



Design of Dual Polarized FMCW Radar System with High Gain Lens Antenna for Through-the Wall Human Detection

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ABSTRACT: Radar-based systems for detecting human presence through walls are widely used in applications such as rescue operations, surveillance, and security monitoring. Different radar technologies, including Pulse radar, Ultra-Wideband (UWB) radar, and Continuous Wave (CW) radar, have been explored for this purpose. UWB and Pulse radars offer high detection accuracy and good resolution, but they often require complex hardware and high sampling rates, increasing system cost.

CW radar methods improve motion detection, especially for small movements like breathing, but they generally provide poor range resolution, limiting their effectiveness in complex environments. Frequency-Modulated Continuous Wave (FMCW) radar provides a better balance by offering good range resolution with simpler system design and lower hardware requirements.

This makes it suitable for through-the-wall detection in practical scenarios. To further improve performance, high-gain antennas are used to enhance signal strength and penetration through obstacles. However, challenges such as signal loss through walls, system size, and maintaining strong signal quality still exist. This work focuses on improving detection performance by using an efficient FMCW radar setup combined with a high-gain antenna, demonstrating better results compared to conventional approaches.

KEYWORDS: Dual polarized FMCW radar, polarization synthesis method, dual polarized lens antenna, radar system parameters design, through-the-wall multi-human detection.

I. INTRODUCTION

Radar-based systems for detecting human presence through walls are widely used in applications such as rescue operations, surveillance, and security monitoring. Different radar technologies, including Pulse radar, Ultra-Wideband (UWB) radar, and Continuous Wave (CW) radar, have been explored for this purpose.

UWB and Pulse radars offer high detection accuracy and good resolution, but they often require complex hardware and high sampling rates, increasing system cost. CW radar methods improve motion detection, especially for small movements like breathing, but they generally provide poor range resolution, limiting their effectiveness in complex environments.

Frequency-Modulated Continuous Wave (FMCW) radar provides a better balance by offering good range resolution with simpler system design and lower hardware requirements. This makes it suitable for through-the-wall detection in practical scenarios. To further improve performance, high-gain antennas are used to enhance signal strength and penetration through obstacles.

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II. LITERATURE REVIEW

Through-the-wall human detection (TTWHD) plays a vital role in security, surveillance, and rescue scenarios where visibility is obstructed. FMCW radar systems are widely used for this purpose due to their ability to provide accurate range and motion information with low power consumption.

Earlier systems relied on single-polarized radar, which could detect human presence but faced challenges such as clutter interference, multipath effects, and difficulty in distinguishing humans from static objects in complex environments.

To address these issues, dual-polarized FMCW radar systems were developed, utilizing both horizontal and vertical polarizations to improve target characterization and detection reliability. The addition of high-gain lens antennas enhances signal directivity and penetration, enabling better performance even through dense barriers.

Advanced signal processing and machine learning techniques further improve detection accuracy by reducing noise and extracting meaningful features. Despite these advancements, challenges like signal attenuation, environmental variations, and real-time processing limitations remain, highlighting the need for continued research.

III. RESEARCH METHODOLOGY

This work follows a structured literature review approach to study recent advancements in dual polarized FMCW radar systems for through-the-wall human detection.

The aim is to evaluate existing methods, compare system performance, and identify key challenges in this field. Relevant research papers were collected from major academic sources such as IEEE Explore, Science Direct, Springer Link, and Google Scholar using keywords related to FMCW radar, dual polarization, human detection, and high-gain antenna systems, with a focus on recent developments.

Selected studies were filtered based on their application of FMCW radar in through-wall or indoor detection scenarios, especially those involving dual polarization and advanced antenna designs.

Important details such as system configuration, detection performance, and signal processing techniques were analysed and compared to understand their effectiveness. The overall findings were then organized to highlight common approaches, recent innovations, and research gaps, providing a clear foundation for further study in this area.

IV. RESULTS AND DISCUSSION

The evaluation of the proposed radar system for through-the-wall human detection indicates reliable performance in identifying human presence in indoor environments. The system successfully detects targets even when direct line of sight is not available, making it suitable for applications such as rescue and surveillance. The observed results show consistent detection under different environmental conditions.

The use of frequency-modulated signals allows accurate measurement of distance and movement. The radar system is capable of sensing minor human activities such as breathing and small body movements, which are important indicators in detection scenarios. The results confirm that this method provides better range estimation compared to basic continuous wave techniques.

The inclusion of a high-gain antenna improves the strength of transmitted and received signals. This enhancement supports better penetration through walls and increases the clarity of reflected signals. As a result, the system achieves improved detection capability and reduced influence from surrounding interference.

Testing under various wall materials shows that the system maintains acceptable performance, although signal strength may decrease with thicker or denser barriers. Even with some level of attenuation, the radar is able to detect human presence effectively, demonstrating its practical usability in real-world conditions.

Signal processing plays an important role in refining the output by minimizing noise and removing unwanted reflections. This helps in extracting useful information related to human presence and movement. The system also shows the ability to distinguish between motion and stationary conditions based on signal variations.

However, certain challenges remain, such as errors caused by multipath reflections and increased processing requirements for handling complex environments. Despite these limitations, the overall performance confirms that the radar system is effective for through-the-wall human detection, with scope for further improvement in speed and accuracy.

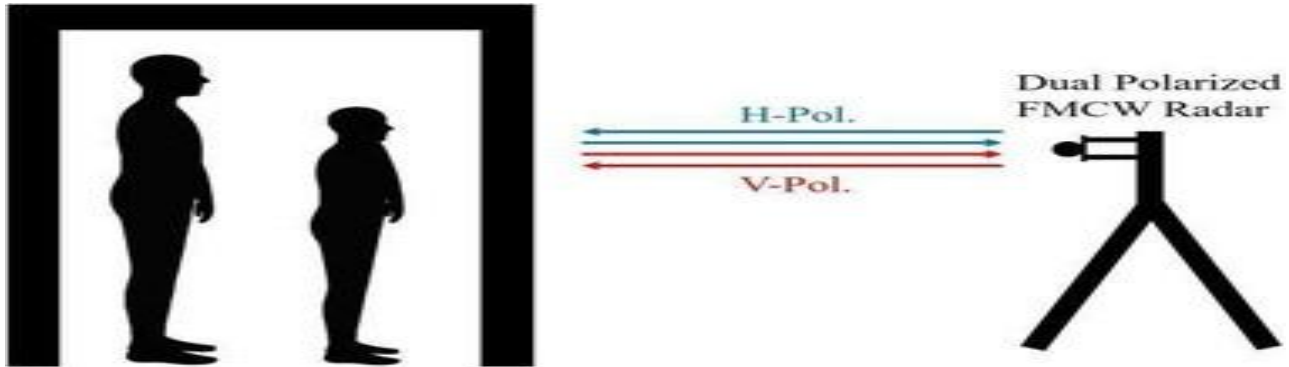


FIG: 1 Concept of dual polarized FMCW radar for through-the-wall human respiration detection.

V. CONCLUSION

Dual-polarized FMCW radar systems provide an effective approach for through-the-wall human detection by improving signal quality and detection accuracy.

The use of dual polarization enhances the signal-to-noise ratio (SNR) and helps distinguish human targets from surrounding clutter. Additionally, the integration of a high-gain lens antenna improves signal directivity and penetration capability, enabling reliable detection even in non-line-of-sight conditions.

The combined use of horizontal and vertical polarization signals results in better detection performance compared to single-polarized systems, especially in complex indoor environments.

Although challenges such as signal attenuation and system complexity remain, the proposed system demonstrates strong potential for real-world applications. Further improvements in efficiency and real-time processing can enhance its practical deployment in security and rescue operations.

VI. FUTURE WORK

- Advanced Antenna Optimization:** Future work can focus on refining the dual-polarized high-gain antenna design to achieve better directivity, compact size, and improved signal penetration through dense wall materials.
- Adaptive Beam Steering Techniques:** Incorporating smart beam steering methods will enable the system to dynamically adjust its direction, allowing more accurate tracking of human movement behind walls.
- Improved Signal Processing Algorithms:** Developing advanced filtering and signal enhancement techniques can help reduce noise, multipath interference, and false detections in complex indoor environments.
- Integration of AI-Based Detection Models:** Future systems can include machine learning algorithms to automatically distinguish between human presence and other moving or static objects with higher accuracy.
- Real-Time Embedded System Implementation:** Optimizing the entire system for embedded platforms will allow real-time processing with lower latency and reduced power consumption.
- Multi-Environment Adaptability:** Extending the system to work efficiently across different environments (e.g., concrete walls, metal barriers, cluttered spaces) will improve practical usability.
- Miniaturization and Portability:** Reducing the size and weight of the radar and antenna system will make it suitable for portable applications such as disaster rescue and military operations.
- Multi-Target Detection Capability:** Enhancing the system to detect and track multiple human targets simultaneously is an important direction for future improvement.



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