CHAPTER 1

INTRODUCTION AND LITERATURE REVIEW

Through the wall electromagnetic imaging is an emerging area which enables one to sense the objects behind a wall. This type of technology is required for various applications such as search and rescue operation, surveillance reconnaissance in urban areas, detection and identification of targets behind the wall. Research in through wall imaging (TWI) system is focused either on detection of stationary target or moving target. The major issue while imaging targets behind a wall is strong clutter due to reflection from wall and antenna mismatch in through-the-wall radar image (TWRI) which obscure the presence of target. There is a need to process the image in such a way that information carrying the presence of targets and its position become apparent by mitigating the clutter. This is primarily achieved on radar principles.

1.1 Applications of Radar

The term RADAR was coined in 1940 for the description of its primary role as Radio Detection and Ranging system. It transmits radio frequency wave in the direction of object. When radio frequency waves incidents on the object, a small part of energy is reflected back from the object to the Radar. The information related to object such as its position, velocity and other characteristics are obtained by processing the transmitted and received radio frequency waves. The range of object is indicated as a function of the round trip delay of pulse while traveling from radar to the object and object to radar. The direction of the object is indicated by the direction of the antenna at the time the reflected pulse is received. In most cases, the radar operates by transmitting RF energy through a directional antenna and receives the reflected pulse from object in between transmission of pulses using duplexer.

These days various radar systems have found an increasing number of important military and civilian applications. In aviation, air traffic control radar systems are used for safe and efficient travelling by aircraft. It is used for short range as well as long range tracking and navigation of aircraft near the airport, and on routes between the airports, and observation of aircraft and ground vehicle on the runways. Radar altimeter installed on aircraft indicates the height of the aircraft above the ground for safe landing of aircraft. Precision approach radars are used to guide the aircraft to safe landing under zero visibility condition. Weather radars are used to measure precipitation and detect hazardous weather conditions such as cyclones etc. and track them for evacuation of people at coastal areas. Terrain-avoidance radars that assist the pilot to fly over or around the ground and other obstacles in his path. Marine radars are used to detect ships and land obstacles, assist in avoiding collisions and to provide navigation at sea through the fog. Space borne radars used for sea surveillance, remote sensing, ground mapping, navigation, and weather forecasting. Speed-gun radars are well-known applications of Doppler radar that is used for measurement of speed of vehicle on road.

Another category of radar systems are microwave imaging radar systems. These radars have shorter range but have better resolution. In active microwave imaging radar the scene under test is illuminated with microwave signals through transmitters and scattered signals are collected by receivers. These transmitted and received signals are further processed to form virtual image of scenario. There are three main microwave radar imaging systems, namely: ground penetrating radar, medical radar imaging and through-the-wall imaging radar. Ground penetrating radar (GPR) is used to detect objects buried below the surface of the earth. This radar has been used for defence application especially for anti-personnel or anti-tank landmine detection [Tiwari *et al.* (2008)]. It is also used for civilian applications such as locating buried pipes (water or gas) and cables lie in the fields and alongside the roads and footpaths [Tong *et al.* (1993)]. GPR have been also used for geological survey such as mineral exploration [Francke (2010)], glacier mapping [Bohleber *et al.* (2017)], and ground water mapping [Igel *et al.* (2013)]. It can also be used for rescue of survivors buried under snow after an avalanche [Yamaguchi *et al.* (1991)].

Medical radar imaging techniques, based on microwave signals, have been used for breast cancer detection and have gained attention of various researches. Presently, medical imaging using radar within the research community has become an alternative imaging modality for breast tumor detection for cancer diagnoses [Islam *et al.* (2019)]. This technique offers advantages of a low cost screening device, fast screening time, no patient discomfort or health risk. This technique is based on the dielectric contrast between the tissues in the breast which causes an incident electromagnetic signal to be absorbed or scattered differently as it passes through the breast. The received signal scattered from or around the breast is processed to form an image map of the breast interior.

Through wall imaging radar system is an emerging technology which is used to image the scene and allow us to detect and identify objects and/or life signs behind a wall which cannot be directly accessed or seen using conventional measures [Baranoski (2008)]. Such system is based on the principle of radar that uses radio frequency waves that have the capability to penetrate through the wall. Currently, such technology is in great need of various military and civilian applications [Baranoski (2008), Farewell *et al.* (2008)]. For military applications, such system can be used to detect and locate concealed objects such as bombs and for searching terrorists in an urban environment. It can be useful for detecting and classifying concealed weapons and explosives in military actions or for homeland security purposes. It can be helpful in assisting police units to rescue people in a hostage situation. On the other hand, in rescue applications, TWI system can be helpful for rescuing survivors after natural disaster such as an earthquake, trapped people inside a building where fire has broken out, and miners trapped in underground mines. Recently, such system has been used in Nepal to rescue four men trapped under debris.

1.2 Motivation

The technologies developed for Through Wall Imaging can be categorized into three types. The first type is based on acoustics principle, where an ultrasonic signal is used as means of transmission [Ferris and Curie (1998)]. The object image is obtained by processing the transmitted and received signal. The second type is based on X-rays, where a high energy X-rays are transmitted and image is captured at the photographic detector [Callerame (2006)]. The third type is based on principle of radar, where a radio frequency (RF) signal is transmitted and image of the object is obtained by processing the transmitted and received signal [Baranoski (2008)]. Though technologies based on X-rays and acoustic waves have their advantages of not being affected by the frequency parameter, X-ray technology is limited by its short range and potential safety risks whereas acoustic waves are limited by its inability to penetrate multilayered walls [Callerame (2006), Ferris and Curie (1998)]. Thus, the development of TWI systems based on X-ray and acoustic technology have been limited to date. Radio frequency on the other hand, is the most commonly used technology for TWI systems. However, the use of RF presents a trade-off between wall penetration and target resolution. This is because, lower frequencies can easily penetrate through walls, but higher frequencies provide better resolution. Thus, requirement of high resolution encourages the development of TWI systems based on the ultra-wideband (UWB) radar. Since, in UWB technology-based radar, high bandwidth can be achieved with comparatively lower center frequency compare to narrow-band systems in which to achieve large bandwidth, operation at high frequencies is required. In order to standardize the development of RF based TWI systems, the Federal Communication Commission (FCC) released a report on using ultra-wideband technology with imaging systems, which restrict the system to operate below 960 MHz or within 1.99 GHz and 10.6 GHz [Gentile and Kik (2007)]. According to this release, any signals or systems that have bandwidth ~ 500 MHz or instantaneous fractional bandwidth ~ 0.20 is considered as ultra-wideband system. Further, compared to the conventional narrowband radar, the ultra-wideband radar has many advantages [Gaikwad *et al.* (2011a)]. UWB radar has large absolute signal bandwidth due to which it has better range measurement accuracy and range resolution. It also has immunity to passive interference, such as, rain, fog, aerosols, and metalized strips. Since it has better range resolution due to which it provides information not only about the whole target but also about its constituting separate elements, which aids in the identifying of the class of target. It has higher probability of target detection and good target tracking capability. The transmit power of UWB radar is much lower compared to narrowband radar.

Therefore, it is a challenge for current researchers to develop UWB radar for through wall imaging behind different types of walls, such as, wood, brick, etc. The microwave radar systems often employed for TWI are impulse radar, stepped frequency continuous wave (SFCW) radar and noise radar. The simplest to generate is the impulse radar or short pulse radar [Yang *et al.* (2008), Yang *et al.* (2009)]. The pulse duration of these impulses is usually sub-nanosecond which enables a range resolution of 15 cm or less. A UWB impulse radar system can be designed as such that it transmits receives and samples the RF signal directly. This approach eliminates the use of components such as high quality oscillators, mixers and tuned circuits that are commonly used by narrowband systems to modulate a high frequency RF carrier wave to transmit and receive information. However, the receiver will require a high speed sampling architecture in order to sample large bandwidth signals [Yang *et al.* (2008)], which increase cost and complexity of system. With the recent advancement of a programmable delay line receiver [Yang *et al.* (2009)], the design complexity and cost of the proposed UWB system hardware is significantly reduced when compared to the conventional narrowband system. Despite a number of advantages, UWB impulse radar systems have also some drawbacks [Gaikwad *et al.* (2011)]. The shortness of the pulse makes the bandwidth become wider and reduces the signal to noise ratio (SNR). On the other hand, in SFCW radar, the waveform is synthesized from series of continuous wave signals in UWB frequency range. SFCW radar system has several advantages over impulse radar systems [Gaikwad *et al.* (2011a)]. The main advantage of the using SFCW radar is that it requires low speed analog to digital converters. It is relatively easy with current technologies to efficiently sample ultra-wideband signals with low speed analog to digital converters. It offers high dynamic range and high signal to noise ratio. Due to transmission of continuous signals, mean transmitted power of radar increases, thus more distance can be covered compared to impulse radar. Owing to these advantages, it becomes viable to use SFCW radar for through wall imaging system.

Applications primarily driving the TWI system development can be divided based upon whether information is needed about moving target inside a building or stationary target. The need to detect moving target inside a building is highly desirable for rescue of people in many fire and hostage situations [Hunt (2009), Mareef *et al.* (2009)]. Detection of moving target while suppressing stationary clutter has been achieved via change detection technique or by exploitation of doppler feature [Amin *et al.* (2013a), Soldovieri *et al.* (2009), Ram and Ling (2008), Ram *et al.* (2008)]. Doppler-based radars are excellent for detecting movement while suppressing any stationary clutters in the background. The doppler information is less susceptible to propagation effect of wall because it represents the presence of moving of target by rate of change of phase of the signal. Another aspect of doppler returns is the generation of “micro-doppler” features from the motion of human limb. Micro-doppler features contain valuable information related to human motions. Such feature has been to classify various human activities [Thayapan *et al.* (2008), Orovic and Amin (2011)]. However, doppler technique become ineffective for detection and classification of stationary target behind walls due to the absence of frequency-domain or time-domain variation associated with stationary target [Debes *et al.* (2011)].

TWI system has several challenges to achieve the goal of detect, classification and recognition of stationary target of behind the wall. One of the several challenges in TWI is to form high resolution image of target for determining highly accurate information about target location, and its approximate shape, that can be used for detection and recognition of object. Synthetic aperture radar (SAR) based imaging algorithm has been the most commonly used algorithms for this purpose. However, conventional synthetic aperture based imaging algorithm based on the assumption of homogeneous medium become ineffective in TWI because the propagation path is not a straight line anymore. When electromagnetic (EM) wave travels through wall propagation distortions occurs due to refraction of EM wave that occur at the front and rear side of the wall and propagation delay. Without considering the propagation effect of wall, the formed image of targets behind wall will be blurred and show ambiguity in position of target which ultimately degrades the performance of radar [Nkwari *et al.* (2018)]. In addition to the propagation effect of wall, the presence of multipath and wall clutter significantly contaminates the radar image that deteriorates the detection and recognition performance. Multipath propagation caused from multiple reflections of EM waves off the targets in conjunction with the walls, floors, and ceilings gives rise to appearance of ghosts targets which can be confused with the real targets inside buildings [Nkwari *et al*. (2018)]. Thus, one of the significant challenges in TWI is to develop an efficient imaging algorithm that can give maximum information about target [Baranoski (2008)]. In the literature, various imaging algorithms are reported. The most commonly used algorithm for image formations are backprojection, delay and sum beamforming, and frequency-wavenumber. So far, very less work has been reported about the application of these three imaging techniques on TWI data and checking the consequences and effect of imaging. So, it becomes essential to explore the application of these algorithms on TWI data to analyze the effect of imaging and evaluating the performance.

The radar images show very little resemblance to optical images due to which it becomes difficult to interpret from imaged scene. Therefore, there is need of a methodology for analysis of the radar images which can automatically perform recognition task and thereby help in decision making. Several authors have proposed two step methodologies for classification of stationary target behind a wall from through-the-wall radar images. First the target region is detected and then feature is extracted from target region. Detection has been carried out by using thresholding techniques. Various techniques have been reported for choosing an optimum threshold for mitigating background noises or clutters. However, finding an optimum thresholding becomes difficult when dielectric contrast between object and background are very low. So, it becomes challenging to detect high and low dielectric targets with the same image processing method. Thus, further research is required for developing an optimal thresholding technique.

Another important aspect is the recognition of target. To recognize the target, a robust feature that gives description of target is required. A robust feature should have resolution-independent or target position-invariant, orientation and size invariance property. Many authors have contributed in the direction of recognition of target behind a wall using different features. Application of artificial neural networks can also be used to address the problem of recognizing an object through wall. Thus, artificial neural network based recognition of target in TWI is an area that need further exploration.

1.3 Literature Review

Several imaging algorithms have been devised for two-dimension (2D) and three-dimension (3D) image formation of stationary target that compensate the propagation effect the wall. The 3D imaging systems have higher computational requirements compared to 2D localization systems which makes it time consuming. However, the third dimension provides height information that will be useful in distinguishing standing and sitting people or people from animals, such as household pets for TWI applications. Ahmad *et al.* (2005) have proposed delay and sum beamforming imaging algorithm that is closely related to SAR technique. The image is formed pixel by pixel by coherent summation of the received signal with proper phase compensation. The wall effect is compensated based on ray tracing method. In order to accurately model the EM wave propagation through wall, a non-linear inverse scattering based contrast source inversion imaging algorithm that compensate effect of the wall through modeling of the layered medium using Green's function is developed and reported by Song *et al.* (2005). With such nonlinear inverse scattering method, high-resolution images has been obtained. However, such nonlinear inverse scattering method becomes a nonlinear optimization algorithm that has to be solved iteratively making it very time consuming. Soldovieri and Solimene (2007) has proposed a linear inverse scattering imaging algorithm based on first order born approximation. Linear inverse scattering algorithm has showed significant improvement in terms of computation speed over contract source inversion algorithm. Soldovieri *et al*. (2008) has proposed a linear inversion algorithm for a multiarray multimonostatic/multifrequency configuration in which scattering equations are formulated under the linear Born model by means of the truncated singular value decomposition. Yoon and Amin (2008) has proposed a BS-MUSIC for image formation method in which the MUSIC algorithm is applied to multiple beams. The proposed BS-MUSIC can locate spatially extended targets in low SNR environments. Most of aforementioned through-the-wall radar imaging algorithms have been devised for single layer homogeneous wall in the two and three dimensional scenarios. Zhang and Hoorfar (2013) has proposed a generalized three-dimension beamforming algorithm for the focused image formation of targets behind multilayered building walls by modeling EM wave propagation through wall through far field layered medium Green's function to compensate the effect of multilayered wall. Zhang and Hoorfar (2012) has proposed a 3D diffraction tomographic algorithm based on Born approximation and a three-layered medium dyadic Green's function to formulate a linear relationship between the spatial Fourier transforms of the image and the scattered field. The linearization of the inverse scattered field with implementation of FFT/IFFT increases the effectiveness and efficiency of the proposed algorithm making it suitable for on-site applications.

The above aforementioned imaging algorithms are based on the assumption that the wall parameters are exactly known a priori. However, in practical situations, the wall parameters are not exactly known a priori. Ambiguities in wall parameters can smear and blur the target image as well as shift away the target from their true positions [Nkwari *et al.* (2018)]. Therefore, to form though-the-wall radar images, the wall characteristics need to be estimated apriori. Several imaging techniques which does not require knowledge of the wall parameters have been devised. A TWI technique that provides correct locations of stationary targets without the knowledge of wall parameters, as was proposed by Wang and Amin (2006) and Wang *et al.* (2006),. This technique is based on coherent wideband beamforming and utilizes two or more different array structures. A trajectory of the shifts in the target position is generated with different assumed wall parameters with each array structure. The target position is then determined as the crossover point of trajectories. In order to avoid the use of different antenna array, an autofocusing method is proposed based on the idea that the through-the-wall radar image of target can be well focused when the estimated values of the wall parameters will be close to the true values [Ahmad *et al.* (2007)]. At each iteration, the image formation process is performed assuming updated wall parameters and image quality is determined by the image contrast or sharpness metric. Then optimal image quality is obtained using some optimization method. The optimal image quality occurs when the assumed wall parameters values are close to the true values. Ahmad *et al.* (2007) have proposed image domain approach based on higher order statistics image contrast focusing metric. The technique is applicable when the errors in the values of wall parameter are small and the targets are positioned at the far field of the transmitters. Li *et al.* (2009) has proposed real-time through wall imaging algorithm employing a spectrum Green's function and Fast Fourier Transform to formulate the through wall imaging algorithm and minimum entropy criteria as image focusing metric. With such technique high-quality focused image has been obtained in a short computation time regardless of the estimated value of the wall parameters. The image quality optimization methods are highly precise but have low computational efficiency because of its feedback scheme. During the feedback procedure, the imaging formation process has to be performed with updated wall parameters at each iteration due to which computational burden increases. Solimene *et al.* (2009a) has proposed fast and efficient two-step imaging procedure. First, the wall thickness and its dielectric permittivity is estimated by a simple procedure. Then, the problem is formulated as a linear inverse scattering problem and solved by means of a truncated-singular value decomposition algorithm. Dehmollaian and Sarabandi (2008) have described an alternative approach to address TWI problem using synthetic aperture radar, in which the values of wall parameters have to be estimated by solving a nonlinear optimization problem.

The through-the-wall radar images of stationary target behind a wall are subject to the stationary clutter from the strong reflection of the wall which obscures the target image [Tivive *et al.* (2014)]. Thus, there is a need of a methodology to enhance the detection of the target while mitigating the clutters. During the past years, several methods have been reported for suppressing the wall clutter. The proposed techniques can be categorized into four categories. The first technique is based on background subtraction technique [Tivive *et al.* (2014)]. This approach relies on prior knowledge of the background scene. It gives good results, but is not feasible in real scenario because prior knowledge of the background scene cannot be obtained in real scenario. The second technique is two step procedure based on modeling of the EM waves for the wall returns [Dehmollaian and Sarabandi (2008)]. First, the values of wall parameters such as the relative permittivity and thickness have been estimated through the measurements. Then modeled wall returns are subtracted from the raw data. The third is based on subspace decomposition or spatial filter that removes the zero spatial frequency component. Such method can be applied if the wall is parallel to the antenna scanning path and invariant properties of the wall returns along the scanning path [Gaikwad *et al.* (2011), Tivive *et al.* (2014)]. These techniques don't rely on prior knowledge of the background scene. Gaikwad *et al.* (2011) have applied statistical clutter reduction techniques, like, singular value decomposition (SVD), prinicipal component analysis (PCA), factor analysis (FA) and independent component analysis (ICA) on TWI images obtained when brick wall is used. It was reported that metal target got detected easily after applying clutter reduction techniques. Comparison is shown among these techniques by obtaining signal to clutter ratio and it has reported that ICA techniques gives highest signal to noise ratio. But when low dielectric target such as Teflon is used then only ICA is able to detect target. Similar results are obtained when plywood wall is replaced by brick wall to increase the complexity of detection of low dielectric target. The third technique is based on spatial filter based clutter reduction technique that is notched from the image [Yoon and Amin (2009)]. This filter was applied across the antenna array to remove low frequency components captured from homogeneous or near-homogeneous wall returns. The fourth technique is based on time gating which is another method used to reduce clutter [Solimene and Cuccaro (2013)]. It is successful for the targets which are far away from wall but for the targets near to the wall, the target response might overlap in time domain and cannot be separated in time domain.

For determining highly accurate information about target location, and its approximate shape, high resolution image of target is required. High resolution image requires a high crossrange resolution. High crossrange resolution can be achieved by synthesizing a long synthetic aperture. Synthesizing a long synthetic aperture increases the amount of space-time/space-frequency data thereby, increases the data acquisition time.

Moreover, large amount of space-time/space-frequency data also increases the storage and memory requirement. Thus, one of the main drawbacks of through wall imaging with monostatic synthetic aperture radar is the long data acquisition time to synthesize an aperture. Moreover, the target in through-the-wall radar image is not always stationary, thus, while acquiring the data, the target may have moved to another position such that the imaging result is no longer valid. Thus, reduction in larger amount of data is important in TWI applications, as it reduces processing time and, subsequently, allows prompt actionable intelligence. There is a trend among researchers to use compressive sensing signal processing method that is used to reconstruct image with less measurement or signal sample. Compressive sensing is a signal processing method that can be used to reconstruct a signal with less measurement or signal sample. Therefore, using this method in a radar system, the data collection time can be drastically reduced. This is why there is a growing interest among researchers to use this method in TWI to decrease the acquisition time of data. So far several applications of compressed sensing technique to TWI have been reported. The first application of the compressive sensing (CS) technique to TWI was reported by Tang *et al.* (2013). Afterward a number of CS algorithms applied to TWI in conjunction with delay and sum beamforming algorithm [Huang *et al.* (2009), Amin and Ahmad (2013)] and other electromagnetic inverse scattering based imaging algorithms [Oliveri and Massa (2014), Soldovieri *et al.* (2012)] have been reported. Lagunas *et al.* (2012) reported a wall mitigation technique in conjunction with CS to achieve enhanced imaging capability. Li and Burkholder (2015) have proposed a distributed greedy algorithm named hybrid matching pursuit (HMP) for reconstructing high-resolution image of the scene of interest under the compressed sensing framework. Greedy algorithm method is much more computationally efficient than linear programming method.

Several methods have also been devised for dealing with multipath ghosts. These methods can be classified into two types. The first type focuses on the post signal processing algorithms [Setlur *et al.* (2011), Setlur *et al.* (2013)]. Setlur *et al.* (2011) devised a multipath exploitation technique that associate and map back the multipath ghosts to their true targets location by using point spread functions. Later, Setlur *et al.* (2013) have proposed an effective method to cancel multipath echoes from the raw data. The second type is based on the array configuration by exploiting the aspect-dependent (AD) feature [Abdalla *et al.* (2015), Li *et al.* (2013), Yan *et al.* (2016)]. Li *et al.* (2013) and Yan *et al.* (2016) have proposed the sub-aperture based technique to eliminate the multipath ghosts. Tan *et al.* (2014) proposed multipath ghost suppression method based on Hidden Markov Model which is developed by using the AD characteristic of the ghost. Recently, Guo *et al.* (2018) have developed a novel framework via array rotating to suppress the multipath ghosts.

The radar images show very little resemblance to optical images due to which it becomes difficult to interpret from imaged scene. Therefore, there is need a methodology for analysis of radar images which can automatically perform recognition task and thereby help in decision making. Several authors have developed two step methodologies for the identification of stationary targets behind the wall from through-the-wall radar images. First the target region is segmented and then feature is extracted from target region. After mitigating the stationary clutter in through-the-wall radar image, thresholding is applied to the image to separate target pixels from background noise or clutters, and thereby further enhance the image quality. In TWI, detection of target depends on dielectric contrasts between two different kinds of targets or between target and media. If a contrast is very weak the detection becomes difficult. The electromagnetic waves transmitted by radar propagate through air, nonmetallic wall and other objects. TWI radar detects any object that lie in its line of sight if the dielectric constant of object is different from the surrounding medium. Metal target will reflect more energy and appear bright while target having low dielectric constant will reflect less energy and appear dark. Bright area will indicate presence of target while dark area will not be detected. One of the important aspects in radar is to detect low dielectric target because the reflection of signal from the low dielectric constant target is very weak and reflection from low dielectric target in presence of clutter is very difficult to be distinguished. Various researchers have reported about choosing optimum threshold for mitigating non-stationary clutter. Debes *et al.* (2009a) have devised statistical detectors based on likelihood ratio tests for detection of stationary targets in through-the-wall radar images. In this test, a Neyman-Pearson criteria was formulated for choosing a threshold for separating targets pixels in through-the-wall radar images while controlling false alarm rate. But such test requires apriori probability density functions (pdfs) for the through-the-wall radar images. Since information about pdf cannot be obtained apriori, therefore Debes *et al.* (2009b) developed a methodology which adapts the statistics parameters corresponds to the through-the-wall radar image statistics for implementation of Neyman-Pearson test. Later, morphological filtering was used to optimize the estimates test parameters [Debes *et al.* (2010)]. These approaches provide quality images, but they assume apriori probability density functions (pdfs) of targets and clutters in radar images. These assumed pdfs may differ for various scenario. Therefore, in the most cases appropriate pdfs and false alarm rate needs to define apriori every time for both targets and clutter in through wall radar image, which presents a shortcoming of using likelihood ratio tests detection of target. To overcome this limitation, some automatic threshold selection techniques are also reported. Such techniques use discriminant criterion by maximize the separability of the resultant classes in order to select an optimal threshold. However, thresholding becomes difficult when target and background level possess substantially overlapping distribution. Thus, thresholding techniques need further investigation from TWI point of view.

To identify the target, a robust feature that gives description of target is required. A robust feature should have resolution-independent or target position-invariant, orientation and size invariance property. Many authors have contributed in the direction of classification of target behind a wall using different techniques. Previous work on target classification in TWI, includes the use of the principal component analysis on two-dimensional imaging (downrange vs crossrange) [Mobasseri and Rosenbaum (2008)] and super-quadric fitting [Debes *et al*. (2010b)] on segmented objects on three- dimensional imaging. Both approaches, however, provide features that are not system resolution-independent or target position-invariant. As per reported literature, identification of target in TWI is achieved with the use of high range resolution profile (HRRP) based feature on segmented three-dimensional through-the-wall images of target [Smith and Mobasseri (2011)]. As reported in their papers, although they have obtained good quality of results in same orientation but the proposed framework was not modeled explicitly for the target orientation. Thus, it will assign separate feature for different orientations of the same target rather than having a single feature that covers all orientations. This makes the process complex and computationally intensive.

Another more promising technique for recognition of target is to estimate of shape of target [Hantscher *et al*. (2006a)]. Various authors have developed techniques for the shape estimation of target behind a wall. In previous reported work, shape of target has been estimated with use of the Inverse Boundary Scattering Transform (IBST) on B-scan data [Hantscher *et al.* (2006b)], and enveloped of modified sphere on C-scan data [Kidera *et al.* (2009)]. With these techniques quite accurate shape of target has been achieved however these methods often need complex preprocessing like the IBST where wavefronts need to be recognized and estimated and the Enveloped of modified sphere where the curvature of target shape have to estimated [Mirbach and Menzel (2011)]. Recent development have achieved even higher accuracy but with a significant increase in complexity and computational time [Mirbach and Menzel (2011), Wu *et al.* (2013), Delmollaian (2010)].

1.4 Research Objective and Proposed Contributions

In the present thesis, methodology for detection and recognition of target shape and size from through-the-wall radar images is to be developed. The developed methodology is less complex and easy to implement. This proposed methodology can recognize shape of target irrespective of its variation in orientation and size. Instead of analyzing three- dimensional image of target, two-dimensional through-the-wall image of target (horizontal cross range vs vertical cross range) is analyzed. The two-dimensional image of target is extracted from three-dimensional image of target by selecting a plane at fixed target range bin which is selected by observing range profile. The foremost step while performing the task of recognition of stationary targets behind a wall is to first detect the target position, its approximate shape and size, and then, subsequent treatment of these detected targets with use of image processing techniques for the shape recognition of targets. To determine highly accurate information about target location, and its approximate shape, high resolution image of target is required. Thus, one of the major challenges in TWI is to develop an efficient imaging algorithm which can give maximum information about target.

Previously various imaging algorithms are reported in literature for this purpose. So, it becomes important to explore the use of these algorithms with TWI data to analyze the effect of imaging and evaluating the performance. The most commonly used technique in TWI for image formations are back projection, delay and sum beamforming, and frequency-wavenumber. So far very less work has been reported in the reported articles for application of these three imaging techniques on same data and checking the consequences and effect of imaging. Therefore, main focus of the work is to first see the possibility of these imaging techniques on real data and compare their results to select the effective imaging algorithm that can be used for shape detection of target. Then, segment the target pixels from the background noises or clutters in the image using novel statistical based thresholding technique for recognition of the target through-the-wall radar image. The detected target images do not correspond to the actual shape and size of targets therefore this detected target image is further used to teach the artificial neural network for estimating actual shape and size of target. An effective training technique is used to improve the effectiveness of the proposed algorithm.

1.5 Plan and Scope

Application of artificial neural networks is increasing day by day in processing the data collected by various remote sensing systems. The distinctive capability of human brain to recognize objects under poor observable situation motivated us to apply artificial neural networks to the problem of recognizing an object through wall using SFCW radar. In the present work, a detailed insight of the methodology, analysis and results of developed through wall imaging system including the application of artificial neural network with an effective training technique are presented. The work embodied in the present thesis is organized into six chapters, as follows.

In Chapter 1, which is an introduction to the work embodied in the present thesis, the fundamentals of the radar and its applications are talked about. An overview and literature survey of the through wall sensing system is presented. Various advancements in the through wall imaging system are reviewed with their scope and limitations. The problems facing in the present status of Through-the-Wall Imaging System are identified, and the objectives and scope of the present work to overcome the problems are discussed in detail. The significant contributions of the author in the present work are also described.

In Chapter 2, details of measurement set-up, data acquisition procedure including radar parameters for formation of through-the-wall radar images are presented. The pre-processing required before formation of through-the-wall radar image such as wall characterization that include estimation of wall thickness and dielectric constant, and antenna delay calculation are also presented.

In Chapter 3, analysis of imaging algorithm for shape detection is described. Some of the existing imaging algorithm like backprojection, frequency-wavenumber and delay and sum beamforming imaging techniques are studied. The experiments are carried out using SFCW radar based TWI system to collect C-scan data with different targets and their 2D through-the-wall images have obtained after applying back projection, frequency-wavenumber and delay and sum imaging techniques on TWI data of different target. The 2D through-the-wall radar images obtained with these imaging algorithms are analyzed and compared to select the effective imaging algorithm for shape detection.

In Chapter 4, a novel statistical based optimal thresholding technique to detect shape and size of target behind a wall from through-the-wall radar image is presented.

Experiments are performed using SFCW radar based TWI system to collect C-scan data with different targets and through-the-wall images have obtained after applying delay and sum beamforming imaging algorithm. The performance of developed algorithms for optimal thresholding is evaluated by computing two performance measures, true positive pixels and false positive pixels. Essential design constraints for the choice of selecting threshold are explained. Various important design constraints and their role in selecting the threshold are also illustrated. The performance of proposed algorithms are evaluated and compared with the existing thresholding methods, like, mean based thresholding, maximum entropy based thresholding, and Otsu based thresholding.

In Chapter 5, application of artificial neural network to recognize and reconstruct shape of target behind a wall is presented. Here, experiment is carried out to collect C-scan data of various shapes of wooden and metallic targets using indigenously developed SFCW radar in frequency range of 3.5GHz – 5.5 GHz and through-the-wall images have obtained after applying delay and sum beamforming imaging algorithm. An effective training technique is presented to improve the effectiveness of the proposed algorithm. Further, performance of trained artificial neural network is verified through real independent data for its usefulness and practicality.

Finally, in Chapter 6, the works embodied in the present thesis are summarized, and the significant conclusions are drawn from the major findings. In addition to this, the limitations of the present study are also discussed, pointing out the scope for the future work.