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CHAPTER 1

Introduction and Literature Review

Radar, an acronym for radio detection and ranging, is a device that detects radio frequency (RF) signals scattered from distant objects [Amin (2017)]. It emits an electromagnetic wave (EMW) towards the target and extracts the target properties by measuring the change in the characteristics of the backscattered echo signal from the target with the aid of signal processing [Skolnik (1980)]. The received echo contains the reflection from the target along with the reflections from unwanted targets known as clutter [Shnidman (2005)]. Although radar was originally motivated and fostered by defense applications, the radar technology has been continuously developing and found numerous applications in both military and civilian areas. The advancement of electronics technology has driven the ubiquitous applicability of radar, ranging from the micro-scale radars applied in biomedical engineering to macro-scale radars used in radio astronomy [Amin (2017)]. The conventional military applications of radar system include detection and search, aviation support, air traffic control, maritime surveillance, target acquisition, target tracking, missile guidance, weather forecasting and airborne synthetic aperture radar [Denoeux and Rizand (1995), Vasiloff (2001), Wei *et al.* (2017), Amin (2011)]. However, the civilian applications of radar include automotive, collision and avoidance, medical imaging, detection of abnormal conditions of structures, nondestructive testing, and detection of subsurface objects, etc. During last two decades, radars have also found its applications in emerging areas, such as, assisted lifestyle for elders, homeland security, through-the-wall detection, and indoor monitoring [Liu *et al.* (2003), Amin (2017)].

The safety, reliability, and affordability are the most essential feature of any monitoring system deployed to recognize the regular and abnormal motion activities inside the office buildings, homes, schools, and hospitals [Majumder *et el.* (2017)]. Monitoring of such regular human activities can be achieved using different sensing modalities, including cameras, X-ray, infrared sensors and radars, however the radars operating in the microwave frequency regime are better alternative [Gaikwad (2011)]. Optical sensors based imaging cameras provide cheaper solution, and camera captured images are extensively used for automatic target recognition (ATR). However, the optical system cannot work for non-line of sight scenario as the optical sensors has poor wall penetration. X-rays based systems possess good wall penetration and high resolution imaging capabilities but these technologies cannot be easily deployed for surveillance due to its harmful ionizing radiation and higher cost. Infrared sensing results in a limited range application. On the other side, the microwave based systems have very good wall and dielectric penetration ability which can be used to achieve target information for non-line of sight condition and causes no harmful radiation exposure. The microwave based ranging systems can work in continuation for longer coverage and in all-weather condition and are cheaper solution for monitoring purposes when they are deployed with low-cost commercial off the shelf components (COTS) [Akhtar (2003)]. The radar system based monitoring facilitates the privacy prevention hence it can be deployed in the living areas also [Tahmoush (2011)].

1.1 Working Principle of Radar

The essence of conventional radar (pulsed radar) operation is to emit short pulses with very high peak power and listen to the echoes reflected by the targets of interest. Figure 1.1 shows a simplified block diagram of a typical radar system using single antenna. Transmitting pulses with high peak power of short pulse duration usually results in low average power, which further limits the maximum achievable detection range. The radar antenna focuses the transmit energy into narrow beams to localize the target in angle, then intercepts the target returns for additional processing. The receiver enhances the received signal through amplification, down-conversion of the radar signal to a low intermediate frequency, applying matched filter to the radar returns, detection of the signal envelope, and signal digitization for further processing. The post-processing stage is intended to further separate the target returns from perturbed (clutter + interference) signals, and estimate target associated parameters, including range, angle, and velocity. If the object is moving, either toward or away from the radar, shift in the frequency of the radio frequency (RF) waves have been observed, and this effect is popularly known as the Doppler Effect.

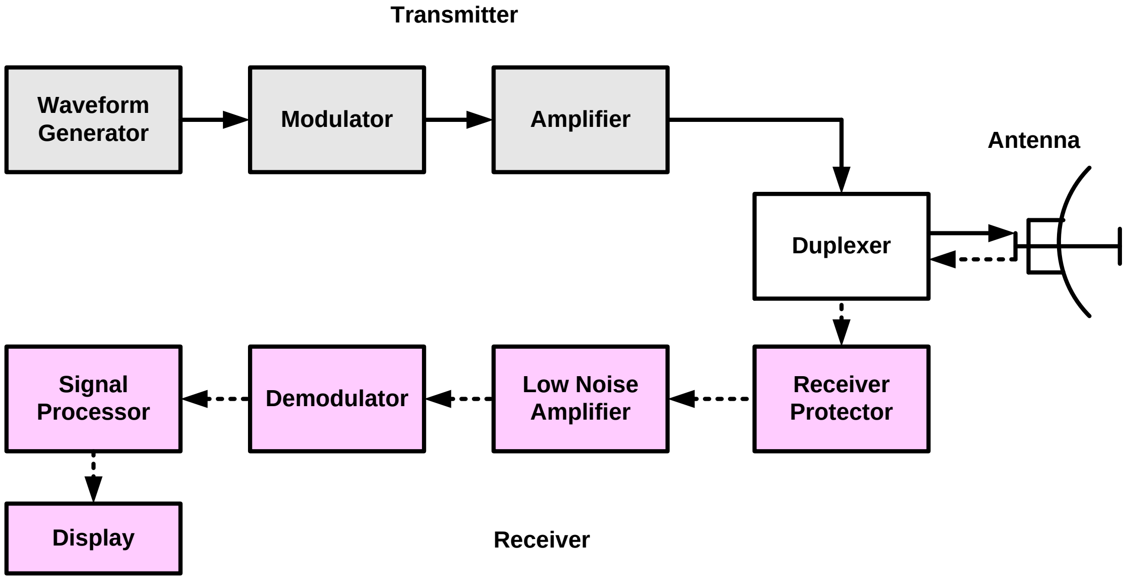


Figure 1.1: A basic block diagram of a radar system.

The tracker then processes these detections to provide target history over time and predict future positions. Most radar systems are equipped with display console that shows the operator the location of all detectable objects within operating range of the deployed radar system. Let a radar system transmit a signal $s_T(t)$ at the operating frequency f_0 . The received echo signal $s_R(t)$ from a target is proportional to the transmitted signal with a round trip delay $s_T(t-\tau)$ and scaled by the reflectivity function ρ of the target,

$$s_R(t) \propto \rho s_T(t-\tau) = \rho \exp\{\mathrm{j}2\pi \mathrm{f}_0(\mathrm{t}-\tau)\} \quad , \qquad (0 \le t \le T_p) \tag{1.1}$$

where T_p is the time duration of the signal [Chen and Ling (2002)]. If the R is the distance from radar to the target and c is the speed of propagation of electromagnetic wave (EMW) then the round trip delay τ can be determined by:

$$\tau = \frac{2R}{c} \quad . \tag{1.2}$$

The radar can be used for the detection of target range as well as velocity of the target. The radar can sense the target only if the conditions, arises due to electromagnetic and signal processing, and must be satisfied by the targets.

1.1.1 Radar Range Equation

The maximum range R_{max} can be given as [Mahafza and Elsherbeni (2004)]:

$$R_{\max} = \left(\frac{P_t G_t G_r \sigma \lambda_0^{\ 2}}{(4\pi)^3 kTBF(S_0 / \mathrm{N}_0)L} \right)^{1/4} \quad . \tag{1.3}$$

Here, P_t is the output power of the source, G_t and G_r are the transmitting and receiving antenna gains respectively, σ is the radar cross section, λ_0 is the wavelength, k is the Boltzmann constant, T is the radar temperature, B is the operating bandwidth, F is the noise figure, S_0/N_0 is the minimum output signal-to-noise ratio of the receiver and L is the system losses. It is worth noting that the radar equation (1.3) depends on the average power (S_0) of the transmit signal regardless of the waveform shape (Ahmad and Amin 2010). The condition for the target at distance R from the radar can be detected only if,

$$R \le R_{\max} \quad . \tag{1.4}$$

This chapter covers the basic differences of different radars for indoor monitoring purposes. Various possible cases arise in detecting human target signatures related literature survey has been carried out to identify the current state of the art. At last, the final objectives of this research work are listed along with the chapter wise organization of this thesis work.

1.2 Radar Classifications

Based on principle of operation, the radar systems can be classified into mainly into pulsed and continuous wave systems and their derivatives as shown in Figure 1.2.

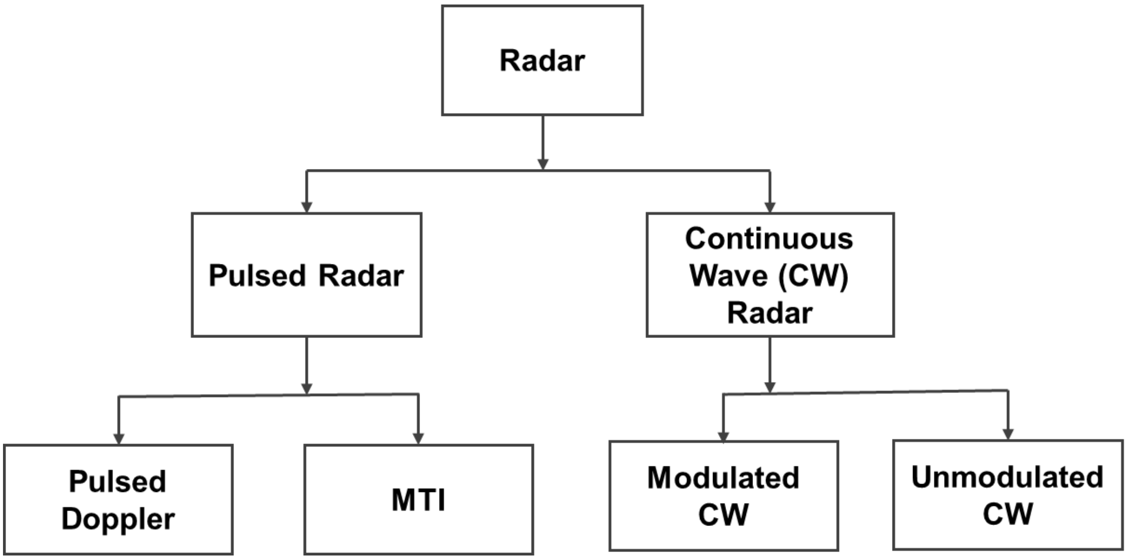


Figure 1.2: Different types of radar.

1.2.1 Pulsed versus Continuous Wave Radar

Pulsed radar transmits high power, high-frequency pulses toward the target; then it waits for the echo of the transmitted signal for some time before it transmits a new pulse. Choice of the pulse repetition frequency governs the range and resolution of the radar. The target range and bearings can be determined from the measured antenna position and time-of-arrival of the reflected signal. Pulse radars can be used to measure target velocities. Two broad categories of pulsed radar employing Doppler shifts are moving target indicator

(MTI) and Pulse Doppler Radar. MTI radar uses low pulse repetition frequency (PRF) to avoid range ambiguities, but these radars can have Doppler ambiguities. On the contrary to MTI radar, pulse Doppler radar uses high PRF to avoid Doppler ambiguities, however, it can have numerous range ambiguities.

Continuous wave radars continuously transmit a high-frequency signal and the reflected energy is also received and processed continuously. These radars have to ensure that the transmitted energy doesn't leak into the receiver (feedback connection). Continuous wave (CW) radars may be bi-static or mono-static; measures radial velocity of the target using Doppler Effect. In unmodulated CW systems, the transmitted signal remains constant in amplitude and frequency. CW radar transmitting unmodulated power can measure the speed only by using the Doppler-effect. It cannot measure a range and it cannot differ between two reflecting objects.

1.2.2 Pulse-Doppler Radar

Pulse-Doppler radar is designed to simultaneously determine the range and velocity of a target, that is, it combines the features and benefits of pulse and CW radars [Amin (2017)]. The target range is determined using pulse-timing techniques via measuring the time required for the transmitted pulse(s) to hit the target and for the reflected wave to arrive at the radar receiver. At the same time, the Doppler effect of the returned signal is used to determine the velocity of the target. Another essential feature of pulse-Doppler radar is its ability to detect small targets observed in the background of strong clutter.

In early radars, rough estimates of target speed and/or direction used to be obtained through successive measurements of range over several scans. The introduction of Doppler radar enabled a direct and accurate way of range rate estimation via measuring the Doppler shift. Coherent detection methods are typically used for Doppler shift estimation. Recent advances in hardware, software, and computational methods permitted Doppler sensing in near real time.

A pulsed radar system transmits a series of modulated RF pulses where the number of pulses within one second refers to the pulse repetition frequency (PRF) [Mahafza and Elsherbeni (2004)]. The maximum unambiguous target range is directly related to the pulse repetition interval (PRI = 1/PRF). Therefore, lower PRF rate corresponds to higher unambiguous range and vice-versa. The minimum range difference between two targets such that their echoes are received separately defines the range resolution of a pulsed radar. Doppler sensing capabilities are achieved by collecting multiple pulses within a certain coherent processing interval (CPI) and sampling the collected data at a sampling frequency that is equal to the PRF as shown in Figure 1.3. The maximum detectable Doppler frequency is equal to half of the sampling frequency. Therefore, to increase the maximum target velocity that can be uniquely detected, the radar pulse repetition frequency ($PRF=1/T_{PRI}$) should be increased. Hence, increasing the maximum detectable range comes at a price of reducing the maximum detectable velocity and vice versa.

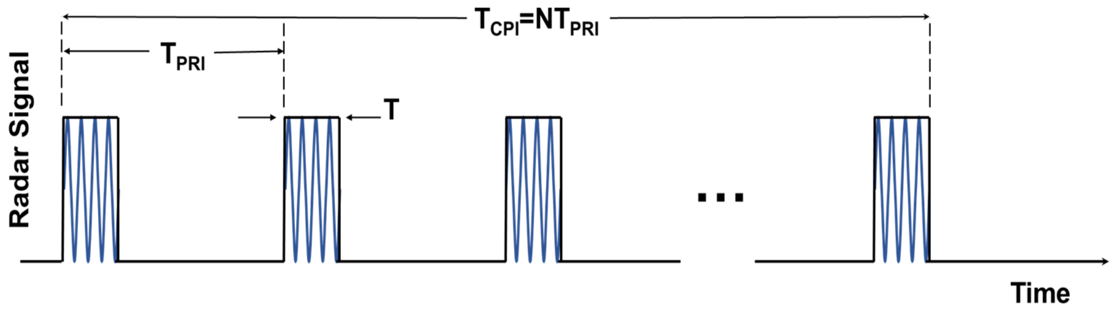


Figure 1.3: Pulsed radar waveform.

1.2.3 Frequency-Modulated CW Radar

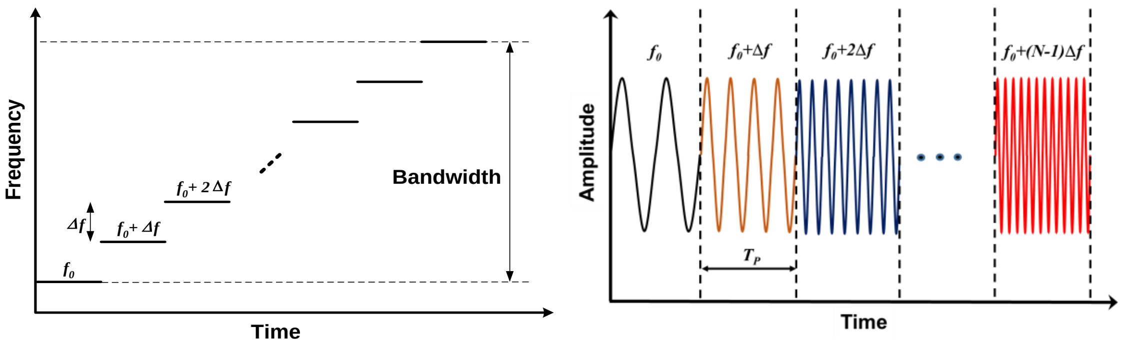
Typical pulsed radar systems operate with short duration pulses of very high peak transmit signal is used to detect the target range. The radar duty cycle is ratio of the transmitted pulse duration to the PRI. The shorter pulse duty cycle, higher instantaneous power needed to achieve a certain average transmitted power [Koppenjan (2009), Amin (2017)]. This makes pulsed radar complex to build and expensive to operate. However, continuous wave (CW) radar uses a stable frequency, making it less expensive and energy efficient. It uses Doppler processing to detect targets and determine their speeds. In the CW radar, maximum range limit is determined by the transmit power level, while there is no minimum range limit. A large number of samples can be used along with signal integration in order to extend the detection range without increasing the transmitted power. The main shortcoming of the fixed frequency CW radar is its inability to determine the target range.

Frequency-modulated CW (FMCW) radar can achieve an average power higher than that of pulsed radar. It enables measuring the range and Doppler simultaneously while enjoying the advantages of CW radar, for example, smaller instantaneous transmit power and physical size. FMCW radar systems emit periodic pulses whose frequency content varies with time. There are several types of FMCW radars, such as, linear FM sweep, saw-tooth modulation, sinusoidal frequency modulation, or frequency hopping. In the FMCW radar, the target range is found by detecting change in the frequency spectrum, i. e., frequency difference between the received and emitted radar signals. The target range is proportional to this frequency difference or spectrum spreading. The change in frequency is sometimes referred to as the beat frequency and is proportional to target distance. Therefore, measurement of the range is estimated by beating the reflected wave with the generated one [Koppenjan (2009), Amin (2017)].

In the FMCW radar, range measurement accuracy and range resolution depend on the frequency sweeping rate accuracy [Stove (1992), Koppenjan (2008)]. Unfortunately, it is difficult in practice to achieve a fixed and accurate frequency sweeping rate over a wide extent; this results in so-called range smearing. In addition, the noise figure of the receiver degrades due to the wide bandwidth used. As a result, the use of FMCW radar may not be suitable for applications that require high range accuracy and wideband operation.

1.2.4 Stepped Frequency Radar

Stepped frequency radars are those radar systems that transmit stepped frequency CW (SFCW) signals. Similar to FMCW radar, SFCW radar acquires target range information using continuous waveforms. The main advantage of SFCW radar compared to FMCW radar is the enhanced range resolution. High range resolution is a desirable feature in many indoor radar applications. Apart from providing the ability to resolve closely spaced targets or events, it also enhances the range accuracy, enables clutter rejection, and provides the means to reduce multipath. The essence of SFCW radar is to transmit consecutive intervals of CW signals, where the carrier frequency at each interval is different. The frequency change from interval to interval follows a step function, and the separation between two adjacent frequencies is fixed. Figure 1.4(a) shows the stepped frequencies versus time for a typical SFCW radar waveform while its time-dependent amplitude plot is shown in Figure 1.4(b) [Amin (2017)].



(a) (b)

Figure 1.4: SFCW waveform (a) Frequency versus Time plot; (b) Amplitude versus Time plot.

At each stepped frequency, the signals reflected from targets located within the operational range of the SFCW radar are collected at the receiver and demodulated into the baseband. The in-phase and quadrature-phase components of the received baseband signals contain the amplitude and phase information of the signals reflected by the targets. The aggregate signals corresponding to all stepped frequencies are transformed into the time domain using the inverse Fourier transform yielding a synthetic radar pulse. The target(s) information is then extracted via post-processing the synthetic pulse, similar to the conventional radar. The total bandwidth of the SFCW radar B can be partitioned into N equidistant stepped frequencies, that is,

$$f_n = f_0 + n\Delta f \ , \quad n = 0,....,\mathrm{N}-1, \tag{1.5}$$

where f_0 is initial frequency and $\Delta f = B / N$ is frequency separation at each step. In SFCW the signal transmitted at n^{th} pulse is given by;

$$S_n(t) = A_n \exp(j2\pi(f_0 + n\Delta f)t) \ , \quad nT_p \le t \le (n+1)T_p \tag{1.6}$$

for the PRI of T_p and A_n is the signal's amplitude of n^{th} pulse.

The signal bounced off a target located at range R impinges on the radar receiver after time delay τ and the speed of light c. The received signal can be represented as [Ma (1995), Gaikwad *et al.* (2011)]:

$$r_n(t) = \tilde{A}_n \exp(j2\pi(f_0 + n\Delta f)\frac{2\mathrm{R}}{c}) \ , \ n = 0,....,\mathrm{N}-1 \tag{1.7}$$

From equation (1.7) it can be observed as the received signal's phase is function of range R, the range resolution of the SFCW can be given by [Ma (1995), Chandra *et al.* (2008)]:

$$\Delta R = \frac{c}{2B_{inst}} = \frac{cT_p}{2} \quad . \tag{1.8}$$

B_{inst} is the instantaneous bandwidth and inverse of PRI. In this thesis the focus is on the short range radar (range ~10 to15 m) which are well suited for indoor monitoring applications and facilitate the safe emission level and simpler implementation at a cheaper cost.

1.3 Detection of Human Target Signature using Radars

Range, velocity, size and direction are the most basic and common information of the target which are essential to identify in any application. For indoor monitoring, humans are the most important targets which need to be observed to assure that their behavior is not abnormal than the usual. From that point of view, their locations and activities are the main concern. In this study, we have mainly focused upon the human targets (subjects) signature whether it is in rest or motion as given in Figure 1.5.

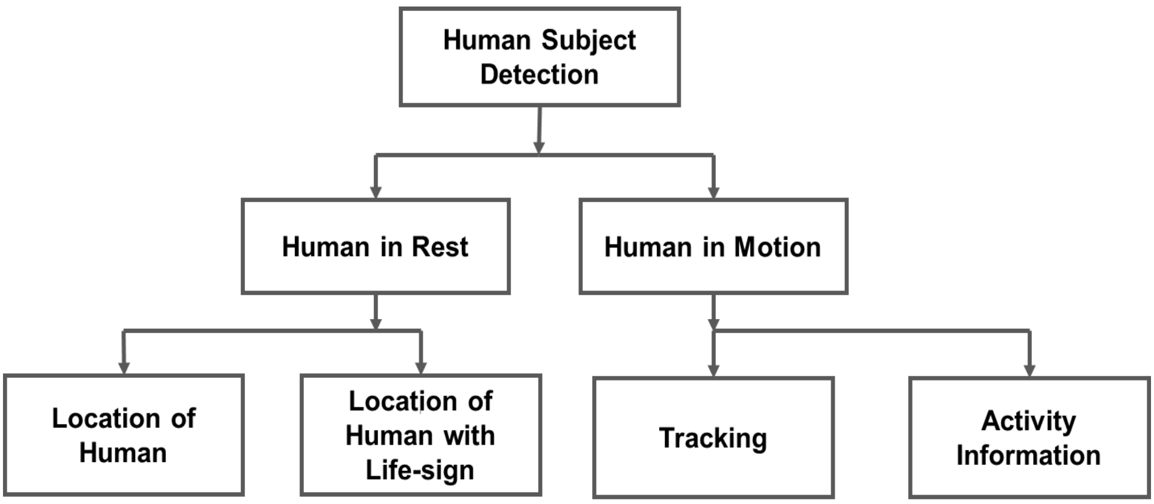


Figure 1.5: Human target detection study.

The rest situation occurs when subject is willingly trying to hide himself (situation of an intruder) or unwillingly not able to perform any action (sick or trapped victim in any disaster condition). Under rest situation, although there is no movement of the limbs, but there will be some small movement in the human torso due to physiological phonon like breathing and heart beating. In this condition, the two important information which required are the characteristics of life and the position from where it is coming. To make the accurate detection of location, lots of effort has been made and the problem is defined as target localization. While the presence of a living target with live sign vital characteristics is obtained by signal processing approaches like moving target indicator (MTI) filtering, independent component analysis(ICA), variational mode decomposition (VMD) etc. [Ding *et al.* (2017), Singh *et al.* (2018), Yue *et al.* (2018)]. For humans in movement, the desired subject of interest performs limb motions to move or execute some activity depending upon his specific need. There are two microwave solutions to probe the mover information. In first method, when the target moves with his limbs, the location of the target with time can be obtained, which in literatures termed as tracking problem while in another method, to identify the activities performed by the person in the observation area. To solve this issue the velocity information with time is essential to obtain the actual variation at time instant.

1.4 Literature Survey

In the previous section, the target type and its possible cases are explained with the block diagrams. The literature survey covering the cases is performed in brief below.

1.4.1 Stationary Human Target Localization

The target position probing is always of prime interest for sensing applications. The process of finding the location is often performed with respect to a reference plane so that its final output data can be used with other systems to make appropriate decisions. The target localization system remains invariant for living and nonliving targets, if the only concern is to track target movements.

1.4.1.1 Target Localization

Localization scheme finds applications in diverse areas, like medical scanning, tumor detection, disaster rescue, military operation, law enforcement system, underground object scanning and so on [Noghanian *et al.* (2014), Mohammed *et al.* (2013), Singh *et al.* (2018), Jol (2008)]. The aim of a localization system is to find position of the desired object in a defined coordinate system [Rovnáková *et al.* (2008)]. Depending upon type of application, radio frequency and microwave-based various solutions have been tested for the applications mentioned [Noghanian *et al.* (2014), Mohammed *et al.* (2013), Singh *et al.* (2018), Jol (2008)]. The complete target localization process has been achieved using different stages like detection, decision followed by localization [Svecova et al. (2008)]. The final stage of localization is also processed with certain algorithms to track the moving target [Svecova *et al.* (2008)].

Indoor localization problems have been addressed such as multipath exploitation, microwave imaging, and multistation-based localization, etc. To localize an indoor target, microwave imaging method using antenna array has been explained to obtain the target location [Amin and Ahmad (2008)]. In this work, signal received from the target generates the scene image which contains dimensionally extended information of the target localization using different image reconstruction techniques [Amin and Ahmad (2008)]. Thus, it draws unnecessary large data collection and processing complexity for localization purpose. Another technique for indoor target localization is multipath exploitation where only one antenna is required; although it involves complex algorithm to identify the desired reflections, angles of arrival and also need a sensitive receiver to detect the reflected signals [Sen and Nehorai (2010), Kuang (2013), Muqaibel (2015), Smith and Mobasseri (2012)].

1.4.1.2 Stationary Living Subject Detection

In applications where the search for a live target is necessary, such as location of victim detection at disaster sites or intruder detection during military operation, the main concern remains the detection of life signatures. For the majority of cases, it is necessary to locate a human who is not moving any type of organs willingly or unwillingly. In that case a physiological phenomenon generated movements such as the heartbeat and the target's respiration are used to find targets location [Donelli (2011)].

Heartbeat monitoring is essential in many application areas like medical sector, sport-fitness observation, defense sector, rescue operations, etc. [Jelen and Biebl (2006), Zhou *et al.* (2009)]. The frequencies of respiration and heartbeat are the essential characteristics of any living animal. Although the human subject is in the rest condition, still there is some micro motion present due to its physiological phenomenon in which heartbeat and breathing are main components because these two causes significant displacement in human torso [Jelen and Biebl (2006)]. The heartbeat frequency of a human being lies between 0.8 to 2.5 Hz, and that of for respiration is 0.2 to 0.5 Hz [Shirodkar *et al.* (2011)]. Since heartbeat frequency lie within a frequency range, human-being present can be detected as its characteristic frequency presence.

1.4.2 Moving Target Classification

For moving target detection, one can take resort of micro-Doppler evaluation in the desired area, while monitoring the movers and/or their activity rather than the target location and/or size. The use of micro-Doppler has been successfully demonstrated for its ability to detect minute movements [Chen (2014)]. A human subject performing a particular task has its unique body parts motions, which generate unique micro-Doppler signatures. For classification of the human activities, features can be extracted from the micro-Doppler signature to obtain the classification accuracy of the monitoring system.

1.4.2.1 Human Movement Classification

Micro-Doppler system has wireless and long-range capabilities which attracted its applications in the fields, like biometrics in sports and health industries, motion dynamics study of the ships, aircraft propellers and helicopter rotors, etc. as well as vibration analysis of the vehicles, life detection in the rescue and military missions, and so forth [Chen *et al.* (2006), Lei *et al.* (2011), Li *et al*. (2012)]. Specifically, for surveillance application, human subjects remain important and their activity monitoring are necessary for the strategic reasons. Human walking can be characterized as the combination of three major components viz., translation of torso, leg movements due to foot strikes and swinging of arms. All the three major characteristic follow a unique pattern of the relative movement for a complete walk cycle [Chen and Ling (2002)].

Doppler radars emit radio frequency (RF) signal towards the target under motion and determines the frequency shift based on phase change measurement in the received signal in order to estimate the target velocity [Mahafza (2000)]. The “target” approaching the radar, provides a positive shift in the carrier frequency while it offers a decrease in returned signal frequency under the receding condition. When a non-rigid target undergoes some movement, apart from its main body translation, the structural components result in micro-motions, like vibration or rotation which in turn modulate the returned signal's carrier frequency and is termed as micro-Doppler. This micro-Doppler appears in addition to the main bulk Doppler shift [Chen *et al.* (2006), Lei *et al.* (2011), Li *et al*. (2012)], Chen and Ling (2002), Kim *et al.* (2018)]. For detection and tracking of the moving objects, spectrogram technique is popular due to its capability to represent the micro-Doppler information at different time instants [Chen and Ling (2002)]. During motion, the relative movement of structural components follows unique and repeated movements which results in a repetition of micro-Doppler intensity pattern in spectrogram's joint time frequency plane [Kim *et al.* (2018), Chen (2005)]. As the moving target can be of different types, the spectrogram analysis can be drifted towards classifying these moving objects using Doppler and micro-Doppler effects.

In real time scenario, for the purpose of security surveillance, a moving human subject is main concern of the study. Depending on the task, the movement styles of human subject changes. To address many such issues and problems, various studies on human movement classifications have been carried out. Typically, a few of them can be differentiation of usual walking with hand confined swings, detection of an armed person or normal walking person, classification of passengers walking with different baggage at the airports [Yang *et al.* (2017)] as well as separation between assisted gait and normal gait [Amin *et al.* (2015)]. In the war field, distinction of vehicles and human walking, and so forth [Du *et al.* (2014), Du *et al.* (2016)]. Till date, time-frequency features of the spectrograms have been exploited rigorously for classification purposes [Tivive *et al.* (2010), Fioranelli *et al.* (2015), Yang *et al.* (2017), Du *et el.* (2014), Amin *et al.* (2015), Du *et al.* (2016)].

1.4.2.2 Moving Target Response Separation in a Radar Channel

Moving target detection and its analysis has important military and civilian applications, such as, security site observation, law enforcement, aircraft identification, vehicle vibration analysis, disaster management, health, sports-industry etc. [Chen *et al.* (2006), Lei *et al.* (2011), Li *et al.* (2012), Mahafza and Elsherbeni (2004)]. Since in the last two decades, radar-based micro-Doppler processing technique has been widely used to identify the moving targets due to its potential to work under all weather conditions and dielectric material penetrating capability [Chen *et al.* (2006), Li *et al.* (2012)]. The movements accompanied with rotation or vibration of any moving target results in frequency modulation in addition to the Doppler shift caused by the target's translational motion; thereby causing micro-Doppler effect [Chen *et al.* (2006), Lei *et al.* (2011), Li *et al.* (2012)].

Micro-Doppler (m-D) variation with time generates the moving target's time-frequency signature. In the last decade extensive studies have demonstrated that m-D features can be exploited for the classification of a variety of ground moving targets such as vehicles, animals, human movements [Chen *et al.* (2014), Singh *et al.* (2020)] wind turbines [Kong (2014)] and other airborne targets [Rahman and Robertson (2018)]. It is essential to accurately detect and track the desired target m-D in the radar observation channel for proper analysis so that the final decision can be reached. Previous studies on the classification were able to differentiate various targets or target classes like man and vehicle, walking of a human with movement of arms and luggage with very higher classification accuracies (more than 90%) [Singh *et al.* (2020), Du *et al.* (2016), Fioranelli *et al.* (2015), Yang *et al.* (2017), Kim and Ling (2009)]. However, most often in such studies, assumptions are taken that either a single moving target or a single class is present in the radar channel during the observation. Nevertheless, in practice, when the radar system is deployed for monitoring purposes, there is a low probability that only a single moving target is present in the radar field of view as there is a possibility of presence of various stationary as well as non-stationary targets. The presence of unwanted static targets over a given target range offer a constant DC offset and can be removed easily [Fairchild *et al.* (2014)]. On the contrary, unwanted moving targets generate their own m-D signature, which creates hiding or alter the desired target response and thereby poses challenge to retrieve the desired target response from the mixed signature.

1.5 Motivation and Scope

Following the study of Švecová and Kocur (2010), Kocur *et al.* (2013) have described the ultrawideband target localization system for indoor applications, where two ranging units were utilized, each having one transmitting and two receiving antennas, i. e., six antennas required to implement this system and hence demands installation of each ranging set in more than one wall side of a rectangular room. In practice, namely, disaster, military or other practical applications, scanning of the room can be performed only from one side; thereby limiting aforementioned localization scheme. Moreover, the use of six distinct antennas leads to the ambiguities in the final calculation of the detected target location as it introduces different ranges corresponding to the different antennas. Thus, the problem is complex in target location estimation due to use of multiple range measurements. The solution to this problem was suggested by applying a processing technique in decision phase of localization, known as joining intersection of ellipse method (JIEM) for selecting the best target estimate.

Another issue is related with sensing of life characteristics behind a wall becomes tough due to presence of large amount of clutter in the received signal. An effort to enhance through the wall life sign signal behavior has been carried out where the clutter reduction technique is tested by implementation of singular value decomposition (SVD) for living static target [Rane *et al.* (2016), Gaikwad and Dongre (2016)]. MTI based non-quantitative approach is an efficient method to discriminate between living and non-living things which allows lower frequencies associated to human physiological properties by filtering out the static frequencies ($f = 0$) [Mahafza and Elsherbeni (2004), Shirodkar *et al.* (2011)]. Hence, combination of SVD with MTI can be used to develop a higher sensitivity system for life signal characteristics.

The concern associated with the time-frequency feature is that it demands the portion of the spectrogram and the local region analysis where feature information exist; thereby increasing the processing complexity as well as human intervention error which may lead to a reduction in classification accuracy. This can be overcome incorporating spatial features based classification which utilizes the statistics of the whole spectrogram image and does not demand any portion analysis [Materka and Strzelecki (1998)]. Texture analysis based work addressed an easily separable movement that includes binary classifications involving moving vehicle and walking man [Shi *et al.*(2015)]. However, in case of security site monitoring, the human activities are very close in nature and offers a serious challenge to distinguish.

In order to address an identical scenario, a sparse coding-based moving target desegregation has been reported for the indoor environment in which the response of the target was decided based on the threshold. The threshold is considered as a one-dimensional data and a function of a sparse time-domain signal [Vishwakarma and Ram (2017)]. However, according to the control theory, two-dimensional decision criteria have improved decision making abilities compared to the single dimensional counterpart [Bartoletti and Conti (2018)]. Two dimensional decision making is very popular in the field of speech signal processing, where time frequency (T-F) masking based methods are used to separate the speech of the speaker from the mixed music and noise. The masking based approaches maps the mixed signal spectrogram to target's segregated spectrogram with the help of a deep learning techniques [Reddy and Raj (2007)].

The present study refers the modest use of microwave engineering and technology on the blend of signal and image processing techniques along with antenna theory. Under the purview of the stated subject area, the scope of the study carried out under the present thesis covers the positioning and detection of indoor living objects using vital sign information inside surveillance region using wideband radar system. Further, advanced study has been carried out with recognizing and classifying the activities in the region distinguishing the living target, performing unusual movement using narrow band CW system. The scope has been further broadened with the separation of intended desired movement of living target through single channel radar. The scope of the study are elaborated below:

(a) To address the living target positioning, target localization system is designed with the help of two antennas, where the target position in simple Cartesian coordinate is represented by one antenna as origin of the references while the line joining the other antenna placed parallel to any wall of the room, treated as *x*-axis, in one reference plane. For the purpose of the study, principle of trilateration is exploited to compute the target position from the measured range of the target from two ranging units [Ahmad *et al.* (2009), Torres-Solis *et al.* (2010)]. The common region of sensing (CROS) of the two antennas is identified and subsequently divided into the sub-regions using the proposed algorithm. Once the CROS sub-region is identified, the target position is calculated using the subregion-dependent expression [Singh *et al.* (2019)]. The proposed study focuses on the localization efficiency at any available space in the room. Furthermore, localization capability of the proposed system for through the wall has also been tested.

(b) The detection of presence of live human subject with the help of a radar system using its vital sign frequency has been addressed. A C-band SFCW radar system is synthesized in laboratory using VNA [(Gaikwad *et al.* (2011)]. The range profiles corresponding to each sweep is generated and SVD based clutter reduction method has been applied to increase the human associated backscattered response and suppress the strong wall clutter appeared in the radar range profiles. After SCNR improvement, small movement detection is done with the help of recursive MTI filtering [Mahafza and Elsherbeni (2004), Li and Kiang (2004)]. Finally, the human heartbeats and the distance from antenna are represented in Range Doppler plane format.

(c) The human movement monitoring is addressed using a low cost, CW radar with the help of potential of spatial features. For the purpose, five different possible human activities are considered in the surveillance area for classification purpose. The time domain data has been captured with the synthesized CW radar for all the activity classes and corresponding spectrograms have been generated using short time Fourier transforms (STFT) in order to represent the time varying Doppler response. The spatial features of the spectrogram corresponding to 80% of the total data has been extracted to train a SVM classifier during the training phase however 20% of the data have been utilized in class validation and prediction purpose. The proposed method for moving target classification involves least complexity and provides high classification accuracy; thereby leading to suitability at the observation sites for more reliable results at low cost.

(d) The extraction of desired target movement from a mixed signature captured at a time in single channel CW radar is addressed using DNN based m-D masking method. The DNN is trained for a combination of mixed signature and the mask corresponding to the desired target response in training has been prepared. In prediction phase, a mixed response portion is provided and at the output of the trained DNN, the mask for the desired output is predicted. The mask contains the highlighted signature of desired target in each time-frequency unit cell from where the desired target spectrogram can be separated. The correlation of the separated response with the clean condition was achieved 0.9807 and 0.9633 from the mixture of two and three moving target responses respectively. The higher value of correlation implies the higher reliability of the method for separation.

1.6 Research Objective

The research objective undertaken for this thesis is to investigate the human target signatures using microwave ranging systems for security and rescue operations. The motivation for human target information gathering using microwave radar sensors is to overcome the limitation of other conventional approaches like optical, infrared and X-ray sensors.

The research tasks carried out for this thesis are as follows:

i Implementation of a simple stepped frequency continuous wave target localization system comprising two antennas based on common region of sensing.

ii Through the wall heartbeat signal improvement and detection using MTI and Clutter reduction approaches.

iii Micro-Doppler classification of human movements using spectrogram spatial features and support vector machine.

iv Desired Moving Target separation from the mixed Micro-Doppler of a single channel using deep neural network

1.7 Organization of the Thesis

Chapter 2 focuses on the 'two antenna-based target localization' which operates on the principle of stepped frequency continuous wave radars. The detailed study of the system generated limitations for a two antenna-based target localization system toward the practical implementation is considered and consequently, a common region of sensing (CROS) is identified. The system capability in different sense like target tracking, spatial coverage, and through the wall localization is investigated properly and it is found that the proposed common region of sensing (CROS) based localization scheme is an improved as well as simple method by utilizing small number of antenna, flexibility of antenna placing, less processing with higher accuracy, and the position fixing in a simple Cartesian coordinate with reference to the two antennas.

In *Chapter 3*, the human heartbeat, a life sign characteristics of a living being is utilized as a key feature as it lies within a certain frequency range. The heart beat frequency of a human subject behind the wall is identified by applying singular value decomposition (SVD) based clutter reduction technique along with moving target indicator (MTI) filtering. The application of SVD improves the signal to clutter noise ratio (SCNR) of a signal coming from a human subject and make it possible for life feature detectable by MTI for through the wall detection. The final detection of human subject by tracking its heartbeat frequency from its distance measured referred to the antenna position is provided in a range-Doppler (RD) plane.

The accurate distinction of dynamic moving objects especially in the context of security surveillance which attracts the attention of researchers and practitioners is dealt in *Chapter 4*. In the same context, present study proposes advancement in feature extraction method from the micro-Doppler spectrogram with the application of spatial statistics for moving human subject classification which minimizes the spectrogram analysis. A novel approach of spatial feature extraction from whole image spectrogram, followed by support vector machine (SVM) classifiers algorithm for multiclass classification, is proposed in the present study. The proposed method is tested for prediction accuracy and validated by applying on a very close and important five distinct human activities (which usually arise at any security observation site) as reported in the literature. The results obtained adopting the proposed approach exhibit high accuracy for multiclass classification. For the prediction of accurate data classes, the post-processing of the spectrogram prior to feature definition is also performed using spatial based methods to enhance micro-Doppler signatures.

The micro-Doppler signature of a walking human separation effort is made from the mixed signatures of multiple moving objects in a single radar observation channel at same time and described in *Chapter 5.* Under Doppler radar observation, every moving target contains a unique micro-Doppler signature due to its structural components movements which works as a target class characteristics in their identification. It becomes challenging to identify the type of target and their motion parameter analyses for multiple moving targets are present in the radar observation channel simultaneously. The separation of the desired target's micro Doppler response is performed from the multiple target signatures captured by a single observation channel using machine learning-based signal processing approaches. The method used here to separate the micro-Doppler information generated by more target classes based on probabilistic masking which yields a mask corresponding to a single desired moving target class. A deep neural network (DNN) trained to generate a mask that operates in the time-frequency domain to separate the target response using regression method.

In *Chapter 6,* the research presented in this thesis work is briefed. The major conclusions originating from the whole research and their consequence are emphasized. At last, some major points derived from the study for future work is suggested.