An Approach To Detect Low-Dielectric Targets For Through Wall Imaging

Mandar K. Bivalkar, Dharmendra Singh
Electronics and Communication Engineering
Indian Institute of Technology, Roorkee
Roorkeee, India

***Abstract*— Detection of low dielectric material behind the wall is always a challenging task. For military or civil application detection of hazardous elements behind the wall is a major challenge. Teflon is the available material having low dielectric constant (≈2.1). We introduced an application of time- gating with thresholding technique to detect low dielectric material like Teflon behind the wall. Experimental setup for different targets of dielectric constants and only low dielectric material behind the wall is made. The observations for above scenario are discussed with the application of time gating along with thresholding technique. The drawback for commonly used Delay and Sum beamforming technique for detection of Teflon target in the vicinity of metal target behind the wall is described briefly. To enhance the imaging and to detect weak targets in the presence of strong target further investigation is required.**

***Keywords*— Contrast imaging, dielectric materials, Through wall Imaging, target detection.**

I. Introduction

Through wall – Imaging (TWI) is an upcoming area and key research interest in the recent years due to its various applications like military, calamity rescue and object detection etc. Electromagnetic signals in the range 1 GHz- 3 GHz provides good resolution in the down- range and cross- range [1]. Delay-and-Sum beamforming algorithm is commonly used for imaging in the through wall imaging, this algorithm consider coherent summation of all sensor data and corresponding delays. Various imaging algorithms for TWI are discussed in[2]. Clutter removal techniques to improve Signal-to- Noise ratio (SNR) are extensively discussed in [3]–[5]. Wall clutter mitigation techniques are discussed in [6]–[8]. Resolution of the images developed in TWI is not generally of acceptable level due to availability of the less number of pixels. Image enhancement is required to construct the image, techniques for image enhancement are proposed in [9]–[11]. High resolution algorithms such as MUSIC and other beamforming techniques are implemented in [12]–[14]. Very few studies have been carried out on detection and imaging for contrast targets i.e. low- dielectric material in the presence of high dielectric material. If the dielectric constant of the material is comparable with the air dielectric constant (≈ 1), then it will be very difficult to detect material having low dielectric behind the wall, as mentioned by Gaikwad et.al. in [15]. They discussed about the clutter reduction techniques in the detection of metallic and low dielectric material such as Teflon behind plywood wall.

978-1-5386-8173-2/18/$31.00 ©2018 IEEE

This paper discuss mainly about the detection of low dielectric material in the vicinity of high dielectric material such as Teflon behind brick wall having thickness of 15 centimeter. Reflections from the wall are often stronger [16], hence weak targets behind the wall get obscured or invisible. Weak targets means the targets with low- dielectric constant such as Teflon. Spatial filtering is applied to mitigate the wall effect in [16] where zero frequency in the spatial domain along with low frequency components which are related to the wall reflections are suppressed. Spatial filtering technique cannot work in case of stationary targets behind the wall. Another approach of placing three antenna arrays in parallel against the wall at different heights are proposed in [17]. Two different arrays are used to give the difference between the received signals and to combat with wall reflections. This scheme does not mentioned the effect of the simple subtraction on the radar returns.

This paper is compiled in sections. In section II experimental set- up and signal model for the TWI for metal target and Teflon target are presented. Different imaging algorithms are discussed in section III. Section IV described about detection of contrast targets and results for different types of targets are discussed. Section V concludes the work with future scope.

II. Experimental Steup and Signal Model

A. Experimental set- up

Synthetic aperture radar (SAR) concept is used in which array of antennas are used in multi- static mode to scan the whole wall. Antennas are located at different N- positions. Reflection coefficient S21 are measured for P- targets in the scene. The set – up for which is shown in fig. 1, transceiver is used to generate 201 stepped frequency continuous wave (SFCW) in the range 1 GHz- 3 GHz.

B. Signal modelling

The M-signal received from different antenna locations are given as (1)

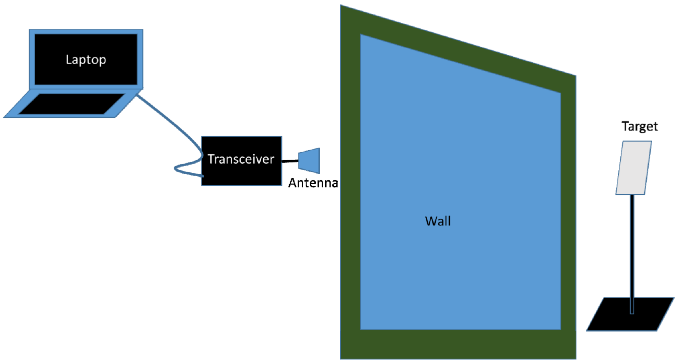

Fig. 1 Set- up for TWI

$$x(n,t) = \sum_{p=0}^{P-1} \sigma_p s(t - \tau_{n,p}) \quad (1)$$

Where, $s(t)$ is the transmitted signal which get convolved with the transfer function of the wall. σ_p is the reflection coefficient, $\tau_{n,p}$ is the two way delay –time between the n^{th} antenna position and the target *P*. If we do not consider the wall between the target and antenna then the signal path will be line of sight and two way delay- time can be expressed as (2)

$$\tau_{n,p} = \frac{2}{c}\sqrt{(x_p - x_n)^2 + (y_p - y_n)^2} \quad (2)$$

Where, c is the speed of light. The co- ordinate (x_p, y_p) and (x_n, y_n) represents the P^{th} target n^{th} antenna position.

In our experimental set- up we have considered a single homogenous wall whose dimensions are larger than the bandwidth of the antenna so that multiple reflections inside the wall can be neglected. A- scan is a one dimensional trace for amplitude vs. delay which we can convert in to the distance to locate the target behind the wall by using (3)

$$d = (t * c)/2 \quad (3)$$

Where, d is the distance and t is the time. Flow-chart to develop A- scan is given in fig. 2. B- scan is the collection of A- scan, resolution of the B- scan developed by mere collection of the A- scans is not accurate since it is not focused [18]. In this paper DS beamforming is used to develop focused image. The i^{th} pixel value in the DS image is given by (4)

$$b(i, j) = \frac{1}{N}\sum_{n=o}^{N-1} x(n, t + \tau_n(i, j)) \quad (4)$$

Where, $\tau_n(i, j)$ is the delay time in both the direction through the air and wall. Stepped Frequency Continuous Wave (SFCW) radar is used whose stepped size is depend upon the selection of frequency bins hence trade – off is required between number of frequency bins and scanning time. In SFCW radar waveform consists of Q- narrowband signals defined as (5)

$$b(i, j) = \sum_{n=o}^{N-1}\sum_{q=o}^{Q} x(n, f_q) \quad (5)$$

Where, $x(n, f_q)$ is the signal received at n^{th} antenna position for the frequency q.

III. Imaging in TWI

SAR imaging will provide data consist of reflection coefficients (S21). This data will be either in the time domain or frequency domain. We collect $A(x,t)$. This data will be used to plot A– scan (Amplitude vs. time) and then time domain converted in to spatial domain $A(x,z)$ which will locate the target in the imaging plane. The geometry for the TWI is shown in fig. 2

If X_p is the point target, to develop the image transformation from time to spatial domain is required. Migration algorithms is the tool to develop the image, algorithms like $\omega - k$, back-projection diffraction summation [19] are proposed.

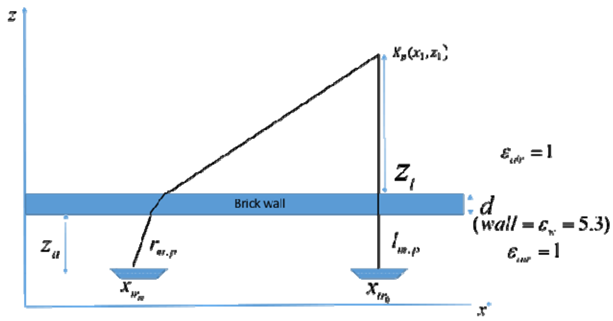

Fig. 2 Geometry for TWI

DS – beamforming is the most popular and less complex imaging algorithm which does not consider the wave equation but require big computational power. Kirchhoff's is based on solving radar wave equation is proposed in [20]. Conventional DS- beamforming [19] used spatial frequency – domain, suppose the signal received at the antenna location is $z[m,n]$ of frequency f_n with delay $\tau_{p,m}$ then $z[m,n]$ can be represented as (6)

$$z[m,n] = \sum_{p=0}^{P} \sigma_p \exp\{-j2\pi f_n \tau_{n,p}\} \quad (6)$$

Where m represents the spatial index and n represents the frequency index. Consider homogenous wall of thickness d with relative permittivity of the wall ε_r. The distance from the antenna and wall is (z_a) and from wall to the target (z_t).

Velocity correction [20] for geometry shown in fig. 2 is given by (7)

$$d_v = z_a + d\sqrt{\varepsilon_r} + z_t \qquad (7)$$

Where d_v is the actual distance between the antenna and target after velocity correction. Delay $\tau_{n,p}$ by putting (7) in to (2)

$$\tau_{n,p} = \sqrt{(x_{tr_0} - x_{tr_n})^2 + (d_v + X_p)^2} \qquad (8)$$

We can recover the image $s[k,l]$ by DS – beamforming using (9)

$$s[x_k, z_l] = \frac{1}{NQ} \sum_{n=0}^{N-1} \sum_{q=0}^{Q-1} z[m,n] \exp\{j2\pi f_n \tau_{p,m}\} \qquad (9)$$

Where k and l are the number of pixels in the image.

IV. DETECTION OF CONTRAST TARGETS

Contrast target detection means detection of weak target in the vicinity of strong target. We use the term strong and weak target in terms of reflections received from targets behind the wall. Term Contrast imaging is used in biomedical field, in ultrasound scanning to increase the scattering from blood, in the vicinity of soft tissue contrast imaging is performed. Reflections from strong targets are always more compared to weak targets and hence it is always difficult to detect weak target in the presence of strong target.

In our experimental setup, first we placed rectangular metal plate of dimensions 40 X 40 cm. and Teflon plate of dimensions 51 X 39 cm. is placed behind the wall at a distance of 83 cm. A- scan for this arrangement is shown in fig. 3 and fig. 4. Since A- scan is one dimensional plot it can show only one target in down- range and we cannot detect how many targets are there in cross range. In our experimental set-up we have placed both the target at a distance of 15 cm. from each other in the cross range, since the cross range resolution at 2 GHz is 7.5 cm. In the next step only Teflon plate is placed at a distance of 60 cm. from the wall. A- scan for second step is shown in fig. 5. B- scan without DS and using DS-beamforming for two targets behind the wall are shown in fig.8 to fig.9. B-scan for only Teflon is shown without DS and with DS in fig.10 and fig.11. From the visual inspection of figures 8 and 9, Teflon plate is not visible properly due to weak reflections received as compared to metal plate. Next, when only Teflon plate is placed behind the wall, we can detect Teflon plate clearly. In both the experiments time gating is used to detect Teflon plate which is not possible otherwise. Hamran et. al. [21] described the application of gating where receive gate is delayed with respect to transmit gate to combat with strong reflections from antenna probe and wall. Time gating is not effective when target is placed very near to the wall because target response get overlapped in time [22]. To overcome the problem of time overlapping we have placed target away from the wall and then applied thresholding technique to remove strong reflections from wall.

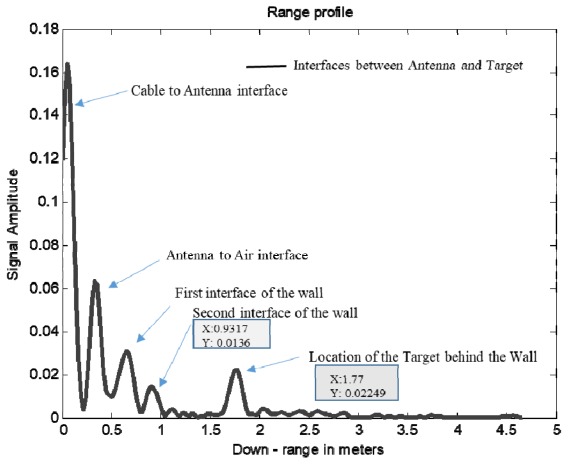

Fig. 3 A- scan for Metal Target

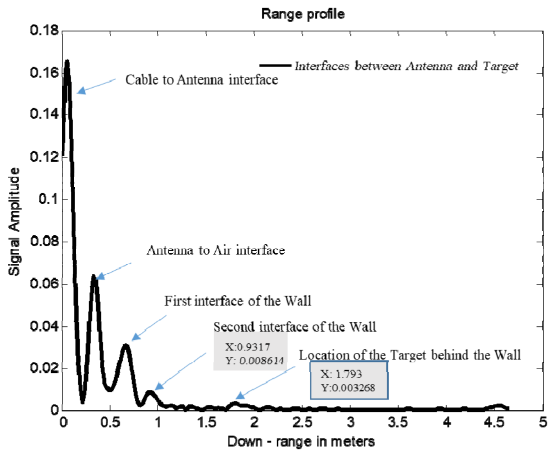

Fig. 4 A- scan for Teflon Target

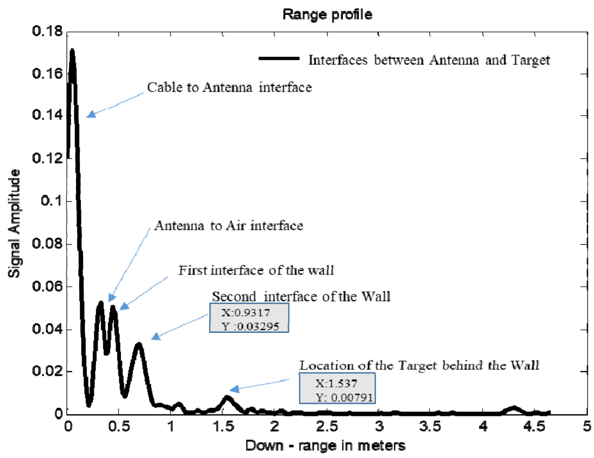

Fig. 5 A- scan for only Teflon Target behind the wall

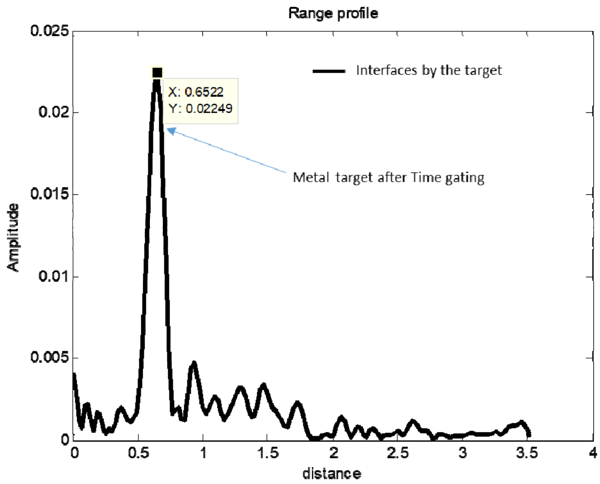

Fig. 6 A- scan for metal target after time gating

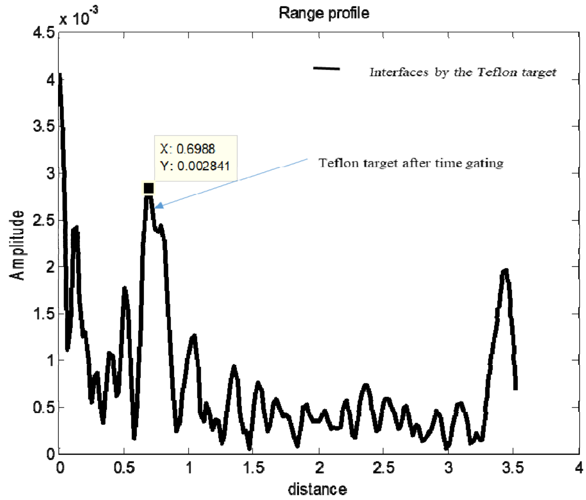

Fig.7 A- scan for teflon target after time gating

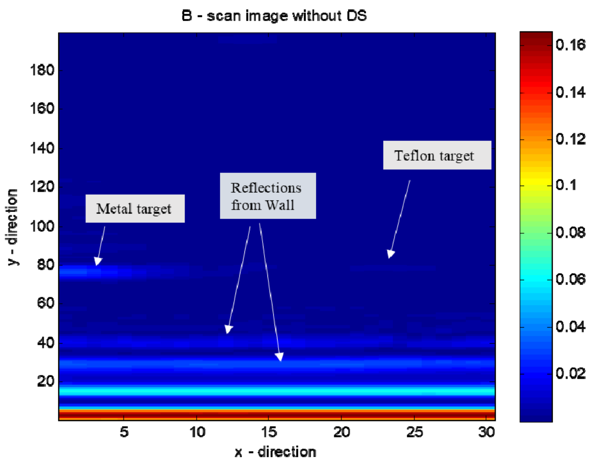

Fig. 8 B- scan for two targets without DS

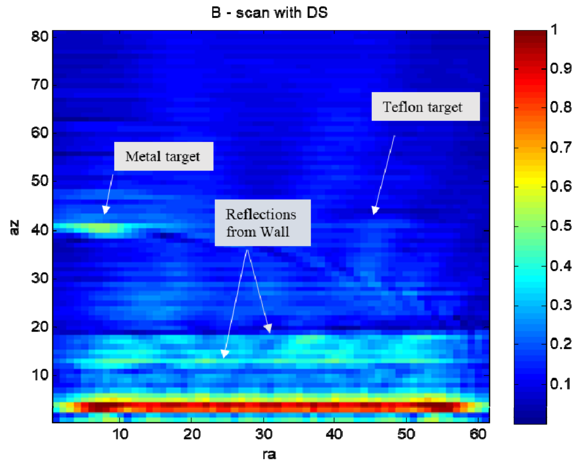

Fig. 9 B- scan for two targets with DS

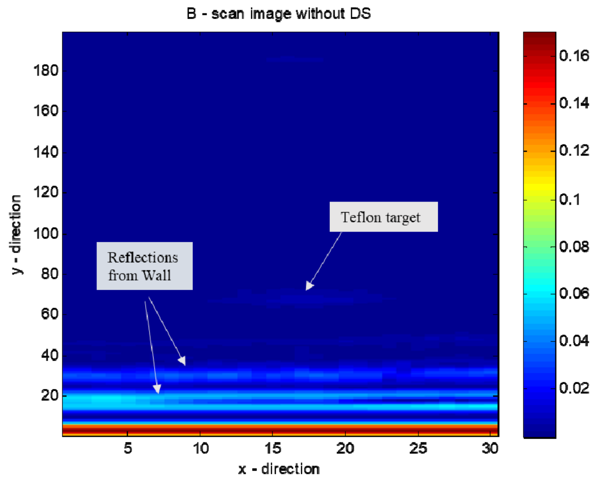

Fig.10 B –scan for only Teflon target without DS

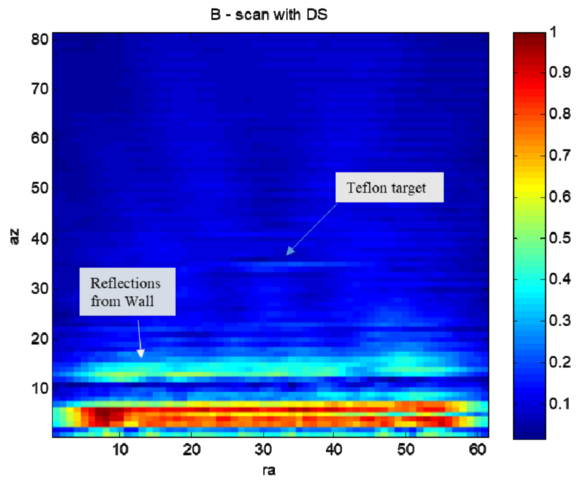

Fig.11 B –scan for only Teflon target with DS

Fig.10 and Fig.12 shows that resolution of the image is high compared to fig.9 and fig.11, but then also Teflon target is not easily visible in fig.10 when it placed near to the metal target. When only Teflon target is placed behind the wall it is visible as can be seen in fig. 12 even though resolution is less compared to fig. 10. DS algorithm which considers coherent summation of delays from all sensor data may be effecting the resolution and making Teflon plate invisible. More study is required in this regard and if necessary further improvement is required in the imaging algorithm.

V. CONCLUSION AND FUTURE SCOPE

All results presented above are real time experimental work. Image formed with the help of DS- beamforming detect metal target clearly but not Teflon target, but when only Teflon target is placed DS- beamforming able to detect it after time- gating with thresholding. Our experimental results of detection of Teflon behind the wall are very effective since detection of low dielectric material is not possible by any other general technique. Results for the DS- beamforming shows that improvement in the imaging algorithm is required for contrast imaging. In our future work we will focus on analysis of contrast imaging technique, and develop adaptive imaging algorithm.

REFERENCES

[1] M. Baharian, H. Rajabalipanah, M. H. Fakheri, and A. Abdolali, “Removing the wall effects using electromagnetic complex coating layer for ultra-wideband through wall imaging,” Antennas Propag. IET Microw., vol. 11, no. 4, pp. 477–482, 2017.

[2] S. Kidera, T. Sakamoto, and T. Sato, “High-resolution 3-D imaging algorithm without derivative operations for UWB through-the-wall radars,” in 2008 IEEE Antennas and Propagation Society International Symposium, 2008, pp. 1–4.

[3] Y. Zhang and T. Xia, “In-Wall Clutter Suppression Based on Low-Rank and Sparse Representation for Through-the-Wall Radar,” IEEE Geosci. Remote Sens. Lett., vol. 13, no. 5, pp. 671–675, May 2016.

[4] B. Yektakhah and M. Dehmollaian, “A Method for Cancellation of Clutter Due to an Object in Transceiver Side of a Wall for Through-Wall Sensing Applications,” IEEE Geosci. Remote Sens. Lett., vol. 9, no. 4, pp. 559–563, Jul. 2012.

[5] R. Solimene and A. Cuccaro, “Front Wall Clutter Rejection Methods in TWI,” IEEE Geosci. Remote Sens. Lett., vol. 11, no. 6, pp. 1158–1162, Jun. 2014.

[6] F. H. C. Tivive, M. G. Amin, and A. Bouzerdoum, “Wall clutter mitigation based on eigen-analysis in through-the-wall radar imaging,” in 2011 17th International Conference on Digital Signal Processing (DSP), 2011, pp. 1–8.

[7] F. H. C. Tivive, A. Bouzerdoum, and M. G. Amin, “An SVD-based approach for mitigating wall reflections in through-the-wall radar imaging,” in 2011 IEEE RadarCon (RADAR), 2011, pp. 519–524.

[8] F. Ahmad, J. Qian, and M. G. Amin, “Wall Clutter Mitigation Using Discrete Prolate Spheroidal Sequences for Sparse Reconstruction of Indoor Stationary Scenes,” IEEE Trans. Geosci. Remote Sens., vol. 53, no. 3, pp. 1549–1557, Mar. 2015.

[9] X. Chen and W. Chen, “Double-Layer Fuzzy Fusion for Multiview Through-Wall Radar Images,” IEEE Geosci. Remote Sens. Lett., vol. 12, no. 10, pp. 2075–2079, Oct. 2015.

[10] P. Zhang and X. Zhang, “A Modified Phase Shift Migration Algorithm Applied to 2D and 3D Through-the-Wall Imaging,” IEEE J. Sel. Top. Appl. Earth Obs. Remote Sens., vol. 7, no. 5, pp. 1700–1708, May 2014.

[11] M. Riaz, Muhammad, and A. Ghafoor, “Through-Wall Image Enhancement Based on Singular Value Decomposition.” International Journal of Antennas and Propagation 2012.

[12] Y. S. Cho, H. K. Jung, C. Cheon, and Y. S. Chung, “Adaptive Back-Projection Algorithm Based on Climb Method for Microwave Imaging,” IEEE Trans. Magn., vol. 52, no. 3, pp. 1–4, Mar. 2016.

[13] P. Zhang, P. Fei, X. Wen, and F. Nian, “A Novel Through-the-Wall Imaging Algorithm Combined with Phase Shift Migration and NUFFT,” Chin. J. Electron., vol. 26, no. 5, pp. 1096–1100, 2017.

[14] M. Klemm, I. J. Craddock, J. A. Leendertz, A. Preece, and R. Benjamin, “Improved Delay-and-Sum Beamforming Algorithm for Breast Cancer Detection,” International Journal of Antennas and Propagation, 2008.

[15] A. N. Gaikwad, D. Singh, and M. J. Nigam, “Application of clutter reduction techniques for detection of metallic and low dielectric target behind the brick wall by stepped frequency continuous wave radar in ultra-wideband range,” Sonar Navig. IET Radar, vol. 5, no. 4, pp. 416–425, Apr. 2011.

[16] Y. S. Yoon and M. G. Amin, “Spatial Filtering for Wall-Clutter Mitigation in Through-the-Wall Radar Imaging,” IEEE Trans. Geosci. Remote Sens., vol. 47, no. 9, pp. 3192–3208, Sep. 2009.

[17] G. Wang and M. Amin, “A new approach for target location of through the wall radar imaging in the presence of wall ambiguities,” in Proceedings of the Fourth IEEE International Symposium on Signal Processing and Information Technology, 2004., 2004, pp. 183–186.

[18] A. N. Gaikwad and K. S. Dongre, “Improvement in detection of human life sign signal hidden behind the wall using clutter reduction technique,” in 2016 International Conference on Emerging Trends in Communication Technologies (ETCT), 2016, pp. 1–5.

[19] F. Ahmad, M. G. Amin, and S. A. Kassam, “A beamforming approach to stepped-frequency synthetic aperture through-the-wall radar imaging,” in 1st IEEE International Workshop on Computational Advances in Multi-Sensor Adaptive Processing, 2005., 2005, pp. 24–27.

[20] Q. Yao and W. Qifu, “Kirchoff Migration Algorithm for Ground Penetrating Radar Data,” in 2012 International Conference on Computer Science and Electronics Engineering, 2012, vol. 2, pp. 396–398.

[21] G. F. Stickley, D. A. Noon, M. Cherniakov, and I. D. Longstaff, “Gated stepped-frequency ground penetrating radar,” J. Appl. Geophys., vol. 43, no. 2–4, pp. 259–269, 2000.

[22] B. Kumar, R. Upadhyay, and D. Singh, “Development of an Adaptive Approach for Identification of Targets (Match Box, Pocket Diary and Cigarette Box) under the Cloth with MMW Imaging System,” Prog. Electromagn. Res., vol. 77, pp. 37–55, 2017.