18] A. M. V. Venkata Sai and Y. Li, “A survey on privacy issues in mobile social networks,” *IEEE Access*, vol. 8, pp. 130906–130921, 2020, doi: 10.1109/ACCESS.2020.3009691.

[19] A. Benouakta, T. M. Nguyen, F. Ferrero, L. Lizzi, and R. Staraj, “Design of a multi-standard UWB-LoRa antenna structure and transceiver board for high-accuracy and long-range localization applications,” *Electronics (Switzerland)*, vol. 12, no. 21, 2023, doi: 10.3390/electronics12214487.

[20] A. Benouakta, F. Ferrero, L. Lizzi, and R. Staraj, “Frequency reconfigurable and circularly polarized patch antenna over dual ultra-wideband channels,” *2022 16th European Conference on Antennas and Propagation, EuCAP 2022*, 2022, doi: 10.23919/eucap53622.2022.9769006.

[21] M. Yamamoto, D. Tokuyama, and T. Nojima, “Design of quasi-millimeter wave leaf-shaped bowtie array antenna for uwb applications,” *2010 IEEE International Symposium on Antennas and Propagation and CNC-USNC/URSI Radio Science Meeting - Leading the Wave, AP-S/URSI 2010*, 2010, doi: 10.1109/APS.2010.5561106.

[22] J. Kang, S. Rao, P. Chiang, and A. Natarajan, “Design and optimization of area-constrained wirelessly powered CMOS UWB SoC for localization applications,” *IEEE Transactions on Microwave Theory and Techniques*, vol. 64, no. 4, pp. 1042–1054, 2016, doi: 10.1109/TMTT.2016.2536663.

[23] S. He and X. Dong, “High-accuracy localization platform using asynchronous time difference of arrival technology,” *IEEE Transactions on Instrumentation and Measurement*, vol. 66, no. 7, pp. 1728–1742, 2017, doi: 10.1109/TIM.2017.2666278.

[24] K. Jebbawi, M. Egels, and P. Pannier, “Design of an ultra-wideband uhf rfid reader antenna for wearable ankle tracking applications,” *Progress In Electromagnetics Research C*, vol. 102, pp. 253–264, 2020, doi: 10.2528/PIERC20040703.

[25] H. Almizan, M. H. Jwair, Y. Al Naiemy, Z. A. Abdul Hassain, L. Nagy, and T. A. Elwi, “Novel metasurface based microstrip antenna design for gain enhancement RF harvesting,” *Infocommunications Journal*, vol. 15, no. 1, pp. 2–8, 2023, doi: 10.36244/ICJ.2023.1.1.

[26] Y. Y. Chen, S. P. Huang, T. W. Wu, W. T. Tsai, C. Y. Liou, and S. G. Mao, “UWB system for indoor positioning and tracking with arbitrary target orientation, optimal anchor location, and adaptive NLOS mitigation,” *IEEE Transactions on Vehicular Technology*, vol. 69, no. 9, pp. 9304–9314, 2020, doi: 10.1109/TVT.2020.2972578.

[27] M. Zhao, T. Chang, A. Arun, R. Ayyalasomayajula, C. Zhang, and D. Bharadia, “ULoc: low-power, scalable and cm-accurate UWB-tag localization and tracking for indoor applications,” *Proceedings of the ACM on Interactive, Mobile, Wearable and Ubiquitous Technologies*, vol. 5, no. 3, 2021, doi: 10.1145/3478124.

[28] P. Grasso, M. S. Innocente, J. J. Tai, O. Haas, and A. M. Dizqah, “Analysis and accuracy improvement of UWB-TDoA-based indoor positioning system,” *Sensors*, vol. 22, no. 23, 2022, doi: 10.3390/s22239136.

[29] S. Milici, A. Esposito, and E. M. Staderini, “Evaluating athletic performances with a real time location and tracking system,” *Materials Science Forum*, vol. 879, pp. 2352–2354, Nov. 2016, doi: 10.4028/www.scientific.net/MSF.879.2352.

[30] S. Lan, C. Yang, B. Liu, J. Qiu, and A. Denisov, “Indoor real-time multiple moving targets detection and tracking using UWB antenna arrays,” *2015 International Symposium on Antennas and Propagation, ISAP 2015*, pp. 1–4, 2016.

[31] B. Hanssens *et al.*, "An indoor variance-based localization technique utilizing the UWB estimation of geometrical propagation parameters," *IEEE Transactions on Antennas and Propagation*, vol. 66, no. 5, pp. 2522–2533, 2018, doi: 10.1109/TAP.2018.2810340.
[32] S. W. Kim and D. Y. Choi, "Analysis of beamforming antenna for practical indoor location-tracking application," *Sensors (Switzerland)*, vol. 19, no. 14, 2019, doi: 10.3390/s19143040.
[33] K. Anitha and M. Thangeswari, "Rough set based optimization techniques," *2020 6th International Conference on Advanced Computing and Communication Systems, ICACCS 2020*, pp. 1021–1024, 2020, doi: 10.1109/ICACCS48705.2020.9074212.
[34] A. M. Ghroutkhar and H. M. Nehi, "Fuzzy–rough set models and fuzzy-rough data reduction," *Croatian Operational Research Review*, vol. 19, no. 1, pp. 67–80, 2020, doi: 10.17535/crorr.2020.0006.
[35] R. Sahu, S. R. Dash, and S. Das, "Career selection of students using hybridized distance measure based on picture fuzzy set and rough set theory," *Decision Making: Applications in Management and Engineering*, vol. 4, no. 1, pp. 104–126, 2021, doi: 10.31181/dmame2104104s.
[36] A. Alghuraid *et al.*, "Development of ultra-wide-band indoor positioning system designed to control the position of a grid confined robotic platform," *2021 4th International Symposium on Advanced Electrical and Communication Technologies, ISAECT 2021*, 2021, doi: 10.1109/ISAECT53699.2021.9668606.
[37] T. Adame, J. Igual, and M. Catalan, "Fast deployment of a UWB-based IPS for emergency response operations," *Sensors*, vol. 23, no. 9, 2023, doi: 10.3390/s23094193.
[38] S. Campaña-Bastidas, M. Espinilla-Estévez, and J. Medina-Quero, "Review of ultra wide band (UWB) for indoor positioning with application to the elderly," *Proceedings of the Annual Hawaii International Conference on System Sciences*, vol. 2022-Janua, pp. 2145–2154, 2022, doi: 10.24251/hicss.2022.269.
[39] F. Vollmer, J. Graßhoff, and P. Rostalski, "Probabilistic ultra-wideband TDoA localization with bias correction," *European Signal Processing Conference*, vol. 2022-Augus, pp. 1512–1516, 2022, doi: 10.23919/eusipco55093.2022.9909651.

BIOGRAPHIES OF AUTHORS

Fredelino A. Galleto Jr. is a licensed electronics engineer in the Philippines. Currently, he is taking up a Doctor of Philosophy in Electronics and Communications Engineering at De La Salle University, Manila. He has been a faculty of the Department of Electronics Engineering at the University of Southern Mindanao, Kabacan, Cotabato, Philippines, since October 2018. His current research interest involves data optimization, antenna and communications systems, and information and communications technology. He can be contacted at email: fredelino_galletojr@dlsu.edu.ph.

Aaron Don M. Africa is a researcher in the field of Communications Network Engineering. He is one of the most promising researchers in that area. His area of expertise are Communications Network Engineering, Expert Systems, Control Systems, Network Design, and Optimization. Specifically, he deals with the Optimization of Communication Systems to make them more efficient in functionality. This is for these systems to adapt effectively in the industry. He creates simulation models to replicate different scenarios in Network design. He can be contacted at email: aaron.africa@dlsu.edu.ph.

Bettina Gaille H. Dayrit is an undergraduate student taking Bachelor of Science in Electronics Engineering at De La Salle University Manila. Her current research interest involves robotics, automation, and computer vision systems. She has worked on projects such as full-stack application development using Python, React, FastAPI, and Docker, as well as implementing a mobile robot using SLAM through a Robot Operating System. She can be contacted at email: bettina_gaille_h_dayrit@dlsu.edu.ph.

Gia Kyla S. Guevarra is a current student taking Bachelor of Science in Electronics Engineering (ECE) at De La Salle University Manila. Her research interests include robotics, automation, computer vision systems, and application development. She has practical experience in app development projects using Java. She can be contacted at email: gia_guevarra@dlsu.edu.ph.

Chrismon Elijah Q. Mansilungan is an undergraduate student taking Electronics and Communications Engineering at De La Salle University. He has particular interest in coding languages such as C++ and Python and is currently looking to widen his knowledge and understanding of other coding languages. He can be contacted at email: chrismon_mansilungan@dlsu.edu.ph.

Michael Angelo M. Obciana is an undergraduate student taking Bachelor of Science in Electronics and Communications Engineering at De La Salle University. His research interests include wireless communications, cybersecurity, and systems design. He has also practical experience in Network Systems Engineering, particularly network planning and management. He can be contacted at email: michael_obciana@dlsu.edu.ph.

Mariah Venice A. Rodriguez is an undergraduate student taking Bachelor of Science in Electronics Engineering at De La Salle University Manila. Her current research interest involves robotics, automation, and computer vision systems. She has worked on projects involving Arduino Uno for control systems and generate creative designs using Fusion 360. She can be contacted at email: mariah_rodriguez@dlsu.edu.ph.

Keane Dwight A. Sulit is an undergraduate student taking Bachelor of Science in Electronics Engineering at De La Salle University. His current research interest involves robotics, automation, and computer vision systems. He has experience working with Python and its libraries, including PyTorch, TensorFlow, and Ultralytics (YOLO). He has also contributed to projects related to digital signal processing and steganography. His hobbies include exploring the field of acoustics. He can be contacted via email: keane_sulit@dlsu.edu.ph.