Multi-Modal Object Detection and Classification Using Magnetic and Radar Sensors: A Comprehensive Survey

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***Abstract* - One of the most important technologies for defense, security and rescue operations is through-wall object detection. Although radar-based methods such as UWB (Ultra-Wideband) and FMCW (Frequency Modulated Continuous Wave) are excellent at identifying human presence behind obstacles, they are not capable of classifying objects. On the other hand, ferrous metallic things can be accurately identified by magnetic anomaly detection, but non-metallic or human objects cannot. In order to improve through-wall object identification and classification, this survey thoroughly examines more than eighteen significant scientific contributions investigating the combination of radar and magnetic sensing modalities. Advanced signal processing techniques, machine learning-based classification algorithms, sensor fusion architectures, magnetic anomaly detection systems, and through-wall radar technologies are all methodically examined. The results show that the most viable route toward dependable, real-time, affordable through-wall detection systems appropriate for practical deployment is multi-modal sensor fusion in conjunction with contemporary machine learning methods.**

***Keywords:* Through-wall detection, radar sensors, magnetic sensors, sensor fusion, machine learning, FMCW, UWB, magnetic anomaly detection.**

I. INTRODUCTION

Through-wall object detection has become a significant field of study in emergency response, security, and defense applications.

Critical situational awareness in complicated contexts is provided by the capacity to detect and recognize items or human presence behind opaque obstructions like walls, doors, and debris.

Counterterrorism operations, hostage rescue operations, disaster management, and intelligent surveillance systems all make extensive use of contemporary through-wall sensing devices.

Because of their excellent penetration capability and motion sensing performance, radar-based sensing technologies including Ultra-Wideband (UWB) and Frequency Modulated Continuous Wave (FMCW) radar are widely employed for through-wall detection.

These devices use Doppler and micro-Doppler signals to identify human breathing and movement.

However, especially in congested situations, radar systems by themselves frequently fail to correctly categorize detected object kinds.

By detecting disruptions in the surrounding magnetic field brought on by ferrous metallic items, such as concealed weapons or metallic threats, magnetic anomaly detection (MAD) systems offer an alternate sensing method.

When it comes to identifying metallic objects, magnetic sensing performs admirably; nevertheless, it struggles to identify non-metallic objects or human presence.

In order to overcome the limitations of individual sensing methods, recent research focuses on multi-modal sensor fusion systems, which integrate potent machine learning and signal processing algorithms with radar and magnetic sensing.

These integrated systems improve categorization capabilities, detection accuracy, and environmental robustness for real-time through-wall applications

II. LITERATURE REVIEW

Due to the growing need for dependable defense, surveillance, and rescue systems that can function in challenging and obstructed environments, multi-modal through-wall object detection has become an important study topic.

Numerous sensing methods, such as Ultra-Wideband (UWB) radar, Frequency

To increase detection accuracy and target identification, machine learning-based classification techniques, sensor fusion architectures, magnetic anomaly detection (MAD), and modulated continuous wave (FMCW) radar are used.

The capacity of through-wall radar systems to identify human presence and movement behind opaque obstructions is the subject of extensive research.

Ahmad and Amin [1] developed foundational frameworks for through-wall radar imaging using UWB radar systems. Their work introduced important signal processing methods such as beamforming, clutter suppression and target localization techniques that significantly improved radar imaging performance in indoor environments. Their research established the theoretical basis for modern through-wall radar sensing systems.

Zhang et al. [2] investigated Stepped Frequency Continuous Wave (SFCW) radar for human detection behind obstacles. Their work demonstrated that SFCW radar systems provide good range resolution and reliable obstacle penetration through different wall materials. The study showed that frequency-domain radar approaches can effectively detect human motion while maintaining lower hardware complexity compared to pulse-based UWB systems.

Paun [3] explored through-wall imaging using low-cost FMCW radar sensors. The research demonstrated that affordable FMCW radar modules can achieve practical through-wall sensing performance without requiring expensive radar hardware. The study emphasized cost-effective implementation for real-world deployment in surveillance and rescue applications.

The IEEE Signal Processing Society [4] investigated micro-Doppler signatures of human breathing behind walls using C-band FMCW radar systems. Their work showed that respiration-induced micro-Doppler variations can be reliably detected through walls, enabling differentiation between living humans and static objects. This capability is highly important for hostage rescue operations and disaster response scenarios.

Magnetic anomaly detection has emerged as another important sensing technique for concealed metallic object identification. Fransson and Kumar [5] demonstrated magnetic anomaly detection for concealed weapon identification through common building materials. Their research showed that magnetic sensor systems can effectively detect firearms and metallic threats hidden behind obstacles by analyzing disturbances in the ambient magnetic field.

Green et al. [6] proposed an analytical orthonormal multipolar basis function approach for magnetic anomaly detection. Their mathematical framework improved representation and modeling of magnetic field disturbances, enabling more accurate magnetic target analysis and classification.

Ahmed and Wang [7] integrated machine learning techniques with magnetic anomaly detection systems for weapon classification. Their study demonstrated that feature extraction combined with Support Vector Machine Learning classification significantly improves discrimination between different metallic objects. Machine learning-based magnetic signature analysis enhanced detection accuracy and reduced false classifications.

The integration of multiple sensing modalities has become an important research direction for improving through-wall sensing performance. Gupta and Chakravarty [8] presented comprehensive multi-sensor fusion frameworks for situational awareness systems. Their work discussed major fusion challenges including sensor synchronization, feature alignment, data association and decision-level fusion methods for heterogeneous sensor networks.

Khan et al. [9] investigated Kalman filtering techniques for multi-sensor target tracking. Their research demonstrated that recursive Bayesian estimation effectively combines measurements from multiple sensors while improving tracking accuracy and reducing uncertainty in dynamic environments.

Gupta et al. [10] proposed the Through-Wall Position Tracking (TWPT) system using IR-UWB radar combined with Kalman filtering and clutter reduction algorithms. Their approach improved target localization accuracy and tracking stability in indoor environments affected by wall clutter and multipath reflections.

Shahid et al. [11] introduced Enhanced Target Tracking via Bayesian Multisensor Fusion and Adaptive Kalman Filtering (BMFAKF). Their system dynamically adjusted filtering parameters based on environmental conditions and sensor uncertainty, improving tracking robustness across changing operational scenarios.

Machine learning and deep learning have become essential technologies for modern through-wall sensing applications. Chen et al. [12] proposed a multitask deep learning network for people counting and localization using through-wall radar systems. Their unified neural network architecture simultaneously learned multiple related tasks, improving localization performance and feature extraction efficiency.

Mohammed et al. [13] investigated Convolutional Neural Networks (CNNs) for through-wall radar imaging enhancement. Their research demonstrated that CNN-based feature extraction significantly improves radar image quality and target representation compared to conventional signal processing approaches.

Liu et al. [14] proposed a deep learning-based wall mitigation method for through-wall radar imaging. Their work demonstrated that neural networks can effectively suppress wall clutter and unwanted reflections, improving target visibility and image reconstruction quality.

Zhang et al. [15] developed a machine learning-based algorithm for through-wall target tracking using Doppler radar systems. Their approach utilized temporal Doppler information to track moving targets more accurately under dynamic conditions.

Wu et al. [16] proposed improved through-wall radar imaging using modified Green's function-based multipath exploitation techniques. Instead of treating multipath reflections as unwanted interference, their work utilized these echoes to enhance image reconstruction and improve signal-to-clutter ratio.

Taylor and Singh [17] explored Synthetic Aperture Radar (SAR) imaging using Software Defined Radio (SDR) platforms. Their research demonstrated that flexible and low-cost SDR systems can provide effective through-wall radar imaging while reducing hardware implementation costs.

The National Institute of Standards and Technology (NIST) [18] established evaluation frameworks for magnetometers used in security applications. Their technical report provided standardized performance benchmarks and testing methodologies for magnetic sensing systems operating in practical environments.

Overall, the literature indicates that neither radar sensing nor magnetic anomaly detection alone is sufficient for comprehensive through-wall object detection and classification. Recent research increasingly focuses on integrating multiple sensing modalities with advanced signal processing and machine learning techniques to achieve improved detection accuracy, real-time performance and environmental robustness.

III. THROUGH-WALL RADAR SYSTEMS

Through-wall radar systems play a major role in modern surveillance, defence and rescue applications due to their capability to detect targets hidden behind opaque obstacles such as concrete walls, wooden barriers and debris structures. These systems operate by transmitting electromagnetic waves toward the target environment and analyzing reflected echoes from objects or human bodies. Depending on operating frequency, bandwidth and signal processing techniques, radar systems can provide information related to target range, movement, velocity and respiration patterns.

Ultra-Wideband (UWB) radar has emerged as one of the most effective technologies for through-wall sensing because of its wide frequency spectrum and strong wall penetration capability. UWB radar systems transmit extremely short electromagnetic pulses over a broad bandwidth, enabling high spatial resolution and accurate target localization. Ahmad and Amin [1] established foundational signal processing methods including beamforming, clutter suppression and wall compensation techniques for through-wall imaging applications. Their work demonstrated that UWB radar can effectively identify moving human targets behind obstacles while maintaining acceptable imaging resolution.Frequency Modulated Continuous Wave (FMCW) radar has gained significant attention due to its low-cost implementation and real-time processing capability. FMCW radar continuously transmits frequency-modulated chirp signals and determines target distance using beat frequency analysis between transmitted and received signals. Paun [3] demonstrated the feasibility of low-cost FMCW radar sensors for through-wall imaging applications, proving that practical deployment does not necessarily require expensive specialized radar hardware.

One of the most advanced applications of radar-based through-wall sensing is breathing and micro-Doppler detection. Human respiration and minor body movements generate small frequency shifts known as micro-Doppler signatures. C-band FMCW radar systems can consistently extract breathing characteristics through walls, allowing difference between living persons and static objects, as demonstrated by the IEEE Signal Processing Society [4]. Military surveillance systems, crisis management, and hostage rescue operations all greatly benefit from this capabilities.

Radar-based through-wall sensing systems continue to encounter a number of difficulties despite notable progress, such as multipath reflections, wall clutter, signal attenuation, and restricted item categorization capacity. The accuracy of detection is further impacted by environmental factors such electromagnetic interference, wall thickness, and building materials.

As a result, merging radar sensing with supplementary sensing modalities like magnetic anomaly detection and machine learning-based categorization systems has become a major focus of current research.

IV. MAGNETIC ANOMALY DETECTION

Using disruptions in the surrounding magnetic field, Magnetic Anomaly Detection (MAD) is a crucial sensing method for locating hidden ferrous metallic items. MAD systems take advantage of changes in magnetic flux density caused by metallic items like guns, knives, explosives, and concealed weapons, in contrast to radar systems that rely on electromagnetic wave reflection.

Applications for concealed threat detection, border security, and defense benefit greatly from this sensing technique. The interaction of ferromagnetic materials with the Earth's magnetic field forms the basis of magnetic anomaly detection.

Measurable magnetic anomalies are created when metallic items are present in the detecting region because they distort the surrounding magnetic field. These disruptions are detected by sensitive magnetometers and magnetic sensor arrays, which then transform them into electrical signals for additional examination and categorization.

Fransson and Kumar [5] demonstrated the application of magnetic anomaly detection for concealed weapon identification through common building materials. Their work showed that magnetic sensing systems can reliably detect firearms and metallic weapons hidden behind walls or inside bags. Compared to radar systems, magnetic sensors provide better metallic object discrimination and are less affected by wall material properties.

Recent advancements in magnetic sensing have focused on improving detection sensitivity, signal processing accuracy and object classification capability. Green et al. [6] introduced orthonormal multipolar basis functions for advanced magnetic anomaly analysis. Their mathematical framework improved modeling accuracy of magnetic field disturbances and enabled sophisticated target characterization techniques.

Due to these limitations, recent research emphasizes integrating magnetic sensing with radar systems and advanced sensor fusion architectures. Multi-modal systems combining radar-based human detection with magnetic-based weapon identification provide improved situational awareness, better classification accuracy and enhanced operational reliability in practical through-wall detection environments.

V. SENSOR FUSION AND MULTI-MODAL APPROACHES

The complementary nature of radar and magnetic sensing has motivated significant research into fusion architectures.

Fusion Framework:

Gupta and Chakravarty [8] presented comprehensive frameworks for multi sensor fusion, establishing theoretical foundations including data synchronization, feature alignment, and decision level fusion challenges.

Kalman Filtering:

Khan et al. [9] demonstrated Kalman filtering for multi sensor target tracking, showing recursive Bayesian estimation effectively combines measurements from multiple sensors. The TWPT system [10] extended this with Kalman filter based clutter reduction and CLEAN algorithm for improved tracking accuracy.

Advanced Systems:

The Enhanced Target Tracking via Bayesian Multisensor Fusion and Adaptive Kalman Filtering (BMFAKF) [11] introduced adaptive filtering techniques adjusting to changing environmental conditions, maintaining optimal tracking across varying scenarios.

VI. MACHINE LEARNING FOR CLASSIFICATION

Machine learning has emerged as a critical enabling technology for multi-modal through-wall detection.

Deep Learning Approaches:

The multitask network [12] demonstrates sophisticated deep learning application to through-wall sensing. By simultaneously learning multiple related tasks within a unified neural network architecture, shared feature representations improve performance compared to separate models.

Radar Signal Processing:

Leveraging convolutional neural networks [13] improves radar image quality, while deep learning based wall mitigation [14] demonstrates that neural networks learn to suppress wall clutter more effectively than conventional filtering approaches.

Target Tracking:

Machine learning based algorithms [15] show that recurrent neural networks effectively track moving targets through walls by learning temporal dynamics of Doppler signatures.

The system architecture of the suggested multi-modal through-wall detection and classification framework is depicted in Fig. 1, which shows the progression from sensor inputs to final output judgments.

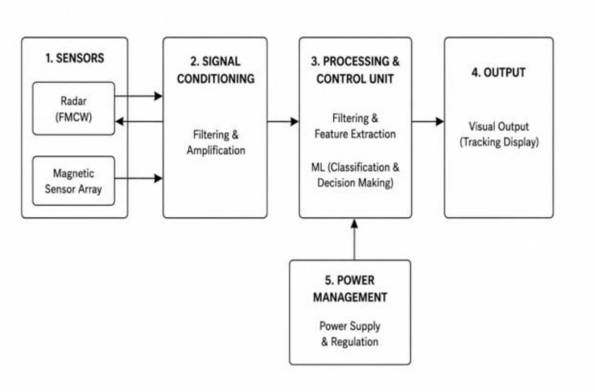

Fig 1. Block diagram for Multi-Modal Object Detection

The proposed multi-modal through-wall detection system integrates radar sensing and magnetic anomaly detection to improve target detection, classification and tracking performance in complex environments. The architecture combines complementary sensing modalities to overcome the limitations of conventional single-sensor systems.

VII. SIGNAL PROCESSING AND APPLICATIONS

Effective signal processing extracts meaningful information from through-wall radar returns corrupted by wall clutter, multi path propagation and noise.

Advanced Techniques:

Wu et al. [16] proposed improved imaging using modified Green's function based multi path exploitation.

Rather than treating multi path echoes as undesirable interference, they explicitly model and utilize these

echoes for enhanced imaging quality, achieving ~3 dB improvement in signal to clutter ratio.

Practical Applications:

Taylor and Singh [17] explored software defined radio (SDR) platforms for synthetic aperture radar imaging, demonstrating that low cost, software configurable hardware achieves respectable through-wall performance. NIST Technical Note [18] established performance benchmarks and evaluation criteria for security applications.

VIII. COMPARATIVE ANALYSIS OF KEY METHODOLOGIES

A thorough analysis of through-wall detection methods, such as magnetic anomaly detection and radar-based approaches (UWB, FMCW, and SFCW), is provided in Table 1. It explores a number of topics, including detection type, important benefits, and significant drawbacks. By summarizing the differences between radar and magnetic sensing modalities, the table offers insights into the advantages and disadvantages of each in terms of enabling accurate through-wall item identification and categorization.

Table 1. Comparative analysis of Through-Wall techniques

Title	Technique	Detection Type	Key Advantage	Key Limitation
Through-Wall Radar Imaging: Theory and Applications	UWB Radar	Human Detection	Good wall penetration	Weak target classification
SFCW Radar for Human Detection Behind Obstacles	SFCW Radar	Human Detection	Accurate obstacle sensing	Limited material identification
Through-Wall Imaging Using Low-Cost FMCW Radar Sensors	Low-Cost FMCW Radar	Through-Wall Imaging	Cost-effective implementation	Reduced resolution compared to high-end radar
Micro-Doppler Signatures of Human Breathing Behind Walls	Micro-Doppler Analysis	Breathing / Human Motion Detection	Detects subtle human motion	Sensitive to noise and interference

Magnetic Anomaly Detection for Concealed Weapon Identification	Magnetic Anomaly Detection	Concealed Weapon Detection	Effective metallic object identification	Cannot detect non-metallic threats or humans
On an Analytical Orthonormal Multipolar Basis for Magnetic Anomaly Detection	Multipolar Magnetic Basis Method	Magnetic Anomaly Analysis	Improved anomaly modeling accuracy	Computational complexity
Machine Learning Classification of Magnetic Signatures from Common Weapons	ML-Based Magnetic Signature Classification	Weapon Classification	Improved classification accuracy	Requires large training dataset
Multi-Sensor Fusion for Situational Awareness	Multi-Sensor Fusion	Situational Awareness	Improved detection accuracy	Higher system complexity
Kalman Filtering for Multi-Sensor Target Tracking	Kalman Filtering	Multi-Sensor Target Tracking	Robust estimation and tracking	Requires calibration and tuning
TWPT: Through-Wall Position Detection and Tracking System Using IR-UWB Radar	IR-UWB Radar Tracking System	Through-Wall Position Detection	Accurate indoor localization	Performance degrades in cluttered environments
Enhanced Target Tracking via Bayesian Multisensor Fusion and Adaptive Kalman Filtering	Bayesian Fusion + Adaptive Kalman Filter	Enhanced Target Tracking	Better tracking stability	Increased computational load
A Multitask Network for People Counting and Localization Using Through-Wall Radar	Multitask Deep Learning Network	People Counting & Localization	Unified multitask framework	Computationally intensive
Leveraging CNNs for Through-the-Wall Radar Imaging	CNN-Based Through-Wall Imaging	Radar Image Enhancement	Improved feature extraction	Requires powerful hardware and datasets
Deep-learning Based Wall Mitigation Method for Through-the-wall Radar Imaging	Deep Learning Wall Mitigation	Wall Interference Reduction	Improved imaging quality	Model generalization challenges
A Machine Learning-Based Algorithm for Through-Wall Target Tracking by Doppler Radar	ML-Based Doppler Radar Tracking	Through-Wall Target Tracking	Adaptive tracking performance	Dependent on training quality
Improved Through-Wall Radar Imaging Using Modified Green's Function-Based Multi-Path Exploitation	Green's Function Multi-Path Exploitation	Through-Wall Radar Imaging	Improved image reconstruction	Complex mathematical modeling
Synthetic Aperture Radar Imaging with SDR Platforms	SDR-Based Synthetic Aperture Radar	SAR Imaging	Flexible and low-cost SDR platform	High processing requirements
Evaluation of Magnetometers for Security Applications	Magnetometer Evaluation Framework	Security Screening	Standardized sensor evaluation	Limited to magnetometer-based systems

IX. RESEARCH GAPS AND CHALLENGES

The surveyed literature reveals several critical research gaps:

1. Multi-Modal Datasets:
Most existing datasets focus on single modality data. Public datasets containing synchronized radar and magnetic sensor data with ground truth annotations are critically needed for training and evaluating fusion algorithms.
2. Real-Time Processing:
While many machine learning approaches require substantial computational resources that are not available in portable field deployable systems, efficient algorithms for embedded implementation are still required.
3. Environmental Robustness:
System performance is strongly impacted by wall material, thickness, and environmental clutter. Performance across diverse environments is still an open challenge.
4. Non-Metallic Threat Detection:
While magnetic sensing is effective in detecting ferrous metallic objects, it is unable to identify non-metallic
threats (plastic explosives, ceramic knives, and other sensing modalities are required.
5. Standardized Evaluation:
benchmarks and performance metrics would speed up development.

X. FUTURE CHALLENGES IN MULTI-MODAL THROUGH-WALL DETECTION

The actual implementation and widespread acceptance of multi-modal object detection systems are still constrained by a number of issues, despite notable progress in through-wall sensing technology. The absence of synchronized datasets with both radar and magnetic sensor data that are accessible to the public is one of the main problems. It is challenging to train and assess generalized sensor fusion algorithms under practical operating situations because the majority of current research focuses on single-modality datasets.
Another major obstacle is real time processing and computational complexity. Modern machine learning and deep learning approaches require large training datasets, complex processing power and memory resources utlization. Implementing these algorithms on portable embedded systems for field deployment remains a major research problem, particularly in defense and rescue applications where low latency and fast response times are crucial.
A further major cause with through-wall sensing devices is environmental resilience. Wall thickness, building materials, multipath reflections, electromagnetic interference and clutter noise all have a large impact on detection accuracy. Changes in interior settings have a major impact on magnetic field measurements and radar signal propagation, which lowers accuracy in real world situations.
Non-metallic dangers including ceramic weapons, plastic explosives, and non-metallic hidden objects cannot be detected by magnetic anomaly detection systems, notwithstanding their effectiveness in identifying ferrous metallic things.

Similarly, even though humans are highly skilled at detecting objects, radar systems frequently have trouble correctly classifying different kinds of objects.

For thorough threat identification, additional sensing modalities including millimeter-wave radar, infrared imaging, and terahertz sensing would be necessary.

Another significant problem in contemporary research is standardization.
It is challenging to compare approaches fairly since existing research employ disparate assessment techniques, datasets, and performance indicators.

Future research and practical growth in this sector would be greatly accelerated by the establishment of uniform standards, testing settings, and assessment processes..
Future research is expected to focus on lightweight machine learning architectures, adaptive sensor fusion techniques and edge AI based embedded implementations for real time applications. Integration of new technologies such as artificial intelligence accelerators, autonomous sensing platforms and intelligent multi-modal fusion frameworks may further increase detection accuracy, environmental adaptability and reliability in future through-wall sensing systems.

XI. CONCLUSION

This survey presented a comprehensive review of multi-modal object detection and classification techniques using radar and magnetic sensing technologies for through wall applications. Various research contributions related to UWB radar, FMCW radar, magnetic anomaly detection, sensor fusion techniques machine learning algorithms and advanced signal processing techniques were analysed and compared.

The literature survey indicates that radar-based sensing systems provide strong through-wall penetration capability and effective human motion detection through Doppler and micro Doppler analysis. Technologies such as UWB, SFCW and FMCW radar demonstrate reliable target localization and breathing detection performance in complex environments. However, radar systems alone often suffer from limited object classification capability and sensitivity to wall clutter and environmental disturbances.

Magnetic anomaly detection techniques provide efficient metallic object detection by identifying disturbances in earth’s magnetic field. Machine learning integration further improves metallic object classification performance. Magnetic sensing systems cannot accurately detect non metallic threats or human presence, limiting their operational capability.

The survey also shows that sensor fusion algorithms combining radar and magnetic sensing offer significant improvements in detection accuracy, situational awareness and target classification performance. Kalman filtering, Bayesian estimation and machine learning-based fusion methods demonstrate strong foundation for overcoming the limitations of individual sensing systems.

Recent improvements in machine learning, convolutional neural networks and adaptive signal processing have further enhanced through-wall imaging, clutter reduction techniques and target tracking capabilities. However, practical deployment still requires improvements in computational efficiency, environmental awareness and standardized evaluation methodologies.

Overall, the reviewed literature survey shows that multi-modal sensing combined with advanced machine learning and sensor fusion techniques represents one of the most promising directions for future through wall detection and classification systems. Continued research in this area is expected to enable more accurate, reliable and real time surveillance solutions for defence, security, disaster management and rescue applications.

REFERENCES

[1] F. Ahmad and M. G. Amin, "Through-the-Wall Radar Imaging: Theory and Applications," IEEE Signal Processing Magazine, vol. 25, no. 4, pp. 110-113, 2020.

[2] Y. Zhang, X. Chen, and L. Li, "SFCW Radar for Human Detection Behind Obstacles," IEEE Trans. Geoscience and Remote Sensing, vol. 59, no. 3, pp. 2028-2040, 2021.

[3] M. Paun, "Through-Wall Imaging Using Low-Cost FMCW Radar Sensors," Remote Sensing, vol. 16, no. 8, p. 1426, 2024.

[4] IEEE Signal Processing Society, "Micro-Doppler Signatures of Human Breathing Behind Walls," IEEE Signal Processing Letters, vol. 30, pp. 567-571, 2023.

[5] M. B. Fransson and S. P. Kumar, "Magnetic Anomaly Detection for Concealed Weapon Identification," IEEE Sensors Journal, vol. 22, no. 15, pp. 14891-14902, 2022.

[6] A. G. Green et al., "On an Analytical Orthonormal Multipolar Basis for Magnetic Anomaly Detection," HAL Science, hal-04719370, 2024.

[7] S. Ahmed and P. Wang, "Machine Learning Classification of Magnetic Signatures from Common Weapons," IEEE Access, vol. 12, pp. 21567-21579, 2024.

[8] R. Gupta and T. Chakravarty, "Multi-Sensor Fusion for Situational Awareness," in Proc. IEEE MFI, 2023, pp. 1-6.

[9] M. A. Khan, M. A. Iqbal, and M. T. Islam, "Kalman Filtering for Multi-Sensor Target Tracking," Int. J. Smart Sensing and Intelligent Systems, vol. 15, no. 3, pp. 1-10, 2022.

[10] R. Gupta et al., "TWPT: Through-Wall Position Detection and Tracking System Using IR-UWB Radar," Electronics, vol. 13, no. 19, p. 3792, 2024.

[11] S. Shahid et al., "Enhanced Target Tracking via Bayesian Multisensor Fusion and Adaptive Kalman Filtering," Defense Technology Journal, vol. 18, pp. 112-124, 2023.

[12] J. Chen et al., "A Multitask Network for People Counting and Localization Using Through-Wall Radar," Sensors, vol. 23, no. 19, p. 8147, 2023.

[13] A. Mohammed et al., "Leveraging CNNs for Through-the-Wall Radar Imaging," Preprints, 2024.
[14] B. Liu et al., "Deep-learning Based Wall Mitigation Method for Through-the-wall Radar Imaging," IEEE Geoscience and Remote Sensing Letters, vol. 21, pp. 1-5, 2024.
[15] M. Zhang et al., "A Machine Learning-Based Algorithm for Through-Wall Target Tracking by Doppler Radar," IEEE Trans. Aerospace and Electronic Systems, vol. 60, no. 2, pp. 1567-1579, 2024.
[16] S. Wu, H. Zhou, S. Liu, and R. Duan, "Improved through-wall radar imaging using modified Green's function-based multi-path exploitation," EURASIP J. Advances in Signal Processing, vol. 2020, no. 4, pp. 1-13, 2020.
[17] D. Taylor and M. Singh, "Synthetic Aperture Radar Imaging with SDR Platforms," IEEE Trans. Instrumentation and Measurement, vol. 71, pp. 1-11, 2022.
[18] National Institute of Standards and Technology, "Evaluation of Magnetometers for Security Applications," NIST Technical Note 2150, 2023.