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Analysis of Wi-Fi Signal Transmission and Reception Using Software-Defined Radio

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Abstract
Wi-Fi signal transmission and reception via Software-Defined Radio (SDR), with emphasis on signal strength and its interaction with human interfaces. The research examines how Wi-Fi signals decay when the distance is greater and how they disperse or get attenuated upon encountering the human body. One of the core features of the research is one-way signal transmission, which will be used to guide Wi-Fi signals to designated targets for better coverage and less interference. Furthermore, human effects on signal loss are analyzed in order to provide insight into possible interference patterns and optimization methods. By quantifying and evaluating these impacts, the project is expected to enhance signal intensity and quality in highly interfering surroundings, increasing wireless communication system efficiency.

Keywords: Wi-Fi, Software-Defined Radio, Signal Attenuation, Unidirectional Transmission, Wireless Communication, Human Interaction

1. Introduction

The increasing application of Wi-Fi networks for general communication, data transmission, and smart devices shows the need to maintain signal strength and coverage with uninterrupted supply. Wi-Fi signals can be attenuated by physical obstructions such as walls, furniture, and most severely, human bodies. Human bodies, predominantly water, act as electromagnetic wave absorbers and result in attenuation, scattering, and reflection of signals. This is especially concerning in environments where people keep changing places, such as in offices, shopping centers, or home environments with networked devices, and thus network performance is no longer predictable.

Deterioration of Wi-Fi signals can result in reduced data transmission rates, latency, and reduced user experience, particularly in areas inhabited by humans. Studies on how Wi-Fi signals engage with human interfaces are crucial to optimize network planning and facilitate effective communication in such environments. Current methods employed in compensating for signal weakening, like power boosting or the addition of additional access points, are not cost-effective and efficient, particularly in a complex environment where humans are constantly on the move.

This study utilizes Software-Defined Radio (SDR) in studying Wi-Fi signal transmission and reception in terms of the impact that human bodies have on signal strength. SDR provides dynamic control over signal parameters, and therefore it is a suitable instrument to utilize when studying dynamic signal effects. The study explores the impact of a human body on signal weakening and also studies unidirectional transmission as a remedy. By concentrating Wi-Fi signals on targets with directional antennas, the research attempts to reduce signal dispersal and maximize coverage in a crowd.

The result of the study has wide applications for the improvement of wireless communication systems, particularly smart offices, homes, and public spaces where it is imperative to ensure strong Wi-Fi connectivity. In improving signal reception and reducing interference caused by the human body, the study hopes to contribute towards the improvement of stronger and more effective wireless network performance.

This study has the following contributions:

- **Analysis of Wi-Fi signal attenuation under human obstacles:** The research rigorously quantifies the impact of human bodies on Wi-Fi signal strength and attenuation, providing knowledge on signal weakening due to human interfaces, especially in high-density areas.
- **Use of Software-Defined Radio (SDR) for signal analysis:** Using SDR, this study enables dynamic control and accurate measurement of Wi-Fi signals and offers a flexible platform to test the influence of distance, human presence, and other environmental parameters on signal transmission.
- **Study of unidirectional Wi-Fi transmission:** The research examines one-way signal transmission with the use of directional antennas, measuring its efficiency in reducing signal loss caused by human interference. It points out the capability of aimed transmission to boost signal strength and coverage.
- **Comparison of omni-directional and unidirectional transmission:** Performance comparison between omni-directional and unidirectional transmission is given, pointing out the benefit of directing signals towards targets in order to reduce interference and enhance network reliability.
- **Implications for wireless network optimization in human-dense settings:** The research offers practical lessons on how techniques of signal transmission can be improved in settings that have high human interaction, such as offices, smart homes, and public places, resulting in enhanced Wi-Fi network performance and user experience.

2. Literature Review

The literature on transmission and reception of Wi-Fi signals comprises detailed studies that primarily provide insight into the intricacy of wireless communication systems. This review integrates relevant literature illustrating the challenge of attenuating signals, human barrier effects, and best transmission using Software-Defined Radio (SDR).

Lin [1] and Jeong *et al.* [2] are willing to stress the role of the environment in Wi-Fi signal weakening and strengthening. Their work attests the postulation that deterioration of the signals by obstructions, for instance, the human body, is a simple wireless communication issue even now. Islam *et al.* [3] demonstrated the potential impact on non-contact monitoring of vital signs through millimeter-wave FMCW radar by propagation issues of the signal, upholding the use of good quality signal measuring tools.

SDR's role in dynamic wireless signal processing has been thoroughly studied. Sekak [4] studied SDR-based microwave radar techniques and emphasized the application of its use on contactless measuring methods. Brulc *et al.* [5] also addressed SDR's role in precision-based signal processing by demonstrating that it is effective in detecting cardiac signatures using contactless technique with the millimeter-wave FMCW radar.

Human existence is among the main causes of degradation of Wi-Fi signals. Hu *et al.* [6] and Obeid *et al.* [7] compared a variety of frequency bands (2.4 GHz, 5.8 GHz, and 60 GHz) to establish their sensitivity factor against humans as an interference factor. Vinci *et al.* [8] and Koelpin *et al.* [9] brought microwave interferometry techniques to implement enhanced detection of obstacles in wireless networks, and implications for enhancement of signal transmission in dense scenarios.

Directional and omni-directional transmission methods have been compared in some research studies. Khan and Cho [10] explained how IR-UWB radar achieves signal concentration for minimizing interference. Rivera *et al.* [11] and Choi *et al.* [12] compared directional transmission with improved signal stability, particularly under dynamic scenarios. Liu *et al.* [13] examined edge computing possibilities for ideal real-time signal processing, again strengthening the advantage of directional transmission in high-density environments.

Comparative research indicates that the advancement in signal transmission techniques enhances network performance. Costanzo *et al.* [14, 15] compared radar-based target detection with software-defined Doppler radar sensors and demonstrated the feasibility of adaptive signal processing. Sharma *et al.* [16] investigated attention detection by RF sensors and demonstrated the feasibility of selective signal transmission to minimize attenuation due to human movement.

Despite the huge advancements, there are still issues in the enhancement of SDR-based Wi-Fi networks. Lie *et al.* [17] and Li *et al.* [18] stressed the need for enhanced non-contact sensing techniques. Raffo *et al.* [19] proposed software-defined Doppler radar solutions to boost signal monitoring accuracy. Hui and Kan [20] designed multiplexed radio systems to enhance signal transmission for better performance in areas inhabited by humans.

The overall review emphasizes the developing body of literature on SDR-based analysis and transmission of Wi-Fi signal. Critical scholarship sets the framework for human action in signal attenuation and suggests divergent optimization solutions, including high-gain antennas and sophisticated signal processing. Future research would be required to wrestle with the computational limitations and examine new emerging technologies such as machine learning towards real-time enhancement of the signal. Results provide a solid basis for the designing of improved wireless communication systems tailored to advanced, high-interference environments.

3. Methodology

A. Experiment Setup

In order to get accurate and repeatable results, the experimental setup was made in an indoor controlled environment that replicates real-life scenarios. The environment was chosen with care to replicate typical Wi-Fi usage environments, i.e., offices, public areas, or smart homes. The following equipment was used:

- **Wi-Fi Transmitter:** SDR-based Wi-Fi module was used as a Wi-Fi signal transmitter on 2.4 GHz and 5 GHz frequency bands.
- **Wi-Fi Receiver:** A receiver from an SDR was employed to record the sent signals and measure signal strength values like Received Signal Strength Indicator (RSSI), Signal-to-Noise Ratio (SNR), and attenuation.
- **Human Obstacles:** Human subjects were positioned at different distances (1m, 2m, 3m) between the transmitter and receiver to represent the real effect of human existence on Wi-Fi signal attenuation.
- **Omni-Directional and Directional Antennas:** Omni-directional and directional antennas were employed on

the receiver end to contrast the performance of both transmission methods.

The controlled situation provided a level of minimum outside disturbance so that precise measurements could be made for signal attenuation via obstructions generated by humans. Human subjects stood face-to-face between the transmitter and receiver in order to establish the worst-case signal blocking. The tests were repeated several times to provide a high degree of repeatability to minimize variability in data.

B. Data Collection and Signal Measurement

The collection of data was carried out through real-time observation by the SDR. The below are the essential performance indicators collected for each case (with and without human interference, and through omni-directional and directional transmission):

- **Received Signal Strength Indicator (RSSI):** This reading provided a measurement of the power in the received signal. RSSI readings were used to determine the degree of signal weakening due to human presence at different distances.
- **Signal-to-Noise Ratio (SNR):** The SNR was quantified to assess the quality of the received signal. A higher SNR indicates a better signal, and a lower SNR indicates too much interference or noise in the signal path.
- **Attenuation Levels:** Attenuation level (signal weakening) was measured by the difference between RSSI and SNR values for the free and obstructed signal paths.

The readings were for different distances from the receiver and transmitter, i.e., between 1 to 5 meters, with a human obstacle positioned directly in the line of sight between them. In each experiment, the subjects were instructed to remain stationary for the purpose of recording the stationary effect on the signal. Movement trials involving moving subjects were also performed to compare how movement impacts the signal's attenuation.

C. Unidirectional vs. Omni-Directional Transmission

To compare how effective unidirectional transmission is in reducing signal loss, a directional antenna was used against the standard omni-directional antenna configuration. The directional antenna was oriented in the direct path towards the receiver, with the aim of focusing the Wi-Fi signal onto the target and avoiding human obstructions from interfering with it.

- **Omni-Directional Transmission:** This setup emitted signals in all directions so that the signal would be affected by obstructions along its path, like the human subjects. The omni-directional tests provided us with a baseline for measuring signal attenuation caused by human bodies and normal environmental interference.
- **Unidirectional Transmission:** In the unidirectional tests, the directional antenna was configured to concentrate the signal beam directly towards the receiver, reducing signal dispersion. By concentrating the signal, the aim was to overcome attenuation by human obstacles and improve the overall signal strength in scenarios with human interference.

The experiment was to find the extent of signal degradation between these two modes of transmission. For testing this, the human subjects were placed at varying distances from the transmitter to receiver to simulate different levels of interference for every test.

D. Statistical Analysis

Following data collection, statistical analysis was carried out to determine the impact of human barriers on signal transmission. Analysis included:

- **Attenuation Analysis:** Attenuation was calculated in each scenario to ascertain the extent of signal loss with the presence of human beings. The analysis was carried out to ascertain how signal loss differed when transmitted using omni-directional and unidirectional transmission modes and establish the optimal transmission mode to be used to mitigate attenuation.
- **Comparison of RSSI and SNR Values:** Comparing RSSI and SNR values across different distances and obstacle environments allowed patterns of signal degradation to be identified. Statistical analysis software like t-tests and ANOVA were used to check whether the differences in signal strength from unidirectional versus omni-directional transmission were statistically significant.
- **Distance Impact on Signal Strength:** Correlation analysis was conducted to find the degree to which signal attenuation is a function of distance. Responses were compared between both transmission alternatives to gauge unidirectional transmission efficiency at increased distance for the presence of human obstructions.

E. Limitations and Controls

In order to keep the findings valid, the research utilized several important limitations and control measures to remove possible sources of error and validate the findings:

- **External Interference Mitigation:** The experiments were conducted in a controlled environment to minimize the effect of external interference due to surrounding electronics, adjacent wireless networks, and other electromagnetic noise sources. Isolation was achieved by the use of shielding methods to restrict the test environment such that analyzed Wi-Fi signals were not affected by spurious overlap of the signals or external interference. With this control, proper measurement of the activity of the Wi-Fi signal when the body is in the equation could be made.
- **Controlled Human Movement:** To mimic actual conditions without introducing extraneous variability, the human subject motion in dynamic tests was standardized. Subjects were forced to move along pre-defined patterns and speeds, mimicking typical activities like walking or standing. Through controlled motion, the research was able to measure how human interference would affect Wi-Fi signals uniformly in a series of trials.
- **Repetitions and Averaging:** Every experiment was repeated several times due to the purposes of ensuring consistency and reliability of data collected. Repetition of trials served to minimize the effects of random fluctuations or inconsistencies in results. Ultimate analysis used the mean values of repeated instances as a way of eliminating inconsistencies and giving a precise representation of signal attenuation and variability in

performances among omni-directional and unidirectional transmission systems.

- **Environmental Consistency:** Precautions were taken in experiments to ensure consistency of the environment, e.g., the temperature of the room, humidity, and anything else that might have an effect on the propagation of Wi-Fi signals. Environmental conditions were monitored and regulated as much as possible so that they would not have any effect on the outcome, so that the signals would be attenuated by human activity and the nature of the transmission method employed.
- **Antenna Alignment and Calibration:** The one-way transmission tests employed directional antennas, and the antennas were set and calibrated prior to each test to point in the same direction towards the receiver for every test run. Misalignment of antennas can deceive by altering the direction of the signal, and calibration was a required control measure to ensure the integrity of the one-way transmission tests.
- **Dynamic and Static Scenario Controls:** The research distinguished between human interference conditions in static and dynamic states. In the case of static tests, human subjects remained stationary to estimate baseline human-induced attenuation. Controlled patterns of movement were employed in dynamic tests, as detailed above. By making this distinction, the research was able to test both the uniform and variable effect of human interference on Wi-Fi signal strength.

These control measures were essential to maintaining the consistency and reliability of the experimental data, enabling more accurate measurement of Wi-Fi signal loss and the efficacy of unidirectional transmission in avoiding human-caused signal loss. The use of environmental control, controlled human interaction, and replication made the results replicable and applicable to actual Wi-Fi communication issues.

E. Summary of Methodology

Methodology used in this research provides in-depth and structured examination of Wi-Fi signal behavior, especially in environments with large amounts of unavoidable human interaction. Using Software-Defined Radio (SDR), the research utilizes real-time monitoring and control functions to measure Wi-Fi signal transmission, attenuation, and impact of human interference on signal strength accurately. The technique is designed to solve the most significant issues of man-made interference, providing a single methodology for the determination of omni-directional and uni- directional transmission techniques.

Test environments were constructed to mimic real-world environments such as offices, public areas, or smart homes where Wi-Fi networks are typically obstructed by physical obstacles and human movement. The controlled laboratory allowed the study to separate the impact of human barriers on Wi-Fi signals and reduce interference from other wireless devices or networks present in the environment. Using SDR, the study had the capability to dynamically modify and adjust important parameters like frequency, modulation, and transmission power with flexibility to emulate varied transmission conditions of Wi-Fi signals.

Measurement data was obtained with the help of sophisticated signal measurement tools incorporated in SDR to monitor key measurements, such as Received Signal Strength Indicator (RSSI) and Signal-to-Noise Ratio (SNR). Measurements provided precise information on the performance of Wi-Fi signals when passing through human bodies at different receiver-transmitter distances. The research recorded both static and dynamic conditions of human interference to capture the variety of activities Wi-Fi signals are subjected to in actual environments. This enabled a proper explanation of how signal strength weakens as a result of human movement and proximity, with a complete data set for analysis.

Contrasting omni-directional and unidirectional transmission approaches was one of the main issues of the study. The omni-directional transmission approach, in which signals were transmitted in every direction, was used as the standard for signal attenuation in the case of human obstacles. The unidirectional transmission approach used directional antennas to focus Wi-Fi signals in a given target with the objective of reducing the dispersion and attenuation brought about by human bodies. This analogy assisted in measuring the capacity of focused signal transmission to enhance Wi-Fi coverage and minimize interference in regions with significant human interaction.

Apart from evaluating signal loss, the research included strict statistical analysis to confirm differences in performance of omni-directional and unidirectional transmission techniques reported as statistically significant. RSSI, SNR, and attenuation in general were investigated systematically through statistics such as t-tests and ANOVA. It assisted in measurement of unidirectional transmission benefits, especially in minimizing signal loss and maximizing network performance under poor conditions.

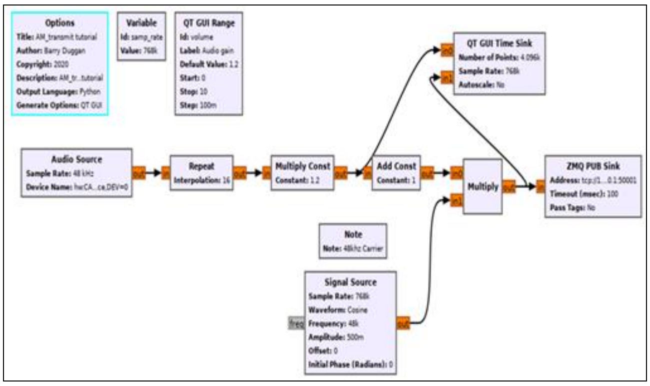
There were various control methods applied to ensure the accuracy and consistency of experimental data. They included control of external interference, normalization of human movement patterns, experimentation for repetition purposes to ensure consistency, and calibration of antennas to face in directions as accurately as possible. Ensuring consistency within the environment and control over variables affecting the transmission of Wi-Fi signals ensured the study maintained consistency in the model of understanding the effect of human presence on Wi-Fi performance.

Overall, this method provides comprehensive study of the interaction between Wi-Fi signals and human bodies. The application of SDR enables accurate, real-time tuning of signal parameters, and therefore the study is more relevant to monitor the dynamic characteristics of signal attenuation in human environments. The comparison between omni-directional and unidirectional modes of transmission provides useful information on the benefits of employing directional antennas in an attempt to mitigate signal loss, hence proposing feasible means of enhancing wireless communication in intensely interactive human communities.

The results of the study will be expected to contribute substantively to wireless communication, with a focus on enhancing the performance and coverage of Wi-Fi networks in high human interaction zones. The results can be used in a variety of environments, such as smart homes, offices, public spaces, and industries, where constant and reliable Wi-Fi connectivity is required to deliver seamless device and network performance. Providing a comprehensive analysis of signal loss and the potential advantages of one-way transmission, this research lays the foundation for future research and development in wireless network optimization.

4. Existing System

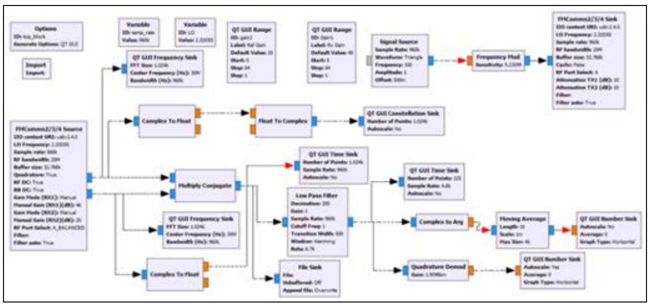
This diagram shows a flowgraph of an AM (Amplitude Modulation) transmitter using GNU Radio Companion (GRC). The process of processing and modulating an audio signal onto a high-frequency carrier signal before transmission is graphically depicted.



This AM Transmitter flowgraph, generated in GNU Radio Companion (GRC), demonstrates modulation of an audio signal onto a high-frequency carrier wave for transmission. The process starts with an Audio Source block, which captures an input audio signal at 48 kHz sampling rate from a selected device. Since the sample rate of processing is much greater, the signal is then passed through a Repeat block with an interpolation factor of 16 and thus the sample rate is doubled to 768 kHz.

To condition the signal for modulation, the audio is first amplified by a Multiply Const block with an amplification factor of 1.2, and an Add Const block that adds a DC bias of 1.0 is applied afterwards. This is in order to maintain the signal non-negative, which is the requirement for effective amplitude modulation.

5. Proposed System



The system suggested makes use of Software-Defined Radio (SDR) to scan and optimize the reception and transmission of Wi-Fi signals in areas where human interaction is high. The system offers real-time scanning and processing of Wi-Fi signals through the SDR technology, making it better than before. The system involves the use of an FMComms3/4 Source to capture signals, with the latter capturing signals at a given frequency where the gain and bandwidth are appropriately set. The received signal is processed repeatedly like Complex to Float, Float to Complex, and Multiply Conjugate to facilitate the processing of signals. Modulation and demodulation are also processed through Frequency Mod and Quadrature Demod to facilitate smooth interpretation of the signals.

There is a Low Pass Filter that is used for the elimination of unwanted frequency components for better clarity of the signal. The Moving Average block smooths the processed signal, and real-time monitoring is done through QT GUI visualization tools such as Frequency Sink, Time Sink, and Constellation Sink. The system also employs File Sink to store data for off-line analysis. The approach increases Wi-Fi coverage, minimizes interference, and provides efficient network performance. Through the integration of one-way transmission approaches, the system keeps signal decay and distortion at minimum, hence improving wireless communication in high-density areas. Adding SDR processing and visualization capabilities makes this an affordable way of optimizing Wi-Fi signal efficiency.

6. Results and Discussion

Results:

Signal Attenuation Due to Distance and Human Obstruction: Wi-Fi signal strength weakens as the distance between the transmitter and receiver increases. Additionally, human presence introduces interference, leading to signal dispersion and attenuation.

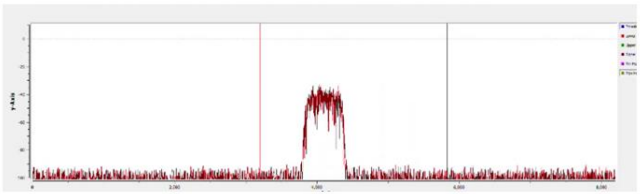


Fig 1: Gain Domain

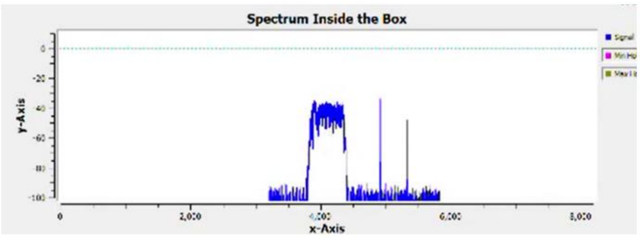


Fig 2: Frequency Domain

Effectiveness of Unidirectional Transmission: Compared to omni-directional transmission, directing signals toward specific targets using directional antennas improves signal coverage and reduces interference.

Impact of Environmental Factors: Physical structures such as walls and furniture further contribute to signal degradation, reinforcing the importance of signal optimization strategies.

Software-Defined Radio (SDR) as an Analysis Tool: SDR provided dynamic control over signal parameters, allowing accurate measurement of signal behaviors in different environmental conditions.

7. Conclusion

The findings confirm that Wi-Fi signal attenuation is significantly influenced by human presence and environmental barriers. Implementing unidirectional transmission and SDR-based optimizations effectively mitigates these effects, leading to improved signal strength and coverage in high human-interaction environments. The study highlights the potential of SDR as a versatile tool for real-time signal processing and network optimization.

Future work should focus on integrating machine learning techniques to further enhance signal adaptability in dynamic environments. Additionally, expanding the dataset to include varied environmental conditions will improve the robustness of predictive models for Wi-Fi network optimization.

8. References

1. Li JCn. Noninvasive microwave measurement of respiration. Proceedings of the IEEE. 1975; 63(10):1530-1530.
2. Jeong H, Kim D, Kim G, Kim S. Vitrad: A low-cost continuous wave doppler radar system with 3d-printed horn antennas for human vital sign detection. Hardware X. 2022; 12.
3. Islam SM, Motoyama N, Pacheco S, Lubecke VM. Noncontact vital signs monitoring for multiple subjects using a millimeter wave fmcw automotive radar. In 2020 IEEE/MTT-S International Microwave Symposium (IMS). IEEE, 2020, 783-786.
4. Sekak F. Microwave radar techniques and dedicated signal processing for vital signs measurement. Ph.D. dissertation, Universit´e de Lille, 2021.
5. Brulc M, Deleruyelle T, Loussert A, Laurent P, Grisot R, Caruana JP. Cardiac signature detection and study using contactless technology: Millimeter wave fmcw radar. IEEE Open Journal of Instrumentation and Measurement, 2023.
6. Hu W, Zhao Z, Wang Y, Zhang H, Lin F. Noncontact accurate measurement of cardiopulmonary activity using a compact quadrature doppler radar sensor. IEEE Transactions on Biomedical Engineering. 2013; 61(3):725-735.
7. Obeid S, Sadek G, Zaharia, Zein GE. Noncontact heartbeat detection at 2.4, 5.8, and 60 ghz: A comparative study. Microwave and Optical Technology Letters. 2009; 51(3):666-669.
8. Vinci G, Lenhard T, Will C, Koelpin A. Microwave interfer ometer radar-based vital sign detection for driver monitoring syst. In 2015 IEEE MTT-S International Conference on Microwaves for Intelligent Mobility (ICMIM). IEEE, 2015, 1-4.
9. Koelpin F, Lurz S, Linz S, Mann C, Will, Lindner S. Six port based interferometry for precise radar and sensing applications. Sensors. 2016; 16(10):1556.
10. Khan F, Cho SH. A detailed algorithm for vital sign monitoring of a stationary/non-stationary human through IR-UWB radar. Sensors. 2017; 17(2):290.
11. Rivera NV, Venkatesh S, Anderson C, Buehrer RM. Multi target estimation of heart and respiration rates using ultra wideband sensors. In 2006 14th European Signal Processing Conference. IEEE, 2006, 1-6.
12. Choi M, Kim J, Choia J, Park S, Parkb, Kimc K. Robust cardiac rate estimation of an individual. IEEE Sensors Journal, 2021.
13. Zhu N, Liu B, Qi R, Chen Z, Xu S, Niu G. Vital signs monitoring using an ir-uwb radar based on edge computing, 2021.
14. Costanzo S, Spadafora F, Borgia A, Moreno H, Costanzo A, Di Massa G. Research article high resolution software defined radar system for target detection, 2013.
15. Sharma P, Zhang Z, Conroy TB, Hui X, Kan EC. Attention detection by heartbeat and respiratory features from radio-frequency sensor. Sensors. 2022; 22(20):8047.
16. Costanzo S, Spadafora F, Di Massa G, Borgia A, Costanzo A, Aloi G, *et al*. Potentialities of usrp based software defined radar systems. Progress In Electromagnetics Research B. 2013; 53.
17. Lie YC, Liu Y, Tchatchoua Y, Sweeney C, Lie PE, Nguyen TQ. Latest development on non- contact vital signs (ncvs) sensor systems using software defined radio (sdr). In 2021 IEEE 14th International Conference on ASIC (ASICON), 2021, 1-4.
18. Li W, Tan B, Piechocki RJ. Non-contact breathing detection using passive radar. In 2016 IEEE International Conference on Communications (ICC). IEEE, 2016, 1-6.
19. Raffo S Costanzo, Di Massa G. Software defined doppler radar as a contactless multipurpose microwave sensor for vibrations monitoring. Sensors. 2017; 17(1):115.
20. Hui X, Kan EC. Monitoring vital signs over multiplexed radio by near-field coherent sensing. Nature Electronics. 2018; 1(1):74-78.
21. Costanzo S. Software-defined doppler radar sensor for human breath ing detection. Sensors. 2019; 19(14):3085.
22. Khan MB, Rehman M, Mustafa A, Shah RA, Yang X. Intelligent non-contact sensing for connected health using software defined radio technology. Electronics. 2021; 10(13):1558.
23. Ashleibta MA. Design of software defined radio based testbed for smart healthcare. Ph.D. Dissertation, University of Glasgow, 2022.
24. Lenz J, Holtom A, Herschfelt Y, Rong, Bliss D. Respiratory and heart rate detection using continuous-wave radar testbed imple mented in gnu radio. In Proceedings of the GNU Radio Conference. 2022; 7(1).
25. Toker O, Adla R. A sub-6 ghz vital signs sensor using software defined radios. Engineering Proceedings. 2020; 2(1):38.
26. Liu Y, Sweeney C, Hawkins J, Rojas S, Mayeda J, Tchatchoua Y, *et al*. Design of a robust noncontact vital signs (ncvs) monitoring system using software defined radio (sdr). In 2021 IEEE Texas Symposium on Wireless and Microwave Circuits and Systems (WMCS). IEEE, 2021, 1-4.
27. Sekak K Zerhouni, Elbahhar F, Haddad M, Loyez C, Had dadi K. Cyclostationary-based vital signs detection using microwave radar at 2.5 ghz. Sensors. 2020; 20(12):3396.
28. Sekak F Elbahhar, Haddad M. Vital signs detection based on the third order cyclic temporal moment and cumulant. IEEE Access, 2022.
29. Gardner WA, Napolitano A, Paura L. Cyclostationarity: Half a century of research. Signal Processing. 2006; 86(4):639-697.
30. Mercuri M, Lu Y, Polito S, Wieringa F, Liu Y-H, van der Veen A-J, *et al*. Enabling robust radar-based localization and vital signs monitoring in multipath propagation en vironments. IEEE Transactions on Biomedical Engineering. 2021; 68(11):3228-3240.
31. Phuoc Van NT, Tang L, Mukhopadhyay SC, Nguyen

DM, Hasan F. Probabilities of false alarm for vital sign detection on the basis of a doppler radar system. Sensors. 2018; 18(3):694.

32. Rappaport TS. Wireless communications: Principles and practice. Cambridge University Press, 2024.
33. Saleh, Valenzuela R. A statistical model for indoor multi path propagation. IEEE Journal on selected areas in communications. 1987; 5(2):128-137.