MICRO-DOPPLER SIGNATURES BASED TARGET RECOGNITION USING TIME-FREQUENCY ANALYSIS TOOLS

Dissertation submitted in partial fulfillment of the requirement for the degree of

BACHELOR OF TECHNOLOGY

IN

ELECTRONICS AND COMMUNICATION ENGINEERING

By

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DECLARATION

We hereby declare that the work reported in the B.Tech Project entitled **“Micro-Doppler Signatures Based Target Recognition Using Time-Frequency Analysis Tools”** submitted in Electronics and Communication department, at **Jaypee University of Information Technology, Waknaghat, India,** is an authentic record of my work carried out under the supervision of **Dr. SunilDatt Sharma**. I have not submitted this work elsewhere for any other degree or diploma.

(Signature) (Signature)

Deepak Sharma (131042) Abhinav Shubham (131046)

Date: 1st May, 2017

SUPERVISOR'S CERTIFICATE

This is to certify that the work reported in the B.Tech Project entitled **"Micro-Doppler Signatures Based Target Recognition Using Time-Frequency Analysis Tools"**, submitted by **Deepak Sharma** and **Abhinav Shubham** at **Jaypee University of Information Technology, Waknaghat, India,** and is a bonafide record of their original work carried out under my supervision. This work has not been submitted elsewhere for any other degree or diploma.

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Assistant Professor (Senior Grade)

Date: 1st May, 2017

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ABSTRACT

Micro-Doppler signature analysis play an important role for target recognition such as, fixed target, vibrating target, moving human, vehicle etc. Therefore, various signal processing based methods have been reported for target recognition. Recently, joint time-frequency analysis methods such as, Short time Fourier transform (STFT), Stockwell transform (ST), have been applied for target recognition In this work, we have applied STFT, ST, and Covariance based modified S-transform for analysis of fixed target, vibrating target. STFT and ST have been applied for analysis of human motion only. The performance of Covariance based S-transform method has been compared with STFT and Stockwell transform.

CHAPTER 1

INTRODUCTION

Since many years, Radar systems have shown their importance in several applications such as military, navigation, surveillance and detecting the targets in their range. They transmit electromagnetic waves, which interacts with the target and are reflected back towards the Radar, then the radar detects, and then the judgement is made about the target. The use of Radar systems over traditional methods can be understand very well by considering the advantages of Radar systems in critical environment conditions.

1.1 Objective

The objective of this project is to obtain micro-Doppler signature for a radar returned signal from a target using time-frequency methods. The moving targets show the Doppler Effect in the returned signal which is directly related to the behaviour of their motions [1]. With the advancement in recent technologies, it is possible for the radar systems to automatically recognize the targets from the returned signal [1]. It is interesting to note that targets with moving parts introduce micro-Doppler effect in addition to Doppler effect that can be used to identify even the micro motions that can be exhibited by the target. For example, a fixed target, vibrating target, a human walking with swinging arms and without swinging arms will have different micro-Doppler signatures [2].

1.2 Motivation and Scope

The advantages of Radar as compared to other surveillance systems are more secure and reliable. These advantages make the radar systems more useful and favourable for the various applications of surveillance systems and security purposes in any environmental and geographical conditions. As we know, the radar systems are based on transmission of electromagnetic waves and their reception from various types of targets in its field of view [3]. These electromagnetic waves are less affected by the environmental conditions as compared to other video surveillance techniques where weather conditions and proper lighting plays an important role in recognizing the nature of the target. In addition, the electromagnetic waves are known for its penetrating power through walls and other oblique substances making it suitable for detecting the hidden targets [3]. Although, this report focuses on the radar returned signals and few human gait signatures, fixed targets, vibrating targets, but it can be very well extended to other types of targets. It can even be used to classify the type of vehicles coming in its field of view, their speed, and thus help in traffic control. Further, these systems can be extended for medical purposes like blood flow monitoring or determining the abnormalities in the bloodstreams [4].

1.3 Flow Graph for micro-Doppler signature detection

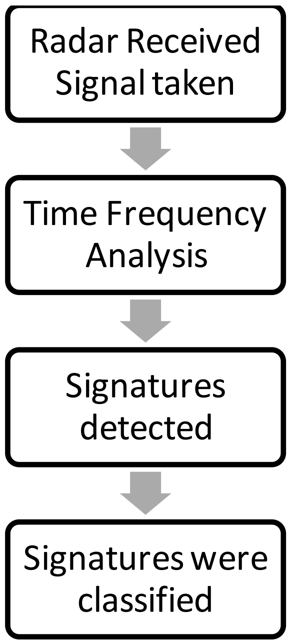


Figure 1.1 Flow Graph

As shown in Figure 1.1, micro-Doppler signature detection can be briefed as:

1. Radar returned signals were received and modeled mathematically.
2. Then we performed different time-frequency tools on them, like STFT, ST.
3. The resultant signatures were noted.
4. Then finally, we classified them into various targets by observing different sources. [1] [3] [5] [6].

1.4 Organization of report

1.4.1 Chapter 2 introduces about various works in this field, micro-Doppler signatures of various targets, its representation techniques.

1.4.2 Chapter 3 discusses about mathematical modeling of radar targets, Doppler effect, extraction of micro-Doppler target signatures.

1.4.3 Chapter 4 gives detailed introduction to different time-frequency tools currently being used extensively.

CHAPTER 2

LITERATURE REVIEW

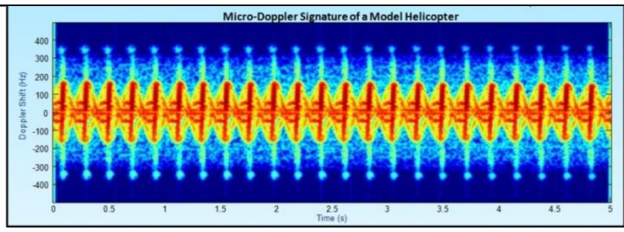
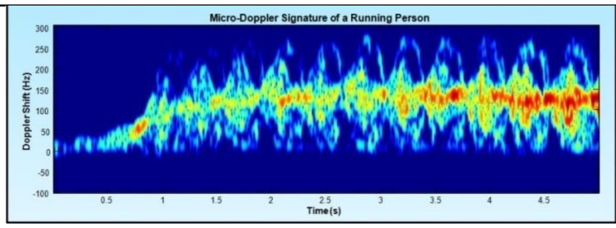
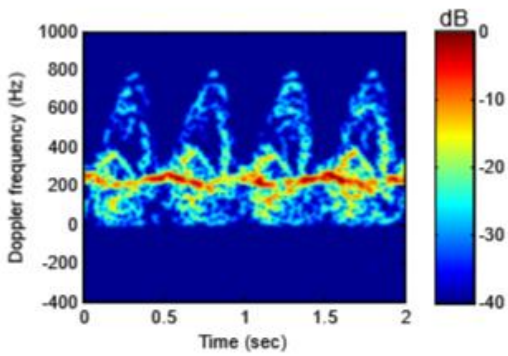
In Radar signal processing, the study of classification of different targets and human activities with the help of their signatures comes under the category of radar target recognition [5]. The concept of target recognition is as important as the radar itself. There is always a requirement of not only to detect, but also to determine which type of target is in the range of the radar. This work focuses mainly on automating the recognition process without any human interference and analyzing the received signals that contains a lot of unwanted noises and signal components to extract information with maximum accuracy [1] [3] [5].

The traditional radar target recognition techniques rely on the target's Doppler shift which is used in the recognition process. These parameters can be very well used in estimating the shape and size of the target by taking the overall velocity of the target. But in human detection, human targets are complex targets [5] that are capable of showing various types of motions. So, while taking human as a target, an ultra-high resolution range is required.

In radar, what is now known as the micro-Doppler effect was first discovered in the audio of the Doppler signal which can be heard through speakers [5]. Different types of target generate unique micro-Doppler signatures that can be used to identify them without human interference. These signatures are shown in Table No. 2.1. Extracting particular features from these signatures is a separate work which is implemented in [7]. Different classification techniques have been discussed in the same work [7]. As we will see in the following paragraphs, this micro-Doppler effect has recently been investigated or studied in different domains to automate the recognition process with maximum accuracy. A good detailed introduction to the micro-Doppler phenomenon can be found in [3] and [8].

2.1 Micro-Doppler Signatures

There are many research papers published on micro-Doppler signatures of Humans [1] [3] [6] [7] [10]. Most of Human signatures involved walking, walking with swinging arms, running, etc.

Targets	Micro-Doppler Signatures
 Helicopter	 Image source : [9]
 Running human	 Image source : [9]
 Human walking with holding a box	 Image source : [10]

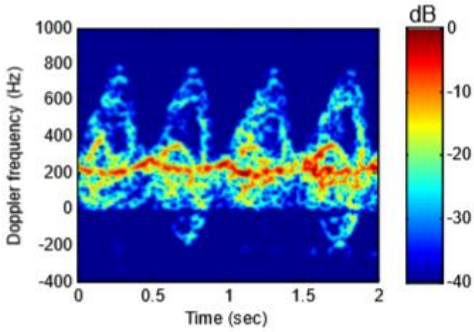
<table>
<tr>
<td>
Human walking holding a bag in one hand</td>
<td>

Image source : [10]</td>
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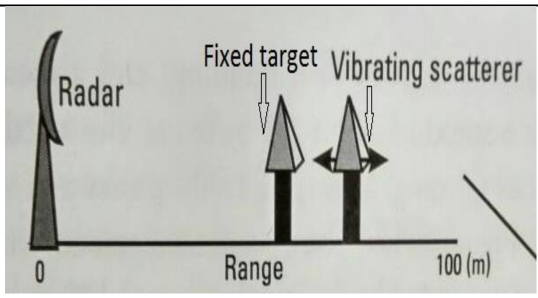
<tr>
<td>

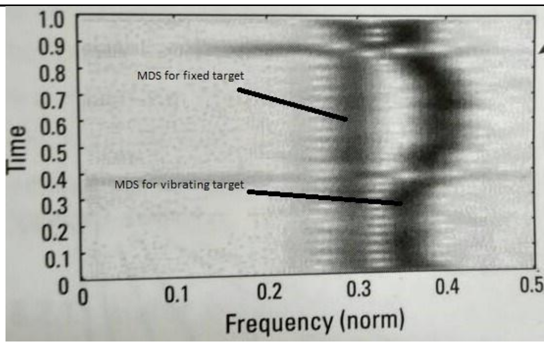
Fixed, Vibrating targets</td>
<td>

Image source : [3]</td>
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</table>

Table 2.1 Micro-Doppler Signatures of Various Targets

2.2 Micro-Doppler Signature recognition techniques

The representation of micro-Doppler signatures is often carried out in the time-frequency domain. In most cases, the Short Time Frequency Transform (STFT) based spectrogram is a very common technique to extract the signatures [5]. Depending on the data being used, the nature and the dynamics of the target can be observed in the signature, and this provides sufficient information for classification [5]. Other time-frequency representations techniques such as Wavelet Transform, Stock well Transform are also used that can either provide more information from the raw radar data [5], or provide higher resolution images [2]. More information about the time-frequency analysis techniques has been found in [1] [5] [11].

CHAPTER 3

MATHEMATICAL MODELING OF RADAR TARGET SIGNATURES

Radar transmits electromagnetic waves to detect targets by receiving the returned signals from those targets. Location of those targets can be found out, based on the time delay between transmitting and receiving the signal [7]. If a target is moving, a frequency shift will be induced in the returned signal, which is caused by the Doppler Effect [7]. If the target has oscillating, rotating, or vibrating parts, these introduce additional Doppler components that modulate about the main Doppler component which was caused by the bulk motion. These additional components are called the micro-Doppler components [7].

3.1 The Doppler Effect

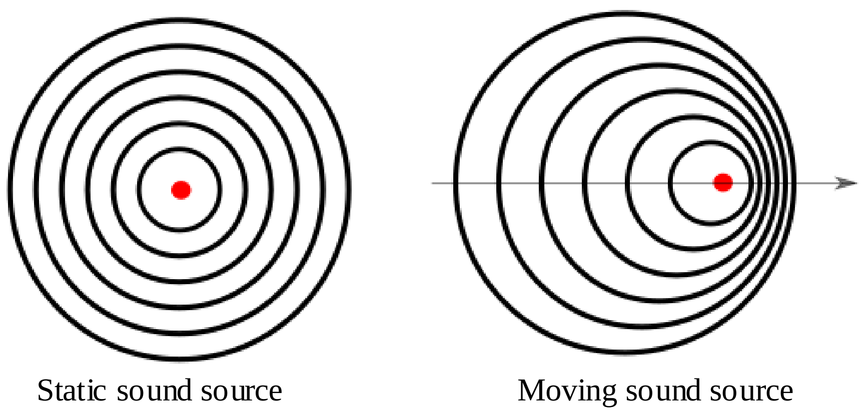

Figure 3.1 The Doppler Effect (Image Source : [9])

Consider Figure 3.1 [9] where there is static and moving source of sound. When the moving sound source approaches a listener, there is a shift in the frequency of sound heard by the listener when there is a relative motion between them. This is called the Doppler Effect, whereas the shift in frequency is called the Doppler Shift. The frequency shift is positive when the relative velocity of the receiver with respect to the source is positive and opposite for the negative relative velocity case [5]. In case of radar systems [5], [6], the Doppler Effect is dominant, when there is a relative motion between the radar and an object in its field of view. Radar transmitter sends out a high frequency electromagnetic signals through an antenna which propagates through the environment and interacts with the target. The frequency of this transmitted signal ranges from about 3 MHz to about 300 GHz depending on the scenario [12]. When the signal strikes the target, it gets reflected back towards the radar's receiver. The phase of this returned signal is different from the transmitted signal by an amount proportional to the velocity of the target relative to the radar [5]. The rate of change of phase shift corresponds to frequency shift in the received signal [7]. This frequency shift is called Doppler Frequency. The Doppler frequency and relative velocity are related as follows [5]:

$$f_{doppler} = \frac{2v\cos\theta}{\lambda} \tag{3.1}$$

where θ is the angle between the main axis of the radar and the direction of motion of the target, v is the speed of the target and λ is the wavelength of the transmitted signal. While calculating the Doppler frequency, we generally take the radial component of the velocity of the target.

3.2 Micro-Doppler signatures

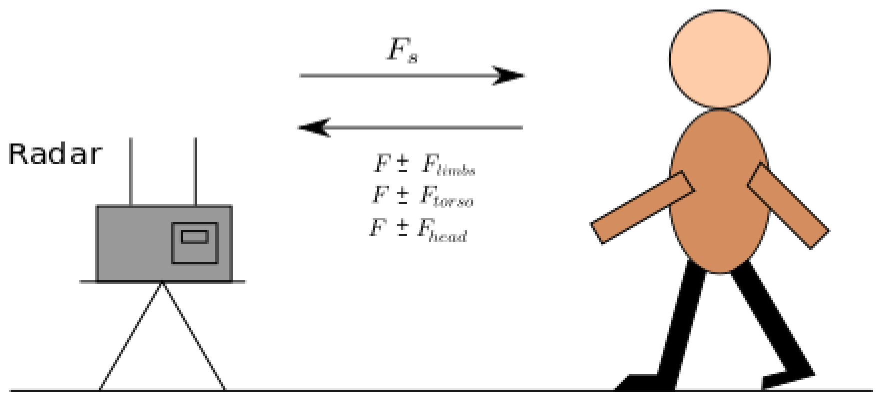

Figure 3.2 Micro-Doppler Signatures reflected from a human

In the previous paragraphs, we discussed that a relative motion between the target and the radar, causes a frequency shift in the reflected signal from the target. However, a target may possess micro-motion wherein multiple small reflecting surfaces on the target are moving relative to the target's center of mass. Consider the Figure 3.2 [5]; here a man is moving towards the radar with swinging arms. So, there is a relative motion with respect to the torso of the man, in addition to that there is also a slight movement of his head relative to his torso. These micro-motions contribute to the frequency shift in the received signal in addition to the macro-motions. The frequency of the transmitted signal is F_s. The signal reflected by the moving person will have a large component produced by reflection from the torso, due to higher radar cross section of the torso, along with smaller components due to the head and limb motions relative to it. These components are together called the micro-Doppler signatures of the person [3], [5], [7]. So, the Doppler frequencies as seen by the radar are as follows [5]: $F_s \pm F_{torso}$, $F_s \pm F_{head}$ and $F_s \pm F_{limbs}$

The same phenomenon can be observed for other types of targets such as animals, vehicles, helicopters, etc [13] and the micro-Doppler signatures produced by each of them will be different from each other due to the differences in the way they move.

3.3 Modeling Radar Targets

Modeling the received radar signals provide us the detailed analysis of human micro-Doppler signatures in the absence of noise [5].

3.3.1 Human Model

Modeling Humans is a complex task, since they show various types of motions [5]. Also, each motion varies depending on physical or geographical conditions. For example, a man carrying an object in one hand will walk differently as compared to a man walking with his arms free and a man walking with and without swinging his arms are all different [6]. Then again, humans possess a series of complicated motions of their head, torso and limbs while running, crawling, and sneaking, etc.

Work done in [14] presented a model of a walking human which is known to be a fairly comprehensive one [15] and is useful for radar data simulation of human targets in [10], wherein they use it to estimate the motion parameters of a walking human and compared their values to real measurements. A very simplified version of this model is shown in Figure 3.3 [5], wherein only 4 joints, viz. those at the hips and shoulders are considered for simulating a walking human's radar echo signal. The weaker components of the µ-D signature produced by arm swings are more or less lost under the torso component [5]. Due to this, only the motion of the torso and the macro-motion of the swinging limbs were considered. Work shown in [10] showed that the echo signal reflected by a human target towards radar can be simulated by adding the responses returned from all the individual body parts. The shapes of the individual body parts were approximated as ellipsoids [5]. Hence, similar modeling work in [16], was assumed to return signals from a single representative point on the surface of each body part.

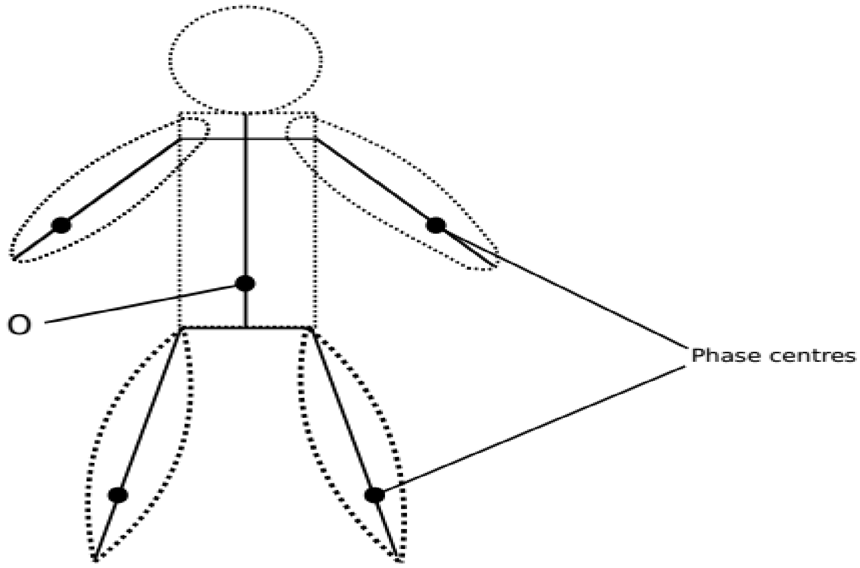

Figure 3.3 Simplified Human Model for Walking Motion

Solid circles in Figure 3.3 are called "phase centers" [5] [16]. As shown in this figure, five phase centers are considered in the model; one for each limb and the remaining which represents the human's center of mass in the torso.

3.4 Extraction of Doppler Data

Radar received signals contain all the relevant information about the target structure and its characteristics. The radar can locate these targets based on the time delay between transmitting and receiving the signal [5]. If one target is moving, a frequency shift will be induced in the returned signal, which is caused by the Doppler Effect.

Radar Signal Processing [5] [6] involves analysing radar returned signals, which are obtained using experimental setups. The returned signal is processed and features are extracted.

Mathematically, [7] Let us assume a single sinusoidal pulse transmitted with a carrier frequency, f_0 and centred at time $t = 0$:

$$s_0(t) = Acos(2\pi f_0 t + \theta), \; -\frac{\tau}{2} \leq t \leq \frac{\tau}{2} \quad (3.2)$$

If the carrier frequency f_0 is known, the pulse can be characterised with its amplitude A and phase θ within its period τ [7]:

$$s_0(t) = \mathbb{Re}\{Ae^{j(2\pi f_0 t+\theta)}\}$$

$$s_0(t) = \mathbb{Re}\{(Ae^{j\theta})e^{j2\pi f_0 t}\} \quad (3.3)$$

If the transmitted pulse in above equation reflects from a target at range R_0, the radar will receive the pulse at time $t' = \frac{2R_0}{c}$. The received pulse is given by [7]:

$$s_r(t) = s_0\left(t - \frac{2R_0}{c}\right)$$

$$= \mathbb{Re}\{(A'e^{j\theta'})e^{j2\pi f_0 t}\} \quad (3.4)$$

The received pulse has a new amplitude A′ which is attenuated according to the radar range equation, a new phase $\theta' = \theta - 4\pi R_0/\lambda$, and is delayed in time by $2R_0/c$. The phase of the received pulse (θ) is shifted by $-4\pi R_0/\lambda$ [7] and is proportional to the range of the target. If the target travels with a constant velocity, the rate of change of its phase will be constant. If the target accelerate or decelerate, the rate of change of phase will vary accordingly. These two facts are the key to Doppler and micro-Doppler estimation in radar systems [5] [7].
A general form of the coherent detector is shown in Figure 3.4.

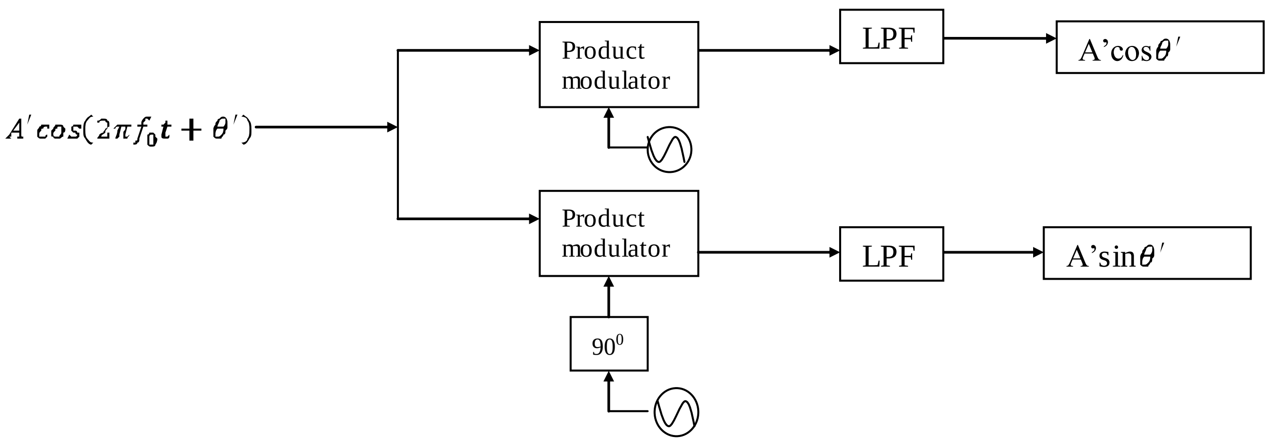

Figure 3.4 Coherent Detector

The above configuration splits the incoming signal (received signal) into two channels. The upper channel signal is mixed with the reference oscillator (in-phase component), while the other channel is mixed with a 90◦ shifted reference signal (quadrature- phase component). By working out the output of the two mixers and the low-pass filters, the output of the two channels is found to be [7]:

$$I = A' \cos\theta'$$
$$Q = A' \sin\theta'$$

Combining the I and Q components gives the complex baseband form of the received signal [7]:

$$s_r = I + jQ = A'(\cos\theta' + j\sin\theta') = A'e^{j\theta'} \quad (3.5)$$

Now, the phase of this complex signal contains information about the motion of the target, it is used to calculate the range profile of the target, .i.e. the radial distance of the target from the radar at each instant of time. [7]

3.5 Micro-Doppler Target Signatures

The word "signature" is widely used in radar and it refers to various characteristic representations of an object or a process [5] [7]. In the micro-Doppler domain, a target signature is the spectral image that shows the micro-Doppler characteristics of the target. This image directly relate to the dynamics of the target [7]. It is a complex-frequency modulation represented in the joint time-and frequency domain, and it is the distinctive characteristics that give the target its identity [7].

The received Doppler-shifted signal from a vibrating scatterer as a function of time is given in the equation [7]:

$$s_r(\boldsymbol{t}) = Aexp[j(2\pi f_0 \boldsymbol{t} + \phi(\boldsymbol{t}))] \quad (3.6)$$

where A is the amplitude of the received signal, f_0 is the center frequency of the transmitted signal, and $\phi(\boldsymbol{t})$ is the time-varying phase change of the vibrating scatterer. The time-varying phase $\phi(\boldsymbol{t})$ of a vibrating scatterer can be modelled as [7]:

$$\phi(\boldsymbol{t}) = \boldsymbol{\beta}\sin(2\pi f_v \boldsymbol{t}) \quad (3.7)$$

where $\beta = 4\pi D_v/\lambda$, D_v is the amplitude of the vibration, and λ is the wavelength of the transmitted signal. Hence,

$$s_r(\boldsymbol{t}) = Aexp[j(2\pi f_0 \boldsymbol{t} + \boldsymbol{\beta}\sin(2\pi f_v \boldsymbol{t}))] \quad (3.8)$$

The phase term in the previous equation is a time-varying function. The Doppler frequency induced by the vibration of the scatterer can be represented as [7]:

$$f_D(\boldsymbol{t}) = \frac{1}{2\pi}\frac{d\phi(\boldsymbol{t})}{d\boldsymbol{t}}$$

$$= \frac{4\pi}{\lambda} D_v f_v \cos(2\pi f_v \boldsymbol{t}) \quad (3.9)$$

From the above equation, we note that the micro-Doppler component induced by a vibrating scatterer is a sinusoidal function of time at the vibrating frequency f_v. This component is an important element to simulate the micro-Doppler signatures of complex targets such as human gait [7].

Now, using radar returned signal from equation no. 3.6, we have analyzed micro-Doppler signatures of a vibrating target [3].

According to the equation 3.6, considering radar to be working in X-band with wavelength of 3 cm, with f_v=10 Hz, D_v=0.1 cm, we get $f_D(\boldsymbol{t})$= 0.66 Hz. Thus, although the vibrating rate is low, we can still detect these signatures using returned signals. Appropriate results have been discussed ahead in the coming sections.

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CHAPTER 4

ROLE OF JOINT TIME-FREQUENCY TOOLS IN MICRO-DOPPLER SIGNATURE ANALYSIS

So far we know that target motion introduces phase shifts [3] [5] [7] in the reflected radar signal. The complex signal produced at the receiver still preserves this phase shift information which can be used to determine information about the target's movement with respect to time. From Chapter 3, we learnt that, the Doppler Effect is caused by phase shifts from sample-to-sample thus resulting in a frequency modulation in the signal which characterizes the target. Also, in addition to the frequency shifts produced by the overall or macro-motion of the object, there are also other relatively weaker, frequency components produced due to the motion of parts of the target, such as the hands, legs and head for a human and so on. These frequency modulations or shifts produced by the motions of different parts of the body are together called the micro-Doppler signatures of the target [5] [6]. These signatures are very helpful in automatic target recognition since they are considerably different for different target classes.

Since target motion occurs across time and produces micro-Doppler signatures which require a spectral analysis, therefore we need to analyze it together through a joint time-frequency representation [3] [5] [6] [7]. Joint time-frequency transforms help in analysing different frequency components present at different instances of time. The most widely used among all time-frequency analysis tools are the Short-Time Fourier transform (STFT), Continuous Wavelet Transform (WT), Stock well Transform (ST) [14] [16].

4.1 The Short-Time Fourier Transform (STFT)

The most frequently used time-frequency representation of a time-varying signal is the STFT. It gives the change of frequency content of a signal over time. The spectrogram is calculated by using the short-time Fourier transform (STFT).

The STFT of a discrete time signal x[n] is given by [5]:

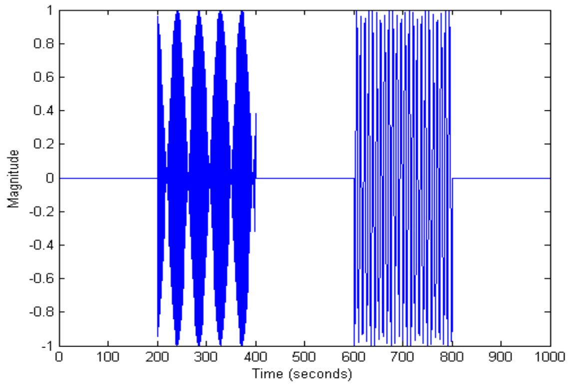
$$X(m,\omega) = \sum_{n=-\infty}^{n=\infty} x[n]w[n-m]e^{-j\omega n} \quad (4.1)$$

where w[n] could be a finite length window such as Hamming, Hanning, Barlett, etc. and ω is the variable representing frequency. This formula can be interpreted as taking the Fourier transform of each of several overlapping segments of x[n] and stacking them one after the other to form a matrix.

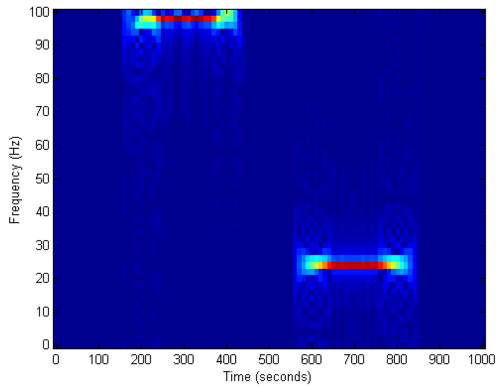
The squared magnitude of the STFT is called the spectrogram [5]. Mathematically, the spectrogram is defined as:

$$\mathrm{spectrogram}(m, \omega) = |X(m, \omega)|^2$$

The STFT and hence the spectrogram thus yield the frequency content of several overlapping time segments of the signal, i.e. its joint time-frequency representation.



(a) A Signal



(b) Spectrogram

Figure 4.1 A signal and its corresponding spectrogram

4.1.1 Characteristics of the STFT

The STFT is advantageous in that it is computationally efficient to compute since its basic element is the Fourier transform which can be optimally computed using any of the several fast Fourier transform (FFT) approaches already known [7].

The STFT can be viewed as the discrete Fourier transform of a signal multiplied by a window function that slides in time. The duration [5] [7] of the window is typically chosen such that the signal of interest is approximately stationary over the duration of the window. A shorter-duration window provides better time resolution but reduced frequency resolution. A longer-duration window provides a better frequency resolution but poor time resolution [5] [6]. Thus, STFT has a major drawback of fixed joint time-frequency resolution. This is due to Heisenberg's Uncertainty Principle applied to Signal Processing which states that a signal cannot be simultaneously localized in both time and frequency domains with arbitrary precision [5] [6]. Mathematically, this means that the product of the temporal and spectral resolutions, .i.e. Δt and Δf respectively, for a given signal is constant and lower bounded. This inequality is called the time-bandwidth product inequality and is given by:

$$\Delta t \Delta f \geq \frac{1}{4\pi} \tag{4.2}$$

where the variable f represents frequency.

4.2 Stockwell Transform (ST)

The STFT can be successfully applied to extract the information from the non-stationary signals but it has a major limitation of fixed resolution due to fixed window length [5] [17]. Continuous Wavelet Transform (CWT) is applied to overcome the problem of STFT, as in CWT scale is inversely proportional to frequency, but it is unable to provide relation between time and frequency as well as phase information is also lost. Stockwell transform (ST) can eliminate the problem of fixed time frequency resolution in STFT and phase problem of the CWT. The ST provides the better time frequency resolution as compared to CWT and STFT without the problem of phase removal and fixed resolution respectively. The Gaussian window is used in ST to provide the time-frequency resolution [1] [17]. The width of this window varies with frequency [17].

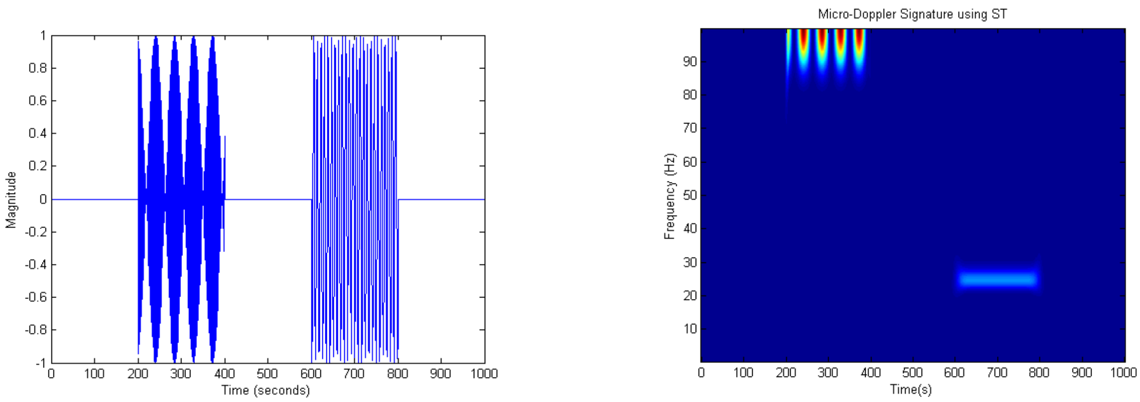
The S-transform of a signal $(\boldsymbol{t})$ is defined as [1] [17] :

$$S(\boldsymbol{t}, f, \sigma) = \int_{-\infty}^{\infty} x(\boldsymbol{t}) G(\boldsymbol{t} - \tau, \sigma) e^{-j2\pi f \tau} \, d\tau \tag{4.4}$$

Where, $G(\boldsymbol{t} - \tau, \sigma) = \frac{1}{\sigma\sqrt{2\pi}} e^{-\frac{(t-\tau)^2}{2\sigma^2}}$ is a variable Gaussian window function, σ its standard deviation which varies as $\frac{1}{|f|}$, $\boldsymbol{t}$ is time, τ is central position of the window, and f is frequency.

4.2.1 Characteristics of Stock well transform (ST)

Joint time-frequency resolution in case of ST is very good as compared to STFT and CWT, with improved phase correction and adaptable window width. The S-transform is defined as a Short Time Fourier Transform with a variable window. The S-transform provides the progressive time frequency resolution but has the problem of poor energy concentration in the time frequency plane as the standard deviation of the Gaussian window is inversely proportional to the frequency. Energy calculations suffer some losses due to which results are not up to the mark. For higher frequencies, window length is taken small, so it contains fewer numbers of periods which results in poor energy concentration. Similarly, for the lower frequencies, window length is taken large, and it contains more number of periods within it and the energy concentration is more.



(a) A signal (b) Corresponding S-Transform

Figure 4.2 A signal and its corresponding S-Transform

There can be further improvement in this method of S-transform. This improvement can be termed as the Modified version of S-transform. In this modified version, the width of the Gaussian window varies with respect to 'covariance' of the signal.

4.3 Covariance based Stock well Transform (ST)

The width of the Gaussian window, which is used in ST to provide the time-frequency resolution, varies with frequency [1]. Therefore, a time-frequency resolution of ST still needs improvement. The Covariance based modified S-transform has a Gaussian window in which the width of the window varies with respect to covariance of the signal.

S-transform can be modified using covariance of the signal which is given by [17]-

$$\beta(f) = n \times \gamma \times f \tag{4.5}$$

In above equation, f is frequency, γ is covariance, n=5, value has been chosen experimentally. The relation between β and standard deviation, σ of the Gaussian is given by following relation-

$$\sigma = \frac{\beta(f)}{|f|} \tag{4.6}$$

Thus window function of the above method is thus represented by [17]-

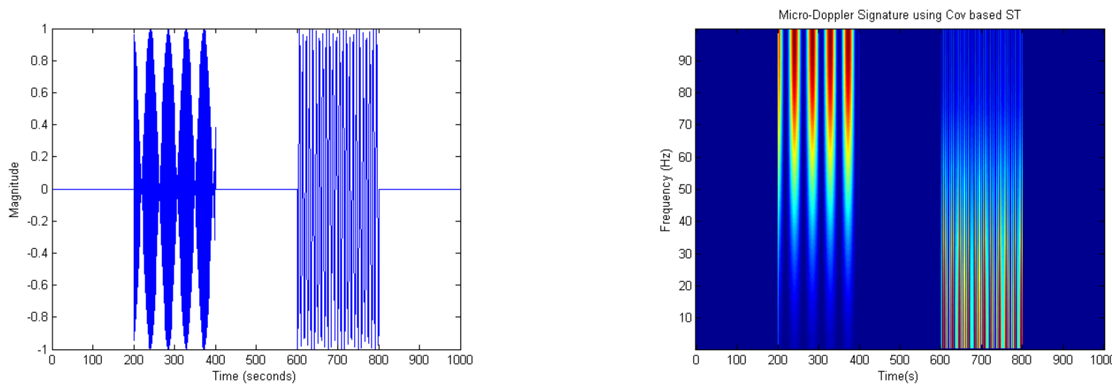
$$w(\tau - t, f, n, \beta) = \frac{|f|}{\sqrt{2\pi}\beta(f)} e^{-\frac{(\tau - t)^2}{2\beta(f)^2}} \tag{4.7}$$

Now, the modified S-transform can be written as:

$$S(\tau, f, n, \gamma) = \int_{-\infty}^{\infty} h(t) \frac{|f|}{\sqrt{2\pi}\beta(f)} e^{-\frac{(\tau - t)^2}{2\beta(f)^2}} e^{-j2\pi f t} dt \tag{4.8}$$

Hence, we can now control the time and frequency resolution using the standard deviation of the Gaussian window.

Below is just an example.



(a) A signal (b) Covariance based ST

Figure 4.3 A signal and its corresponding covariance based S-Transform

CHAPTER 5

RESULTS, CONCLUSION, AND FUTURE WORK

5.1 Results

As described earlier, the radar returns from the targets of interest were analyzed using different time frequency tools to produce the micro-Doppler signatures of the signal. Considering two types of targets, one having a vibration motion and another having no vibration motion.

5.1.1 Fixed Target without vibration

Radar returned signals from the targets having no vibration can be mathematically modelled as by the following equation:

$$s_r(\boldsymbol{t}) = Aexp[j(2\pi f_0 \boldsymbol{t} + \phi(\boldsymbol{t}))] \quad (5.1)$$

Where $\phi(\boldsymbol{t}) = \beta \sin(2\pi f_v \boldsymbol{t})$ with $\phi(\boldsymbol{t})$=0, as there is no vibration, no phase alteration will occur. Hence, from equation (3.9), we have: $f_D(\boldsymbol{t}) = \frac{1}{2\pi}\frac{d\phi(t)}{dt} = \frac{4\pi}{\lambda} D_v f_v \cos(2\pi f_v \boldsymbol{t}) = 0$

Taking all time-frequency transforms of equation (5.1), we obtain:

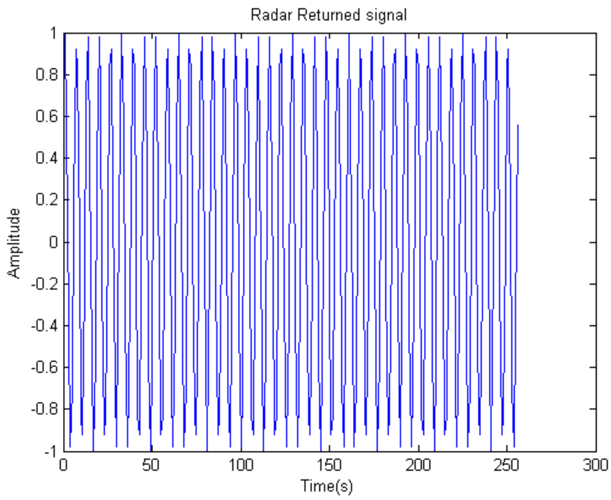


Figure 5.1 Radar returned signal of a fixed target without vibration

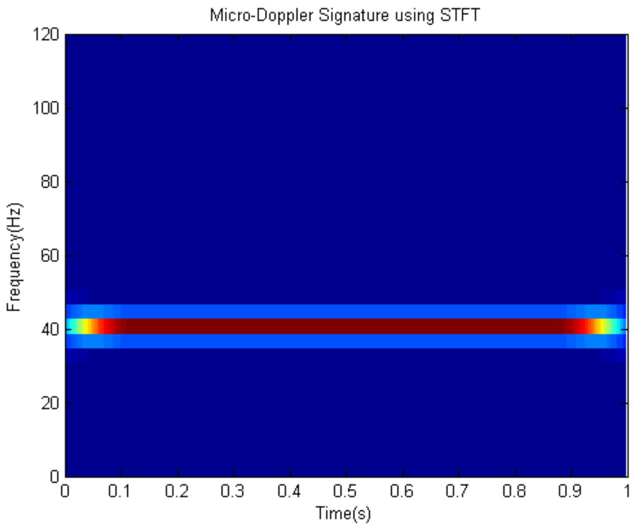


Figure 5.2 STFT of the signal of a fixed target without vibration

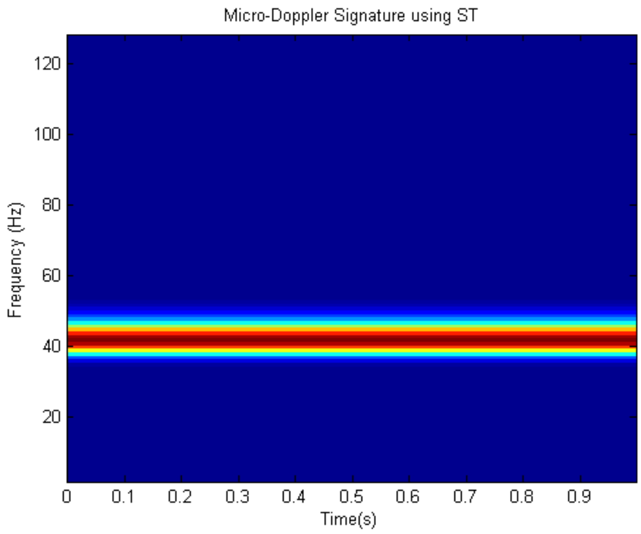


Figure 5.3 ST of the signal of a fixed target without vibration

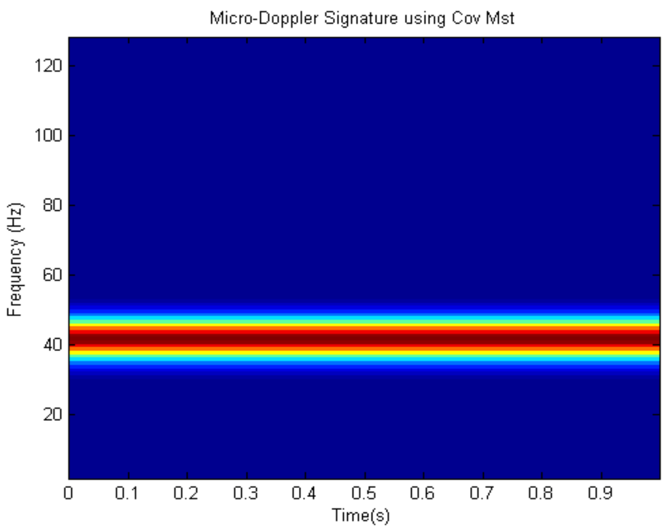


Figure 5.4 Covariance based ST of the signal of a fixed target without vibration

5.1.2 Fixed Target with vibration

Similarly, radar returned signals from the targets having vibration can be modelled as given in equation (5.1). Here, vibration causes phase changes, due to which micro-Doppler signatures are obtained in the signatures. So, from equation (5.1), we have taken values as: $f_0 = 40\ Hz$, A=1, D_v= 0.1 cm, $\lambda = 3\ cm$.

Taking all time-frequency transforms considering above values, we obtain:

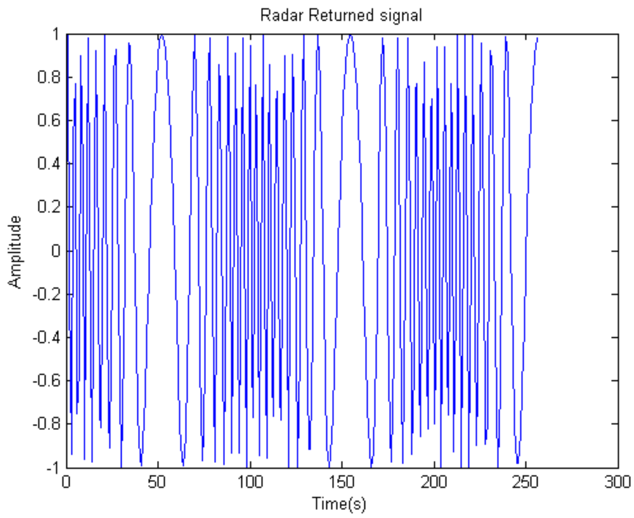


Figure 5.5 Radar returned signal of a fixed target with vibration

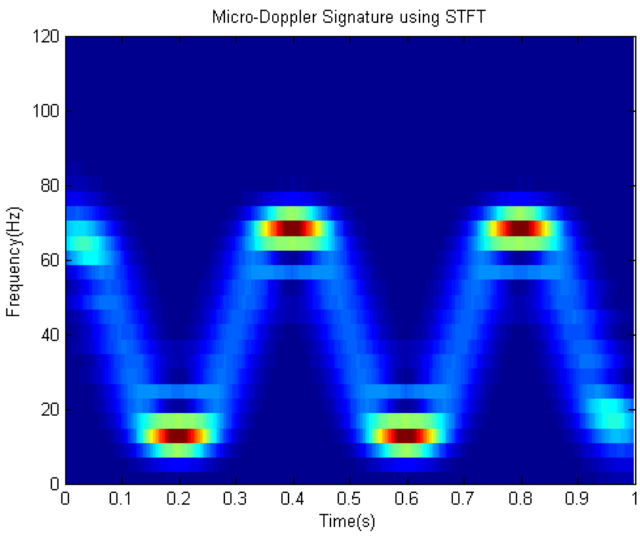


Figure 5.6 STFT of the signal of a fixed target with vibration

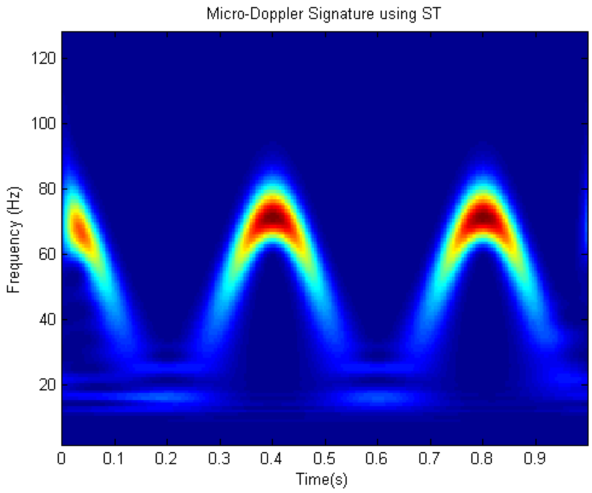


Figure 5.7 ST of the signal of a fixed target with vibration

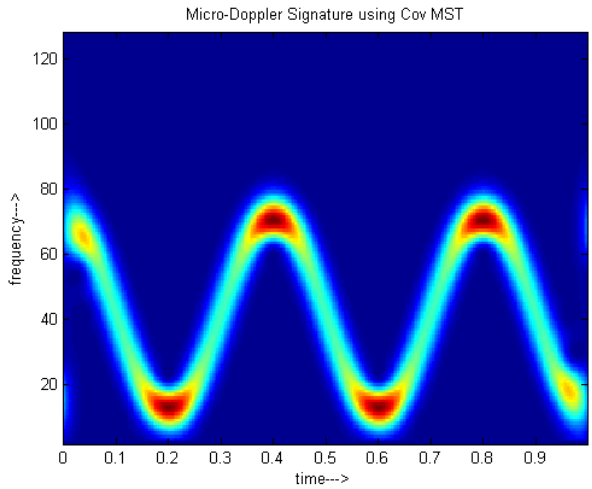


Figure 5.8 Covariance based ST of the signal of a fixed target with vibration

5.1.3 Human target walking with and without swinging both arms

Apart from the simulated results, we have performed time-frequency analysis tools such as STFT, ST only on real data [2] of human walking with and without swinging both arms and their respective signatures are shown below:

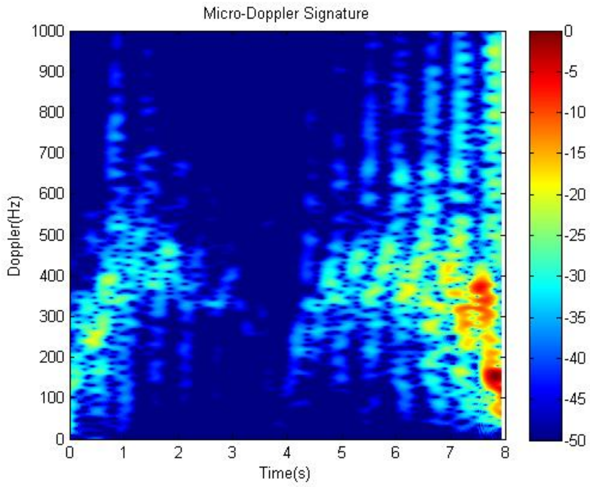


Figure 5.9 Human walking micro-Doppler signatures using STFT

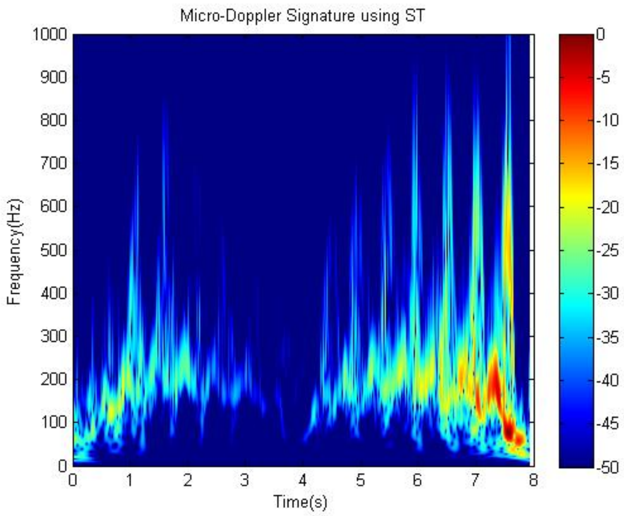


Figure 5.10 Human walking micro-Doppler signatures using ST

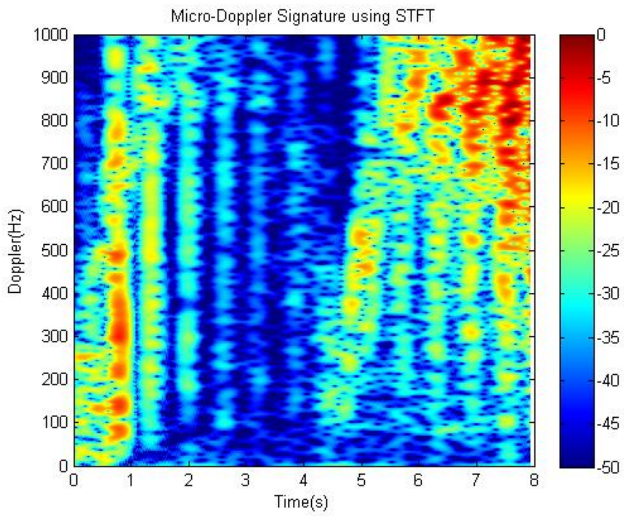


Figure 5.11 Human walking with both arms swinging micro-Doppler signatures using STFT

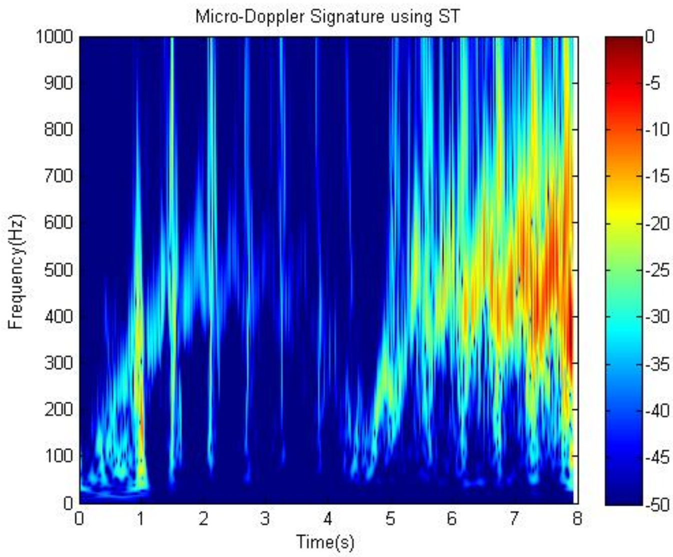


Figure 5.12 Human walking with both arms swinging micro-Doppler signatures using ST

5.2 Conclusion

We studied different aspects of Micro-Doppler Signature analysis using time-frequency tools. In this report, we have performed STFT, ST, Covariance ST of the radar received signals and found out that the features we have obtained are correctly matching with features we had got from the data source [2]. Also we further conclude that STFT and ST have some limitations [5] [6] which Covariance ST tries to solve. We get better results from Covariance based ST. Following points can be concluded from the simulated results:

- Targets without vibration possess zero phase information, so we obtain a straight line in the joint time-frequency plot, which is having single frequency content throughout.
- Targets with vibration possess some phase information, so we obtain signatures which correspond to a vibrating target, with central frequency at 40 Hz.
- We also analyzed micro-Doppler signatures of human walking with and without swinging arms, by performing time-frequency transforms of real data [2]. Our results were as expected, but they still require some enhancements.

5.3 Future Work

The current work can be expanded to include more targets like vehicles (both wheeled and tracked), animals like horses and deer, medium to large birds and so on. It is easier to distinguish between a walking human and dog than a crawling human and a dog. Further work could be done in traffic light monitoring, patient inspection, etc.

REFERENCES

[1] WANG Jun, LEI Peng, SUN Jinping and MAO Shiyi,"*Micro-Doppler Signal Analysis Based on the Generalized S Transform for Radar Targets*", School of Electronic and Information Engineering, Beijing University of Aeronautics and Astronautics, Beijing 100191, China.

[2] http://ancortek.com/wp-content/uploads/2016/05/Micro-Doppler-Signature-Analysis-of-SDR-KIT-CW-Data.zip

[3] VICTOR C. CHEN, FAYIN LI, SHEN-SHYANG HO HARRY WECHSLER, "*Micro-Doppler Effect in Radar: Phenomenon, Model, and Simulation Study*", 0018-9251/06, IEEE TRANSACTIONS ON AEROSPACE AND ELECTRONIC SYSTEMS VOL. 42, NO. 1 JANUARY 2006.

[4] L. Vignaud, A. Ghaleb, J. Le Kernec ONERA, "*Radar high resolution range & micro-doppler analysis of human motions*", (The French Aerospace Lab) Electromagnetism and Radar Department, France

[5] Vinit Kizhakkel, "*Pulsed radar target recognition based on micro-Doppler signatures using wavelet analysis*", a Thesis, Presented in Partial Full-fillment of the Requirements for the Degree Master of Science in the Graduate School of The Ohio State University.

[6] Fok Hing Chi Tivive, Son Lam Phung, Abdesselam Bouzerdoum, "*An image-based approach for classification of human micro-doppler radar signatures*", in Proceedings of SPIE - The International Society for Optical Engineering, 2013, pp. 873406-1-873406-12.

[7] Adel Alzogaiby, "*Using Micro-Doppler Radar Signals for Human Gait Detection*", Department of Electrical and Electronic Engineering, University of Stellenbosch, Private Bag X1, Matieland 7602, South Africa.

[8] T. Thayaparan, S. Abrol, E. Riseborough.,"*Micro-Doppler radar signatures for intelligent target recognition.*", DRDC Ottawa TM 2004-170. Defence R&D Canada – Ottawa.

[9] http://www.plaindsp.com/wp-content/uploads/doppler2.png

[10] P. Van Dorp and F. C. A. Groen, "Human walking estimation with radar," *IEE*E *Proceedings Radar Sonar Navigation*, vol. 150, pp. 356–365, 2003.

[11] David G. Long, Chair D. J. Lee Neal K. Bangerter." *Experiments with GMTI Radar Using Micro-Doppler",* Department of Electrical Engineering Brigham Young University, June 2013.

[12] "IEEE Standard Letter Designations for Radar-Frequency Bands," IEEE Std 521-2002 (Revision of IEEE Std 521-1984), pp. i–3.

[13] Ronald J. Wellman, Jerry L. Silvious, "*Doppler Signature Measurements of an Mi-24 Hind-D Helicopter at 92 GHz*", ARMY RESEARCH LABORATORY, Adelphi, MD 20783-1197.

[14] R. Boulic, N. M. Thalmann, and D. Thalmann, "A global walking model with real-time kinematic personification," *The Visual Computer*, vol. 6, pp. 344–358,1990.

[15] S. Z. G¨urb¨uz, *Radar Detection and Identification of Human Signatures using Moving Platforms*. PhD thesis, Georgia Institute of Technology, 2009.

[16] S. S. Ram, *Radar Simulation of Human Activities in Non Line-of-Sight Environments*. PhD thesis, University of Texas, Austin, 2009.

[17] Jitain Sharma, Sunildatt Sharma," *Analysis of multi-component signals using covariance based Modified S-transform*", Jaypee University of Information Technology, Waknaghat, Solan, India.

[18] J. W. Crispin Jr. and A. L. Maffett, "Radar cross-section estimation for simple shapes," *Proceedings of the IEEE*, vol. 53, pp. 833–848, 1965.

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