Advances in Technology Innovation, vol. 10, no. 1, 2025, pp. 72-83

Investigation of Affordable Technologies for Real-Time See-Through Various Indoor Surfaces and Walls

Qurban Ali Memon*, Selama Tekleab, Jood Albedwawi, Fatima Alantali, Alyazia Ateeq Aldhaheri

Department of Electrical Engineering, UAE University, Al Ain, United Arab Emirates

Received 03 August 2024; received in revised form 28 October 2024; accepted 04 November 2024

DOI: https://doi.org/10.46604/aiti.2024.14091

Abstract

Wireless scanning for detecting objects behind various surfaces or walls in indoor settings has garnered significant interest recently. This study presents experimental results on several widely accessible, affordable, and portable see-through technologies. The technologies evaluated include a radio frequency (RF) device, a chip-sized multiple-input and multiple-output (MIMO) radar, an ultra-wideband sensor, and a motion sensor. These can be used either as standalone transceivers or mounted on unmanned aerial vehicles (UAVs) to extend their range, particularly for emergencies in high-rise buildings. Tests on various wall and surface materials show that RF and Wi-Fi devices can detect objects through wood, glass, and plasterboard, but metal and concrete significantly block or limit signal penetration. The results suggest that affordable see-through technologies need to improve their performance against concrete and metals.

Keywords: object detection, see-through technology, affordable technology, wall scanning

1. Introduction

Various fields like search and rescue, wave propagation through materials, and navigating spaces in urban areas create the need for object detection behind walls, a complex challenge that spans numerous fields and technologies. This technique enables the identification of vibrations and changes in signal strength, which assists in detecting objects. By measuring the signal power and phase reflected from metallic objects, it is possible to determine the presence of metal, considering different frequency ranges. Moving object detection is feasible due to the alteration of object movement depending on the reflected signal strength [1]. The reflected signal strength confirms the presence of an object. Even the mechanics of breathing can affect signal reflection, aiding in detection and proving crucial in emergencies, such as locating people trapped, confined in a seismic event, or fainted.

Previously, technologies that could see through walls were exclusive to specific governmental services such as the military [2]. However, technological advancements have currently rendered it accessible. The RANGE-R radar system uses Through-the-Wall Sensors (TTWS) to detect motion inside buildings by emitting radio waves. Operating in the 1-10 GHz range, TTWS can penetrate materials like concrete and wood, whereas it is blocked by metal and water [3]. Its accuracy varies with frequency, and thick walls over 12 inches or low power can weaken signals, hindering detection. Most TTWS have a detection range of 50-65 feet, though some with larger antennas and stronger power can reach up to 230 feet. These radars can be influenced by moving objects such as pets or curtains, and basic models only indicate whether a person is alive and in motion. More advanced devices can measure distance and direction, generating a fundamental building layout. Experimental systems reveal potential for mapping unknown spaces, whereas the technology is not yet widely accessible [4].

---

* Corresponding author. E-mail address: qurban.memon@uaeu.ac.ae

English language proofreader: Chih-Wei Chang

Terahertz detectors are primarily used in airport inspections for imaging the human body beneath clothing. Despite occasional breakthrough claims, most terahertz applications remain speculative due to signal fading and the requirement for high-power emitters. Additionally, infrared cameras cannot see through walls, thereby proving the inability to penetrate materials like frosted glass or plywood. Scanning through walls is challenging due to several factors, with the type of medium being the most significant [5]. Different building materials can block wireless signals to varying degrees. Typically, materials like silver, aluminum, copper, and tin completely block signals, while insulators like drywall, wood, glass, and plastics partially obstruct but do not fully block signals. Therefore, the type of wall material is a crucial determinant in signal detection behind walls.

Various scientific and societal factors drive the push for advancing see-through technology for indoor walls and surfaces, e.g., see-through technology greatly enhances situational awareness, enabling law enforcement to monitor dangerous areas remotely, and improving safety. It also assists robots in navigating complex spaces boosting the efficiency of service robots in tasks such as rescue operations or maintenance. See-through technology also improves human-robot collaboration by helping robots anticipate movements in tight spaces, ensuring safer interactions. Further, it could revolutionize infrastructure monitoring by enabling non-invasive tracking of internal systems like plumbing and structural components. Integrating this technology into consumer devices like smartphones or tablets could enable practical applications, such as detecting studs or wall pipes.

The aims of this research include investigating cost-effective technologies available in the market for adopting see-through technology tailored to specific application environments. The structure of this paper is as follows. Section 2 reviews recent literature on the technologies and methods for see-through communication. Section 3 discusses the experimental findings on various affordable and portable technologies used to detect objects across different surfaces and walls within a specified range. The conclusions of this study are discussed in Section 4.

2. Literature Review

The through-the-wall radar imaging (TWRI) employs electromagnetic waves to penetrate building materials. These electromagnetic waves generate high-quality images of the interior areas. The technology is used for surveillance and search-and-rescue missions in areas where conventional methods fall short. The TWRI can detect individuals behind walls and identify their actions and postures. Such an achievement can be attributed to radar imaging research, which has grown over the past two decades and concentrates on object detection, its orientation, and scale classification. Li et al. [6] address the detection and tracking of human targets using small-aperture through-wall imaging radar to determine target scale and orientation. To discuss this further, further applications and findings are mentioned as follows.

Singh et al. [7] examine techniques for detecting stationary individuals behind walls by tracking their breathing movements. Specifically, it utilizes a Doppler-based method for detection and presents a novel approach employing a short-time Fourier transform. Furthermore, it implements clutter reduction using singular value decomposition across different measurements. Amin and Ahmad [8] address signal processing algorithms that enhance imaging in environments with clutter and multipath effects, focusing on ground-based imaging systems. It covers essential topics such as mitigating wall interference, exploiting multipath signals, detecting moving targets, and using compressive sensing for faster data collection.

In another work, Maherin and Liang [9] investigate the use of ultra-wide band (UWB) technology and information-theoretic algorithms (such as entropy) to identify human targets concealed behind walls. They propose that periodic changes in signals caused by breathing can be detected using these techniques. The research demonstrates that this method successfully identifies humans behind gypsum and brick walls, but it is ineffective with wooden doors. In a similar application, Gennarelli et al. [10] introduce a short-range radar system to detect individuals behind walls. It identifies human presence by examining phase shifts in the radar signal resulting from movements and breathing patterns. The paper also suggests a data processing algorithm capable of determining the presence of one or more stationary or moving individuals. Experimental results show that the system provides precise and timely information in indoor settings.

An innovative system [11] for detecting human respiration utilizes the impulse UWB radar technique. The system addresses challenges associated with low signal-to-noise ratios (SNRs), which can lead to errors in detecting respiration, heartbeat frequency, and range. To reduce interference from overlapping heartbeat, respiration signals, and unwanted harmonics, a frequency accumulation approach is introduced. Performance improvements are demonstrated through complex signal demodulation by integrating signal logarithms and derivatives. Liang et al. [12] present a technique for precisely detecting vital signs with UWB radar. The method analyzes the skewness of UWB signals affected by human activities. To determine the distance from the radar, the technique employs the discrete short-time Fourier transform (DSFT) on skewness data. Respiratory frequencies are estimated using an ensemble empirical mode decomposition (EEMD)-based method, which effectively removes harmonics.

Terahertz radar is recognized for its potential to achieve high-resolution, see-through capabilities. However, leaky-wave antennas merge signals from the aperture into a single output, making conventional signal processing challenging. To address this, Murata et al. [13] employ an iterative recovery algorithm to manage clutter and synthesize the radar's aperture. The findings highlight the successful see-through detection of objects behind an opaque screen and the 3D reconstruction of targets from various perspectives. Integrating stepped frequency continuous wave (CW) radar with deep learning techniques, such as convolutional neural networks (CNNs), offers a novel solution. Kılıç et al. [14] introduce a method for identifying human posture behind walls using radar signals and CNNs. The radar detects signals reflected from individuals, which the CNN processes to classify whether the person is standing or sitting. This approach delivers impressive results with minimal preprocessing and less data compared to traditional methods.

A novel model is developed that integrates both geometrical and statistical data from the target image. A scale-adaptive tracking method employs the mean-shift tracking framework to dynamically determine the target's scale and orientation using image moments. To identify both stationary and moving targets, Tivive and Bouzerdoum [15] introduce a technique that analyzes a series of radar signals. This approach decomposes 3D radar data into a low-rank tensor and two sets of sparse images. One set represents stationary targets, while the other depicts moving targets. Tests with simulated and real radar signals demonstrate the method's ability to detect and distinguish between stationary and moving targets.

In through-the-wall scenarios, traditional Wi-Fi-based moving target detection algorithms struggle to distinguish between multiple targets when transceivers are located on the same side of a wall. To address this, a novel detection algorithm [16] reconstructs channel state information and estimates angles of arrival and times of flight for interference signals. By subtracting the reconstructed interference, the useful signal is isolated. Experimental results unveil that the algorithm improves target detection accuracy compared to existing methods. However, identifying multiple stationary human targets remains challenging due to missed detections influenced by factors such as the target's distance and the intensity of their respiration. To overcome this, a new approach utilizing CNNs has been proposed by Shi et al. [17]. This method enhances the signal-to-clutter-and-noise ratio of the radar data and applies a clustering algorithm to precisely identify multiple targets.

Wang et al. [18] address challenges in through-wall radar human detection by introducing a novel end-to-end network that directly processes raw radar analog-to-digital converter (ADC) signals, eliminating the need for traditional preprocessing techniques. Conventional algorithms, such as discrete Fourier transform (DFT) and matched filtering, struggle with low SNRs in complex environments. The proposed model includes a DFT-based feature extraction module with learnable 3D convolution layers to enhance feature extraction capabilities. It also incorporates phase information and multi-task learning to improve accuracy.

Single-channel CW radar is favored for its straightforward design, though it cannot determine the range or angular position of targets. Ongoing research focuses on detecting life signs through walls using microwave Doppler radar. Pramanik and Islam [19] suggest employing a single-channel 24 GHz CW radar alongside the maximal overlap discrete wavelet transform to monitor individuals' heart rates through walls. Tests involving seven subjects at distances between 20 and 100 cm through brick and wood barriers achieved a heart rate accuracy of 95.27% when compared to Biopac electrocardiogram (ECG) measurements. Zhang et al. [20] propose a refraction-aware wireless sensing model for through-wall scenarios, focusing on Wi-Fi signal propagation. They tested it with a respiration sensing system using two transceivers, achieving an error of less than 0.5 bpm in typical settings.

Mu et al. [21] focus on "handy" through-wall radar systems, which are low-power, narrowband, lightweight, and do not require body-worn devices. These systems detect, locate, or image humans behind walls but face challenges such as interference from fast-moving objects, urban electromagnetic noise, and dense crowds. Portability is another issue, as most systems require fixed positions and bulky hardware, complicating real-time use in mobile settings. Privacy concerns are also significant, highlighting the need for privacy-preserving solutions before widespread civilian adoption. In a similar literature review, Jamshidi-Zarmehri et al. [22] review through-wall communications, covering wall characterization, technologies, applications, and prospects, offering a valuable guide for researchers and engineers. Lastly, Memon et al. [23] have conducted initial research on sensing through indoor walls of varying heights and thin surfaces using portable devices.

The literature review clearly shows that the majority of approaches and applications discussed rely on radar imaging and signal processing. The commercial technologies available for related applications are not cost-effective, are primarily designed for outdoor use, and lack portability. Research is needed to explore alternative, cost-effective technologies for see-through communication in indoor urban environments. These settings include rooms of varying sizes with partitions, walls, and surfaces of different materials. The next section aims to address this gap.

3. Experimental Results

This section explores the practical application of affordable, commercially available sensors. It commences with outlining the experimental methodology, detailing how each experiment was conducted and assessed. Subsequently, the section delves into the specific setups and results of each experiment. Lastly, it presents an analysis of different indoor wall types and surfaces, summarizing the key findings in a tabular format.

3.1. Sensor types

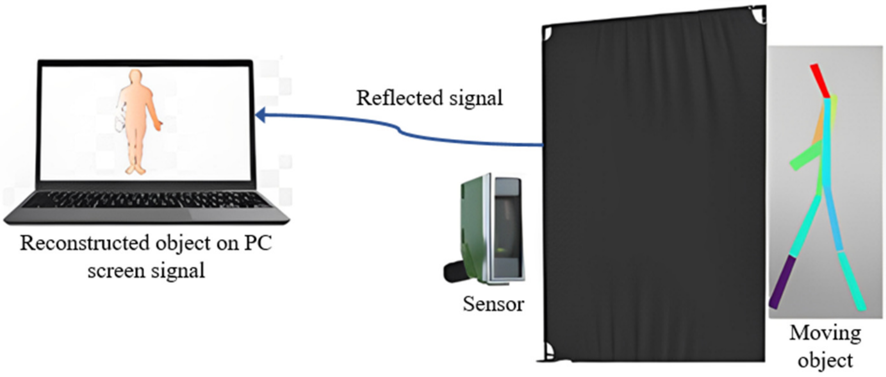


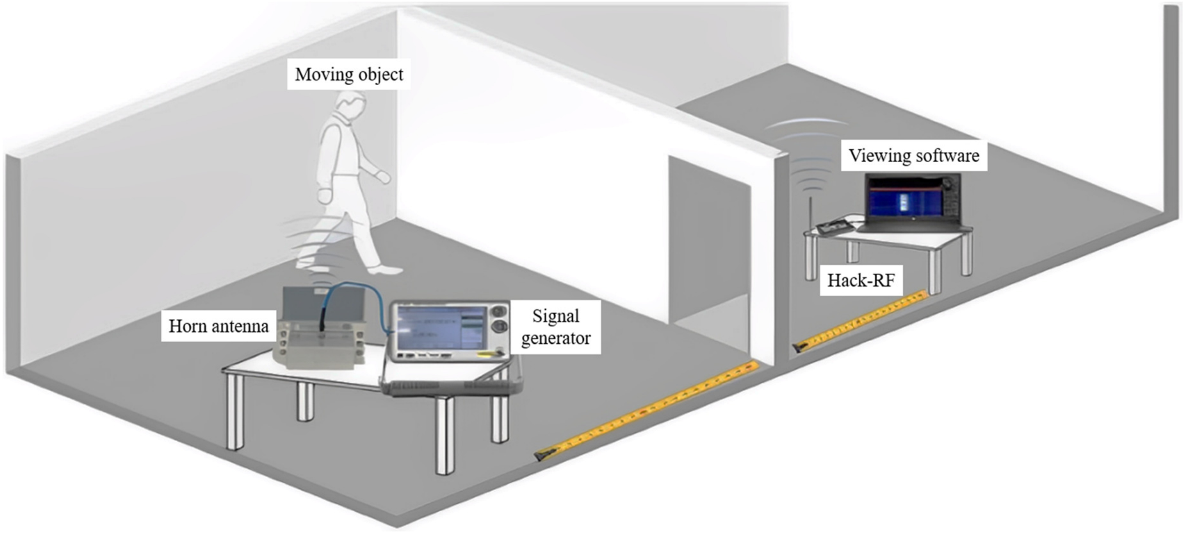
Fig. 1 The concept of an experimental setup

This section presents four indoor experimental setups. The setups employ commercially available, affordable, and portable devices. In Fig. 1, the concept of placing a sensor on one side of the wall and detecting the moving human object on the other side is depicted. The experimental setups included different types of sensors, e.g., a motion sensor, a chip-sized multiple-input and multiple-output (MIMO) radar, a radio frequency (RF) device, and an ultra-wideband sensor, each with a different sensing technology and detection principle. The settings were indoor with different room sizes, wall types, and surfaces. Each experimental setup is discussed separately.

Detection through radiation: The passive infrared sensor includes a motion detector that captures temperature radiation from a targeted room (behind a concrete wall) and alerts when there is interference within 50-80 feet. This passive infrared sensor includes a motion detector that captures temperature radiation from a targeted room (behind a concrete wall) and alerts when interference emerges within 50-80 feet. An 11.5 cm thick wall divided the rooms, and when motion was detected near the transmitters, the receiver sent an alarm. In a follow-up test, the transmitter was positioned two rooms apart from the receiver, and the motion detection produced similar results. The motion detection failed when the experiment was tried on two rooms seven meters apart.

Detection through radar: The sensor is technically a MIMO radar operating in the 1 MHz to 6 GHz range and integrated onto a chip. They detect radio waves, enabling the detection of people's presence and movements within a 10-meter range. Unlike cameras that rely on light and optics, these sensors penetrate through walls, smoke, and darkness. The reflected signals do not generate typical images. Instead, they display people on a grid, enabling tracking of their breathing patterns and determining whether they are sitting, standing, or lying down. The sensors enter a 7-day learning mode after installation, focusing on understanding the standard behavior within the room. This learning period is crucial for the device to adapt and accurately identify abnormal events within the room. To summarize, three trials were conducted, one with no movement in the room, and two with movement (sitting to standing; standing to falling). In each case, the device detected the change and generated the signal.

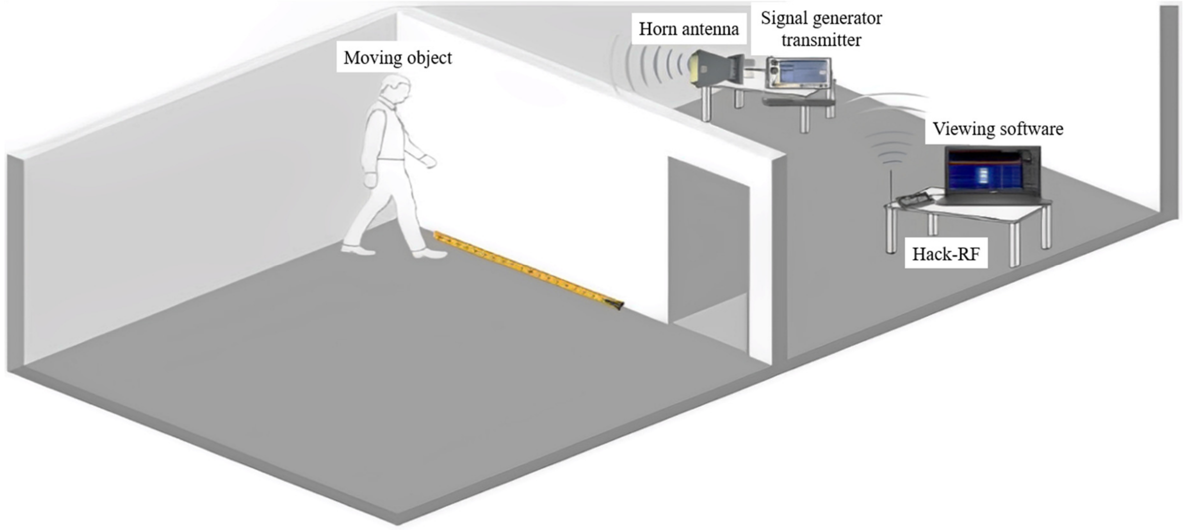
Detection through RF device: The device setup included a PC with a software-defined radio, a horn antenna, a signal generator, and a receiver, operating across a wide frequency range of 1 MHz to 6 GHz. The signals created at the transmitter and received at the receiver were tuned to around 2.45 GHz. Two setups with this device were prepared: (i) motion is generated behind walls when the transmitter and receiver are on the same side, and (ii) motion is created on the same side at the transmitter while the receiver is behind. Additionally, the system was configured so that the horn antenna directs the produced signal toward the receiving side.



(a) Different sides

Fig. 2 Transmitter and receiver

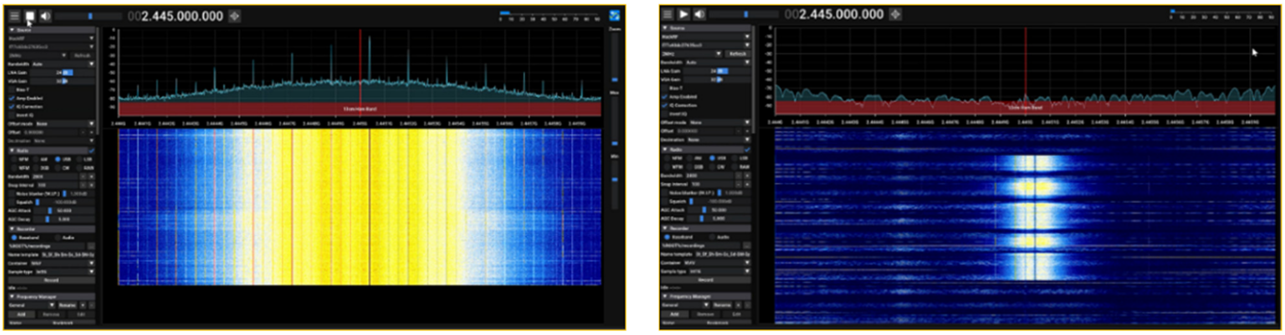
The building used in the experiment contained many small rooms and halls with partitions. The scanning device with limited power failed to transmit across concrete walls. Therefore, the RF device with higher power was used in one of the rooms with concrete walls that were approximately 3 inches thick. In this first setup, the receiver was placed on one side of a concrete wall and the transmitter on the other side, as shown in Fig. 2(a). The sensor gadget is fixed on the other side of the wall and connected to the PC. From the transmitter side, the motion is generated in front of the horn antenna, and data received from the receiving side is observed. In the second setup, just like in the first method, signals were collected and processed with motion occurring entirely behind the wall, as shown in Fig. 2(b).



(b) Same sides (bottom)

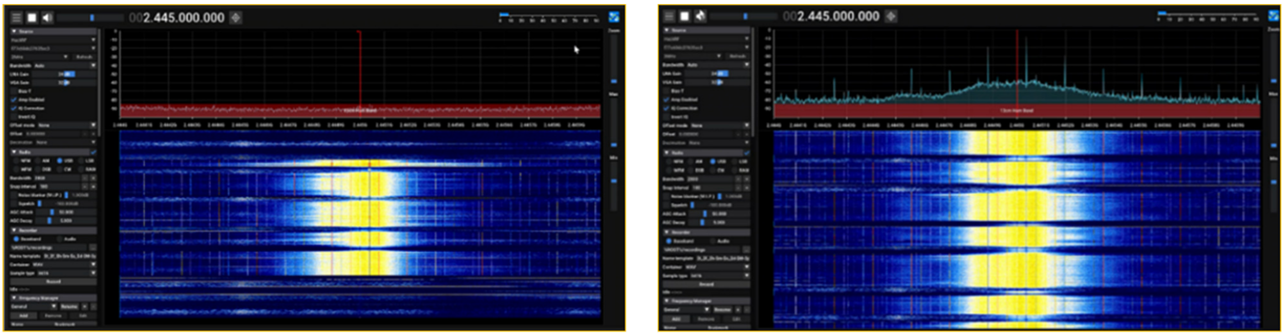
Fig. 2 Transmitter and receiver (continued)

Observations show a cut in the received signal strength indicating the presence of an individual. This process was applied for different transmitted powers and distances, and the results are shown in Table 1. It was concluded that the distance is proportional to the requirement of power for stronger signal reception and movement detection. A sample screenshot of the received signal against different distance settings versus transmitted power is shown in Fig. 3. For the second setup, the distance between the transmitter and the object was 135 cm. The results were comparable to the first setup. The cuts were observed if someone moved directly in front of the transmitter or receiver. However, it was noted that the increase in the power helped to detect the presence of an individual behind barriers. The screenshots are shown in Fig. 4.



(a) No movement

(b) Power −10 dB and distance 1 meter



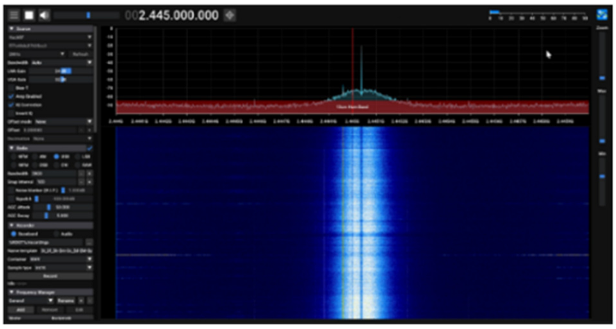
(c) Power −5 dB and distance 1 meter

(d) Power 0 dB and distance 1 meter

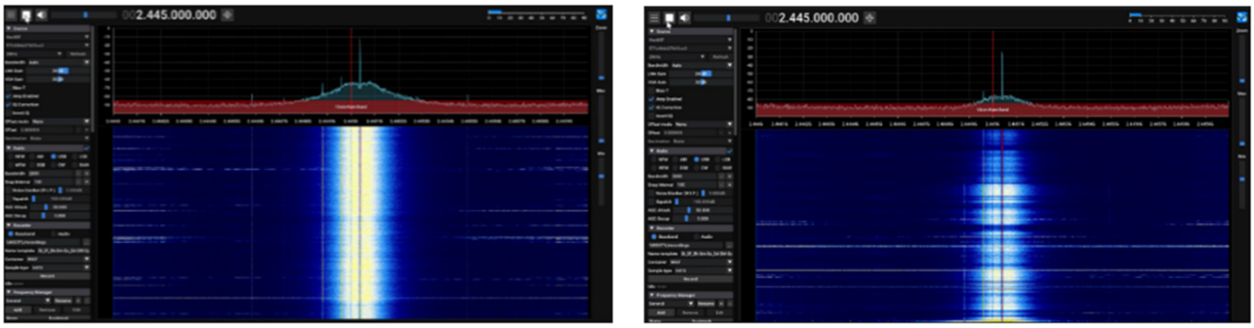
Fig. 3 Distance 1 meter with transmitted different powers

Table 1 Experiment results of the first setup

Distance between transmitter and receiver	Transmitted power	Received power
1 meter	–10 dB	–18 dB
	–5 dB	–13 dB
	0 dB	–6 dB
2 meters	–10 dB	–21 dB
	–5 dB	–17 dB
	0 dB	–8 dB
3 meters	–10 dB	–22 dB
	–5 dB	–19 dB
	0 dB	–9 dB



(a) Power −10 dB and horizontal distance 1 meter



(b) Power –5 dB and horizontal distance 1 meter

(c) Power 0 dB and horizontal distance 1 meter

Fig. 4 Distance 1 meter and different powers, and vertical distance 135 cm

Detection through RF scanning: For wall scanning, the device is placed directly on the surface, and any movement behind the surface (typically less than 10.16 cm in thickness) is displayed on the receiving side. It works over an ultrawideband range of frequencies. This device uses an antenna array to illuminate the targeted area and sense the returning signals. Once the type of wall is chosen. The surfaces are scanned in a circular motion for approximately 30 seconds to identify the material type. This process, known as calibration, helps the system learn the characteristics of the surrounding environment. Calibration entails adjusting various parameters to account for factors affecting measurement accuracy, such as object size and shape, distance from the sensing device, and the presence of materials that absorb or reflect RF waves. Once the reflected signal is received, the graphical representation of the object is observed clearly by modifying the percentage in the intensity bar. To enable remote monitoring, the signals shown through the sensor were transferred from the cell phone to another device via smart view/mirroring [23].

The detections of objects from above the ground and behind the walls work on the principles laid out respectively [24-25]. A portion of the RF signal can penetrate a non-metallic wall, reflect off objects, and return information about the entity behind the wall. By capturing these reflections, the objects hidden from direct view can be visualized. However, the receiver's ADC may be overloaded by strong reflections from the wall, preventing it from detecting subtle fluctuations caused by objects behind it. This phenomenon is known as the "flash effect".

In MIMO systems, multiple antennas encode transmissions to nullify signals at specific receivers, effectively reducing interference to unintended ones. Similarly, reflections can be minimized through nulling [25]. However, if the flash effect is 30 to 40 dB stronger than the reflections, canceling the reflections alone is insufficient, as signals from moving objects behind the wall remain too weak. These weak signals are masked by hardware noise from the receiver. To address this, the transmitted signal strength is increased without saturating the ADC. This boosts the overall power passing through the surface, improving the SNR of the reflections from the hidden targets. To evaluate the estimated accuracy, several trials are necessitated to record the results of each different technology. Mathematically, this evaluation metric is stated as:

$$Accuracy = \frac{1}{N}\sum_{n=1}^{n=N}\left(1-\frac{\left|Y_{m,n}-Y_{t,n}\right|}{T_{t,n}}\right) \tag{1}$$

where N represents the number of trials, $Y_{m,n}$ and $Y_{t,n}$ denote the outputs of the prototype (m) and the ground truth (t) in the n^{th} experiment, respectively. From this equation, it is evident that for 100% accuracy, the numerator term ($\left|Y_{m,n} - Y_{t,n}\right|$) must be 0.

All the devices mentioned above can be attached to the drone to expand its applications. The drone used is the “Bwine F7GB2 aircraft,” featuring a controller, communication system, downlink system, propulsion system, and a 2,600 mAh battery. One limitation of this drone system is that adding extra electronics significantly reduces flight duration; a single battery charge provides approximately 10 minutes of flight time. To address this power limitation, multiple unmanned aerial vehicles (UAVs) could be deployed. Apropos of practical implementation, a wall-scanning device, and receiver cell phone were attached to the UAV to detect objects behind walls of any height or under roofs with height restrictions. To uphold this additional weight, the drone battery should be carefully chosen.

3.2. Indoor wall and surface types

The experimentation explores testing on different surfaces and wall types to detect moving objects across their thickness. A commercially available portable scanning device with limited power serves as a prototype in a typical office environment with manifold wall types and thicknesses. The surfaces include granite, wood, metal, glass, and concrete.

Granite walls are often used in high-end construction and range from a few inches to a foot or more based on structural requirements. On the other hand, metal walls can be constructed from different materials, and their thickness can differ significantly based on industrial or commercial applications. Concrete walls are pervasively adopted in both residential and commercial construction. Their thickness can range from a few inches in interior walls to several feet in foundation or structural components. Plastic walls are not typical structural elements but may be used for partitioning, with thickness differing from thin plastic sheets to thicker, more robust materials used in industrial applications.

Table 2 One-way signal attenuation for wall thickness and effective distance [26]

Material	2.4 GHz			
	Thickness	Attenuation	Effective distance	Applications
Open space (reference)	0 cm	0 dB	100%	
Wood	4 cm	3 dB	20%	Partitioning
Glass	0.8 cm	4 dB	10%	Aesthetic/Natural view/Partitioning
Concrete	10.2 cm	15 dB	14%	Residential/Commercial
Concrete	20.3 cm	29 dB	16%	Residential/Commercial
Metal	8 cm	30 dB	25%	Industrial
Reinforced concrete	20.3 cm	31 dB	18%	Residential/Commercial

Similarly, wooden walls differ depending on the type used and the construction purpose. Residential wooden walls’ thickness may range from 3.5 inches to a thicker dimension for load-bearing or structural walls. Glass walls, on the other hand, are used for aesthetic and natural light but vary in thickness. Thicker panels are used for exterior glass walls, known for their insulation and strong strength, whereas thinner glass is used for interior partitions. However, notably, signal attenuation varies depending on the surface material. Concerning reference, Table 2 provides the signal attenuation values and effective distance at 2.4 GHz for different materials. The effective distance means how much signal is reduced after passing through the obstacle compared to air. The walls, surfaces, typical thickness, and applications are shown in Fig. 5.

(a) Granite (b) Wood (c) Metal (d) Concrete (e) Glass

Fig. 5 Walls and surfaces used in the experimental setup

The results were dependent on material thickness and the type used in the testing. According to the sensing device's specifications, the surface or wall thickness must be less than 10.16 cm for successful detection. Otherwise, the device is unable to detect the object or its movement due to the limited power of the sensing device. Regarding surfaces at lower heights, the devices were mounted on a selfie stick, while for higher elevations, they were attached to the legs of a drone. A human hand, either static or in motion, was used for these trials. In the case of motion, the static hand was first detected, and subsequently, it was slowly moved in one direction, with the sensing device following to track it. On thin surfaces, such as kitchen granite, glass doors, windows, glass surfaces, and wooden walls or doors with a thickness of less than 10.16 cm, the results were 100% accurate, with the object's shape or movement visible in 3D on the screen. However, concerning thick doors or surfaces, the results were unsatisfactory as the thickness exceeded the device's capability. The device also failed to detect objects on metal and concrete surfaces. Fig. 5 illustrates the surfaces tested.

Initially, the work started with a 4 cm thick hardwood substance. The findings for the wooden substance were observable, and the presence of a moving object beneath the cupboard was observed. In this experiment, an 80% intensity bar was set initially and gradually reduced until a clearly defined result was noticed. Subsequently, concrete surfaces and building walls were tested. Due to their larger thickness, it was not possible to accomplish any outcome for the building's outside walls. Instead, only the inside walls' spaces between the walls can detect the presence of moving objects. When the object was stationary, like the wooden object, the identification was not attainable. Instead of sticking to the conventional wall type, other materials such as glass, and granite were experimented with. Moving items were easily discernible on the glass surfaces, with slightly less clear results from the granite.

Table 3 Experimental results of wall scanning device

Material	Transmitted power = −10 dB, Thickness '*h*', Negligible '-'							
	h = 6 cm		h = 8 cm		h = 12 cm		h = 14 cm	
	Received power	Accuracy	Received power	Accuracy	Received power	Accuracy	Received power	Accuracy
Glass	−10 dB	100%	−10 dB	100%	−12 dB	80%	−14 dB	60%
Wooden door	−10 dB	100%	−10 dB	100%	−14 dB	60%	−15.6 dB	44%
Metal door	-	0%	-	0%	-	0%	-	0%
Interior wall (hollow)	−10 dB	100%	−11 dB	90%	−13 dB	70%	−15 dB	50%
Concrete	-	0%	-	0%	-	0%	-	0%

The experimental results are validated using Eq. (1) by repeating the same experiment at different times. The experimentations used glass or wooden surfaces with a thickness of less than 10.16 cm. Results are matching with the predictions for glass and wood when Eq. (1) is used for validation. RF signal absorption in the Industrial Scientific Medical (ISM) band was lower with glass (3 dB) and thin wooden surfaces (6 dB). In contrast, thicker wooden surfaces increased attenuation to 9 dB, reducing the detection rate. Regarding metallic doors and concrete walls up to eighteen inches thick, the attenuation increased to 12.4 dB and 18 dB, respectively. In reinforced concrete, signal loss increased to 40 dB, leading to a poor detection rate. Using $N = 10$ in Eq. (1), the results in Table 3 show that commercially available scanning devices can detect objects through various building walls and surfaces of limited thickness. It should be noted that these results depend upon the power transmitted by the scanning device used in the experiment. For better results, RF devices with higher power output, discussed in Section 3.1, may be used.

4. Discussion

Sustainable Development Goal 11 (SDG-11) aims to make cities safe and resilient, and see-through technology is crucial in achieving these goals by monitoring urban areas for safety. Attaining precise signal detection is crucial in case of object movement across indoor walls and surfaces. Apropos of rescue missions or infrastructure monitoring, the primary goal is to accurately identify the location, shape, and movement of objects behind walls. This study extended the initial research [23] on sensing through indoor walls and surfaces. The detailed experiments examined the performance of different see-through technologies based on the material characteristics of the surface, such as thickness and composition.

Errors in detection could result in false alarms, overlooked threats, or ineffective operations, with potentially severe consequences. While the performance and energy efficiency of the materials are important, they are often secondary considerations due to various factors, including:

(1) In mission-critical systems, inaccuracies could incur life-threatening errors, whereas energy efficiency and material performance can be more flexible.

(2) Enhancing accuracy often demands higher power consumption and more advanced materials, which may be less energy-efficient. Therefore, the initial focus is on achieving high accuracy, with energy efficiency being optimized later as the technology matures.

(3) Material performance and energy efficiency are typically application-specific. For instance, in consumer applications like detecting studs behind walls, energy efficiency may be prioritized more than in high-stakes applications such as law enforcement.

The rapid growth of connected devices and IoT is driving up energy consumption, posing an energy crisis without changes in communication technologies [27]. To address technological challenges, the electronics innovation sector must be prioritized.

5. Conclusions

The aims set in this research have largely been corresponded through multifarious experiments. Through experimental investigations, it was found that affordable and portable RF and Wi-Fi-based devices available in the market can sense through many non-metallic surfaces by measuring reflections and distortions caused by moving objects behind walls. RF and Wi-Fi signals can easily travel through drywall (plasterboard) and wood. These materials, typically found in residential environments and office partitions, do not significantly block or interfere with these signals. Glass enables RF and Wi-Fi signals to pass through it smoothly. However, reflections can sometimes interfere with signal clarity. Concrete materials have constrained penetration as signals are significantly attenuated by thick concrete walls, reducing their effectiveness. Metal walls have a very poor penetration as they block or reflect RF signals almost entirely. The experimental findings were validated by repeating the experiments at different times and days and averaging the accuracy found in the experimental results.

Wi-Fi-based systems may use existing infrastructure, further reducing costs. These devices can be small, handheld, or integrated into smartphones, facilitating the ideal for easy transport and deployment. The findings suggest that selecting an affordable sensing device is applicable for each different wall or surface. The detection range could be extended by transmitting higher power; however, existing affordable technologies possess low power. The choice of technology in the public domain is critical and depends on various market factors. Several factors influence market dynamics, including drivers, restraints, and opportunities. Despite the aforementioned key points, market growth faces other challenges, including state regulatory issues, user privacy concerns, and high initial investment costs.

Conflicts of Interest

The authors declare no conflict of interest.

References

[1] W. B. Thompson and T. C. Pong, “Detecting Moving Objects,” International Journal of Computer Vision, vol. 4, no. 1, pp. 39-57, 1990.

[2] L. R. Kurtz, Encyclopedia of Violence, Peace and Conflict, 3rd. ed., United States of America: Elsevier, pp. 2045-2055, 2008.

[3] R. Narayan, Encyclopedia of Sensors and Biosensors, 1st ed., United States of America: Elsevier, pp. 35-51, 2023.

[4] A. Feng, Y. Xie, Y. Sun, X. Wang, B. Jiang, and J. Xiao, “Efficient Autonomous Exploration and Mapping in Unknown Environments,” Sensors, vol. 23, no. 10, article no. 4766, 2023.

[5] Y. T. Win, N. Afzulpurkar, and C. Punyasai, “Shape Detection of Object Behind Thin Medium Using Ultrasonic Sensors,” International Journal of Advanced Robotic Systems, vol. 15, no. 2, article no. 1729881418764638, 2018.

[6] H. Li, G. Cui, L. Kong, S. Guo, and M. Wang, “Scale-Adaptive Human Target Tracking for Through-Wall Imaging Radar,” IEEE Geoscience and Remote Sensing Letters, vol. 17, no. 8, pp. 1348-1352, 2020.

[7] S. Singh, Q. Liang, D. Chen, and L. Sheng, “Sense Through Wall Human Detection Using UWB Radar,” EURASIP Journal on Wireless Communications and Networking, vol. 2011, article no. 20, 2011

[8] M. G. Amin and F. Ahmad, “Through-the-Wall Radar Imaging: Theory and Applications,” Academic Press Library in Signal Processing, vol. 2, pp. 857-909, 2014.

[9] I. Maherin and Q. Liang, “Human Detection Through Wall Using Information Theory,” The Proceedings of the Third International Conference on Communications, Signal Processing, and Systems, pp. 149-157, 2015.

[10] G. Gennarelli, G. Ludeno, and F. Soldovieri, “Real-Time Through-Wall Situation Awareness Using a Microwave Doppler Radar Sensor,” Remote Sensing, vol. 8, no. 8, article no. 621, 2016.

[11] X. Liang, J. Deng, H. Zhang, and T. A. Gulliver, “Ultra-Wideband Impulse Radar Through-Wall Detection of Vital Signs,” Scientific Reports, vol. 8, article no. 13367, 2018.

[12] X. Liang, T. Lv, H. Zhang, Y. Gao, and G. Fang, “Through-Wall Human Being Detection Using UWB Impulse Radar,” EURASIP Journal on Wireless Communications and Networking, vol. 2018, article no. 46, 2018.

[13] K. Murata, K. Murano, I. Watanabe, A. Kasamatsu, T. Tanaka, and Y. Monnai, “See-Through Detection and 3D Reconstruction Using Terahertz Leaky-Wave Radar Based on Sparse Signal Processing,” Journal of Infrared, Millimeter, and Terahertz Waves, vol. 39, pp. 210-221, 2018.

[14] A. Kılıç, I. Babaoğlu, A. Babalık, and A. Arslan, “Through-Wall Radar Classification of Human Posture Using Convolutional Neural Networks,” International Journal of Antennas and Propagation, vol. 2019, no. 1, article no. 7541814, 2019.

[15] F. H. C. Tivive and A. Bouzerdoum, “Toward Moving Target Detection in Through-the-Wall Radar Imaging,” IEEE Transactions on Geoscience and Remote Sensing, vol. 59, no. 3, pp. 2028-2040, 2021.

[16] Z. Li, T. Tang, X. Yang, W. Nie, and Y. Wang, “Through-the-Wall Passive Detection for Moving Targets Based on Channel State Information Reconstruction,” International Conference on Microwave and Millimeter Wave Technology, pp. 1-3, 2022.

[17] C. Shi, Z. Zheng, J. Pan, Z. K. Ni, S. Ye, and G. Fang, “Multiple Stationary Human Targets Detection in Through-Wall UWB Radar Based on Convolutional Neural Network,” Applied Sciences, vol. 12, no. 9, article no. 4720, 2022.

[18] W. Wang, N. Du, Y. Guo, C. Sun, J. Liu, R. Song, et al., “Human Detection in Realistic Through-the-Wall Environments Using Raw Radar ADC Data and Parametric Neural Networks,” https://doi.org/10.48550/arXiv.2403.15468, 2024.

[19] S. K. Pramanik and S. M. M. Islam, “Through the Wall Human Heart Beat Detection Using Single Channel CW Radar,” Frontiers in Physiology, vol. 15, article no. 1344221, 2024.

[20] H. Zhang, Z. Wang, Z. Sun, W. Song, Z. Ren, Z. Yu, et al., “Understanding the Mechanism of Through-Wall Wireless Sensing: A Model-Based Perspective,” Proceedings of the ACM on Interactive, Mobile, Wearable and Ubiquitous Technologies, vol. 6, no. 4, article no. 195, 2022.

[21] K. Mu, T. H. Luan, L. Zhu, L. X. Cai, and L. Gao, “A Survey of Handy See-Through Wall Technology,” IEEE Access, vol. 8, pp. 82951-82971, 2020.

[22] H. Jamshidi-Zarmehri, A. Akbari, M. Labadlia, K. E. Kedze, J. Shaker, and G. Xiao, “A Review on Through-Wall Communications: Wall Characterization, Applications, Technologies, and Prospects,” IEEE Access, vol. 11, pp. 127837-127854, 2023.

[23] Q. Memon, B. Wodajo, S. Tekleab, and E. Alshehi, “Detection of Static and Moving Objects Behind Walls and Surfaces – An Experimental Investigation,” Proceedings of the 2023 9th International Conference on Computing and Artificial Intelligence, pp. 8-12, 2023.

[24] N. Bachir and Q. A. Memon, “Benchmarking YOLOv5 Models for Improved Human Detection in Search and Rescue Missions,” Journal of Electronic Science and Technology, vol. 22, no. 1, article no. 100243, 2024.

[25] F. Adib and D. Katabi, “See Through Walls with WiFi,” Proceedings of the ACM SIGCOMM 2013 conference on SIGCOMM, pp. 75-86, 2013.

[26] City of Cumberlan, “How Signal is affected,” www.ci.cumberland.md.us/,2022.

[27] O. Bonnaud, “Innovative Strategy to Meet the Challenges of the Future Digital Society,” Advances in Technology Innovation, vol. 6, no. 2, pp. 106-116, 2021.