Tuijin Jishu/Journal of Propulsion Technology
ISSN: 1001-4055
Vol. 44 No. 6 (2023)

Micro-Doppler Parameter Estimation Using Radar

Akshita Rahul Koshe[1], Aaditi Sanjeev Joshi[2], Dinesh R. M.[3], Varsha K.[4]

[1] *Dept. of ECE, PES University, Bengaluru, India*
[2] *Dept. of ECE, PES University, Bengaluru, India*
[3] *Dept. of ECE, PES University, Bengaluru, India*
[4] *Dept. of ECE, PES University, Bengaluru, India*

Abstract:- Doppler effect is the apparent difference between the frequency at which a signal is transmitted and that at which they reach an observer. It is induced due to the bulk motion of radar targets. When a signal reaches its target, it traverses back to the transmitter. When these radar targets have an arbitrary motion involved, we observe a phenomenon called Micro-Doppler effect. This project aims to estimate various radar parameters due to this phenomenon. We introduce this effect in radar and compute various modulations.

Our analyses use the Fourier transform and computation of Fourier Bessel coefficients extensively. We weigh the pros and cons of this approach and advance to another technique that makes use of high-resolution time-frequency transform to analyze time-varying Micro-Doppler effects. We have also used certain other concepts such as Hankel Transform, Bessel Functions and Integration to calculate the coefficients. As the Doppler Effect is termed due to the effect of sound produced by moving objects at a certain speed, Micro-Doppler signal has the properties of a target with moving blades. Hence, various applications like the calculation of rotational and vibrational components use this concept. In this report we restrict ourselves with the study of rotational components only.

Keywords: *Micro-Doppler effect, Fourier Bessel Coefficients, Hankel Transform, Discrete energy separation algorithm (DESA), Wigner-Ville Distribution (WVD), Spectrogram*

1. Introduction

Every radar that transmits the signal is called a transmitter and the one that receives the signal is called the receiver. These signals are electromagnetic (EM) waves. These waves encounter a target and are traversed back to the radar. In a mono-static radar, the transmitter and receiver are at the same location, the distance travelled by the EM wave is twice as the distance of separation between the target and the radar. When these targets are moving with some velocity, they imbibe a change in the carrier frequency and that results in a doppler effect. Doppler effect is said to be negative when the target is moving away from the radar, else it is claimed to be positive. When these targets (moving with some velocity) have an arbitrary velocity(for instance in the propellers, wings of an airplane), it results in a Micro-Doppler effect.

When target identification tests including the addition of resonant dipoles to the aircraft were conducted as early as 1937, the micro doppler effect was utilised. Rapid and reliable target classification is essential in wartime circumstances as it can aid in developing the right response depending on the type of danger being discovered.

The ability to classify targets has become essential for eliminating pointless targets. Drone detection and categorization are essential in the modern world to prevent the use of drones for terrorist and espionage purposes and classification of drones is also crucial in current times for avoiding their misuse for activities like espionage and terrorism.

Thus, the Micro-Doppler effect plays a vital role in determining various parameters and how this affects the whole transmission process.

Tuijin Jishu/Journal of Propulsion Technology
ISSN: 1001-4055
Vol. 44 No. 6 (2023)

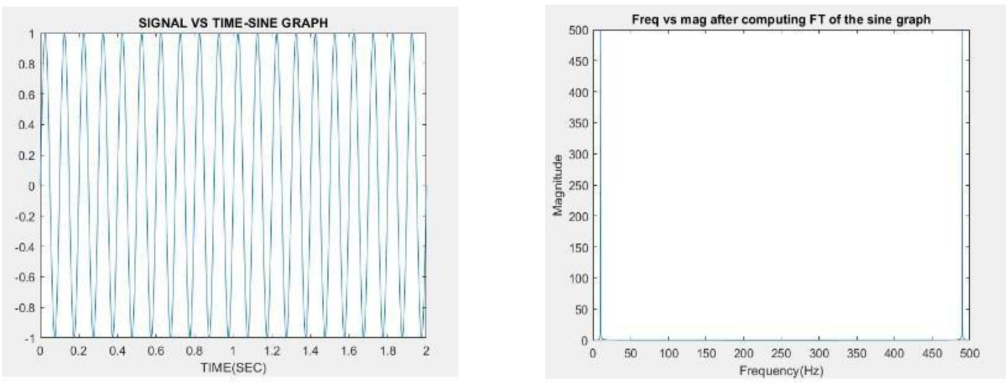
A bi-static radar is a passive radar which provides detection of targets by utilizing a co-operative transmitter or available transmitters in the surrounding. This radar comprises geographically distributed transmit and receive stations connected by high speed data link to form a Bistatic configuration.

The antenna, digital receiver, digital beamforming, bistatic signal processing and tracking forms the various subsystems of a receive station. The bistatic radar will estimate the bi- static range and bi-static Doppler of the target.

If the target has few rotating parts (like rotor blades) then modulations around Doppler frequency will be seen in the received signal from the target. This is called the Micro- Doppler effect. In this project, we will try to estimate the Micro-Doppler parameters using radar signal processing. The project deals with estimating the parameters of Micro-Doppler effect using radar. The transmit and receive units of a bistatic radar system are spatially separated. Various parameters that can be estimated using Micro-Doppler effect are echo simulation, object and range detection and estimation of slow moving objects.

2. System Design

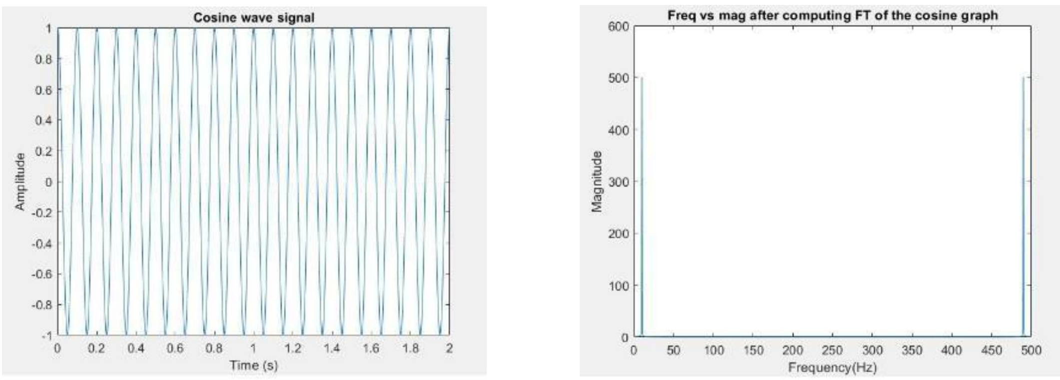
Some of the pre-requisites in the project include plotting graphs sine, cosine and a combination of the two after computing the fast fourier transform (FFT). FFT of simple signals that use parameters like sampling frequency (fs), amplitude(A), frequency(f) and time(t).



(a) (b)

(a) Sine Wave without FFT (b)Sine Wave after computing FFT

Fig. 1: Sine Wave



(a) (b)

(a) Cosine Wave without FFT (b) Cosine wave after computing FFT

Fig. 2: Cosine Wave

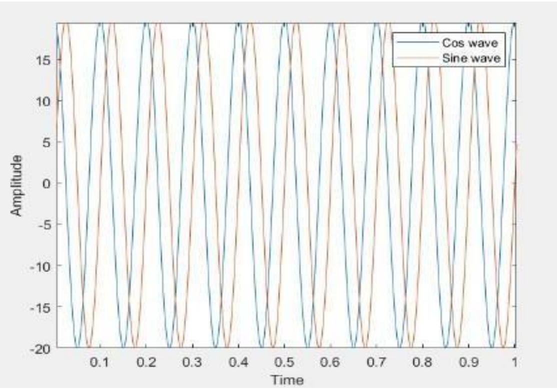
Consider a simple sine signal,x(t) = Asin(2πft) where, f=10 Hz, A=1, t=2 sec

After computing the FFT, we get two peaks, one at 10 Hz, and the other at 490 Hz, with a peak magnitude of 500 (Fig.1)

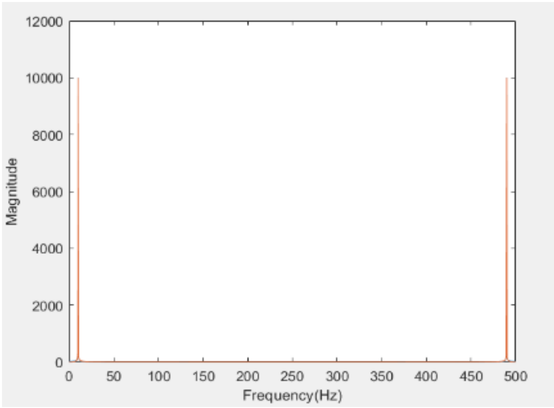
Consider a simple cosine signal, y(t) = Acos(2πft) where, f=10 Hz, A=1, t=2 sec

After computing the FFT, we get two peaks, one at 10 Hz, and the other at 490 Hz, with a peak magnitude of 500 (Fig.2)

Consider a simple signal, z(t) = A(cos(2πft) + jsin(2πft)) where, A = 20, f=10 Hz, t=2 sec and the real component of the signal z(t) is the in- phase component, whereas the imaginary component is the quadrature phase component. With these given parameters, we can obtain the graph and get the peak values as 9998 and 10010 for sine and cosine components respectively, at 10 Hz and 490 Hz, in the FFT graph.(Fig.3)



(a) Combined Wave without FFT



(b)Combined wave after computing FFT

Fig. 3: Combined Wave

3. Computation Of Fourier Bessel Coefficients

- Non-stationary signals, whose signal characteristics are time-varying, are used in many engineering applications, including speech analysis, sonar, and radar. Standard techniques like Power Spectral Density (PSD) cannot be used for spectrum analysis on such signals. To cope with such signals, the time-frequency analysis technique has been suggested. Short-Time Fourier Transform (STFT) is one of the earliest methods to compute spectral analysis of non-stationary signals. STFT has a tradeoff between time resolution and frequency.
- Wigner-Ville Distribution (WVD) [6] has infinite time solutions because of the averaging of finite signals. It introduces cross terms and these can hamper signal properties. These cross terms can have significant amplitudes and corrupt the transform space, serving to be detrimental in fields like speech analysis.
- We can derive the Time-Frequency Representation (TFR) of a multicomponent signal without the use of cross terms by combining the FB expansion and the WVD. Signal components will be associated with various non-overlapping FB coefficients if the signal's components are well separated in the frequency domain. Thus, these can be reconstructed by separately identifying and separating the corresponding FB. The zero-order Fourier–Bessel series expansion of a signal x(t) considered over some arbitrary interval (0, a) is expressed as B coefficients.

Calculation of Fourier Bessel coefficients [3] is done using

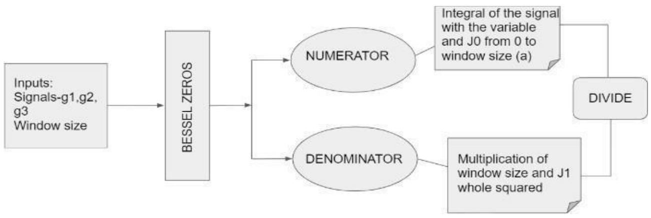
- Zero-order Bessel function and first-order Bessel functions are represented by $J0$ and $J1$ respectively.
- The flowchart explains how each of the coefficients are calculated for a given window size (Fig. 4) and hence are plotted in the coefficients-order graph for that signal. A signal x(t) is examined across an arbitrary range (0, a), and its zero-order Fourier-Bessel series expansion [7] is represented as

$$x(t) = \sum_{l=1} C_l J_0(\lambda_l . t/a) \quad (1)$$

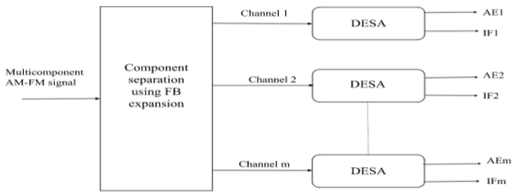
$$C_l = \frac{2 \int_0^a t x(t) J_0(\lambda_l . t/a)\, dt}{a^2 (J_1 . \lambda_l)^2} \quad (2)$$

Hankel transform expresses any given function f(r) as the weighted sum of an infinite number of Bessel functions of the first kind. It can also be used to calculate the coefficients.

$$F_v(s) = \int_0^\infty r f(r) J_v(sr)\, dr \quad (3)$$



Computation of FB Coefficients



FB-DESA Method

Fig. 4: Flowcharts

A. Simulation results of FB Coefficients for signals

Consider a signal,

g1(n)=4cos[2π(n/8)n/256]+4cos[2π((512-n)/8 +40)n/256] The given signal has a window size of 170. It is a combination of two linear chirp signal components with positive– negative and positive–positive chirp rates, respectively,

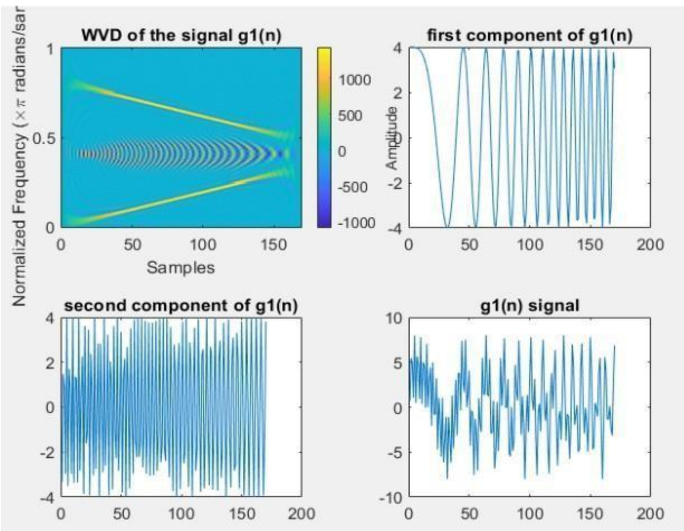


Fig. 5: g1(n) signal

Consider a signal,

g2(n)=cos[(2π32+70n/500)n/500]+cos[(2π80+100n/500)n/500]]

The given signal has a window size of 512. It is a combination of two linear chirp signal components with positive–negative and positive–positive chirp rates, respectively.

4. Implementation Of Micro-Doppler Signal

A spectrogram is a graph of the energy content of a signal expressed as a function of frequency and time (Fig. 7c). It normally depicts a heat map whose intensity can be varied by a colour. Here, the spectrogram of a m-D signal to get a visual representation of the spectrum of frequencies as it varies with time. For plotting m-D signal, we have considered the generalized equation given below:

$md = reflectivityb.A.e^{j(2\pi fdt)}$

$+\ reflectivitymd.Am.sin(2\pi fmt) + phase$

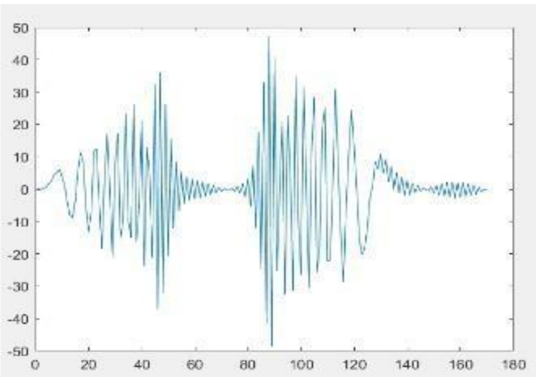
Where,

A = doppler amplitude= 20 fd = doppler frequency=8

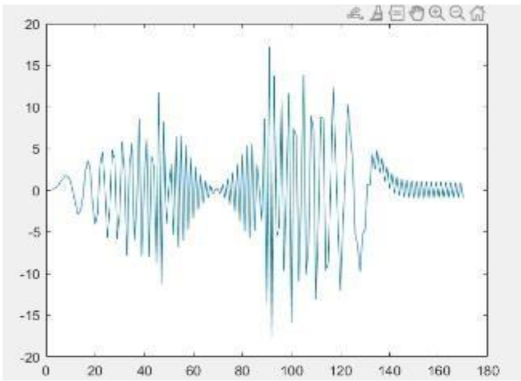
Am = Micro-Doppler amplitude= [50, 140, 130]

fm = Micro-Doppler frequency= [0.5, 1.5, 1] *reflectivityb* = doppler amplitude of reflectivity = 1 *reflectivitymd* = mD amplitude of reflectivity = 0.25 phase = degree to radians = [0, 0, 0]

In Additive White Gaussian Noise (AWGN), the noise gets added to the signal, thus affecting its amplitude (Fig. 7a). We have used AWGN to differentiate the graph from other signal which is without noise (Fig. 7b). It is useful for gaining insights into underlying behaviour of a signal. We take window length as 128 and number of targets as 2.

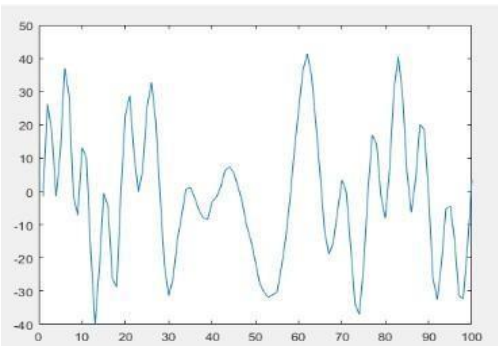


(a) FB coefficients vs Order

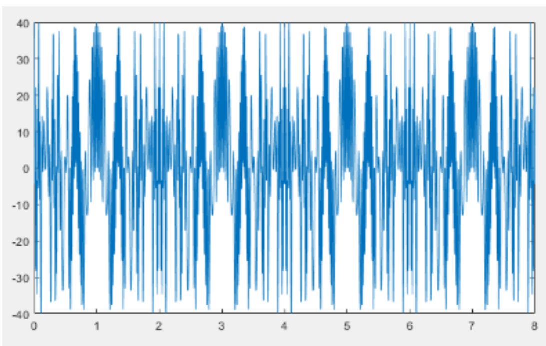


(b) FB coefficients vs Order using Hankel Transform

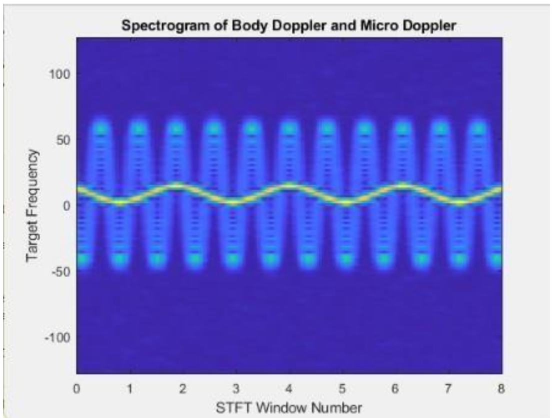
Fig. 6: signal g1(n) using formula



(a) m-D signal with AWGN



(b) m-D signal without AWGN



(c) m-D signal spectrogram

Fig. 7: Graphs of m-D signal

5. FB-DESA Method

In this section we estimate AE and IF using the FB- DESA method [4]. A real multicomponent signal is separated into its monocomponent signals using the Fourier-Bessel (FB) expansion (Fig. 4b). Discrete energy separation algorithm (DESA) is applied to each monocomponent signal to obtain its amplitude envelope (AE) and instantaneous frequency (IF) of the multicomponent AM-FM signal.

A. Simulation Results

Consider a sequence y(n) which consists of M single-tone AM-FM sinusoidal signals (M=2) and is represented as 8b:

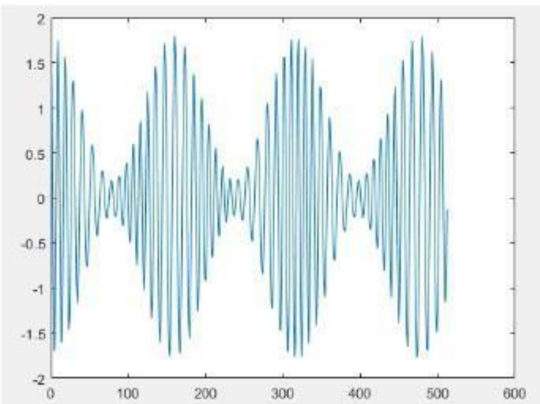
$$y(n) = \sum_{l=1}^{M} (1 + \mu_i cos(v_{ai} n)).cos(\omega_i n + \beta_i sin(v f_i n)) \tag{4}$$

where two sets of parameters are:

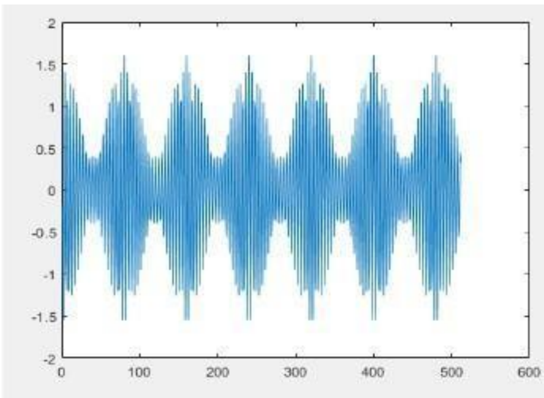
A1 = 1, $\mu 1 = 0.8$, $Va1 = 20.0063$, $\omega 1 = 2\pi x 0.0938$, $\beta 1 = 2$, $vf\,1 = 2\pi x 0.0094$ *and*

A2 = 1, $\mu 1 = 0.6$, $Va2 = 2\pi x 0.0125$, $\omega 2 = 2\pi x 0.0.2550$, $\beta 2 = 1.5$, $vf\,1 = 2\pi x 0.0.0125$

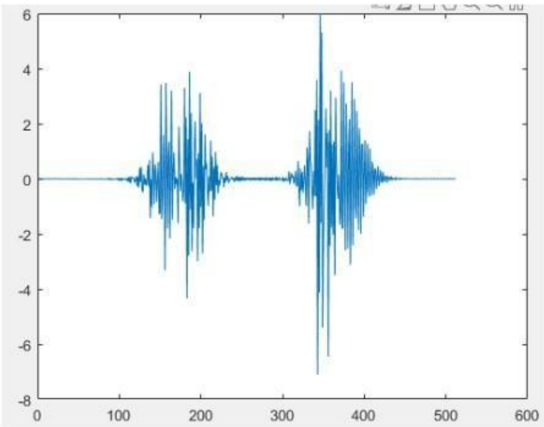
Here, signals use (2) to compute FB-Coefficients



(a) First component of signal y(n) with M=1



(b) Second component of signal y(n) with M=2



(c) FB - coefficients of two components AM-FM sinusoidal signal

Fig. 8: FB-DESA Method

6. Other Ways to Compute FB Coefficients

One of the major ambiguities faced while plotting the FB coefficients was the scaling factors. In the obtained graphs the y-axis or the FB coefficients were scaled more than the original one. Thus, we tried computing the coefficients through other methods, though we were not able to completely rectify it.

A. Trapz function

- trapz(Y) computes the approximate integral of Y via the trapezoidal method with unit spacing
- trapz(X, Y) integrates Y with respect to the coordinates or scalar spacing specified by X.

B. Area under the curve method

- Using the concept of dividing the area under the curve into small rectangular blocks, we computed the integra- tion which was later implemented on the FB coefficients formula.
- We got the same graph, which means that the initial built in function approach was correct. (using int and vpaintegral)

C. Integral using built-in function

We used the common built-in function for computing the integration int. Graph obtained below gives us the same result as the previous method (Fig. 9)

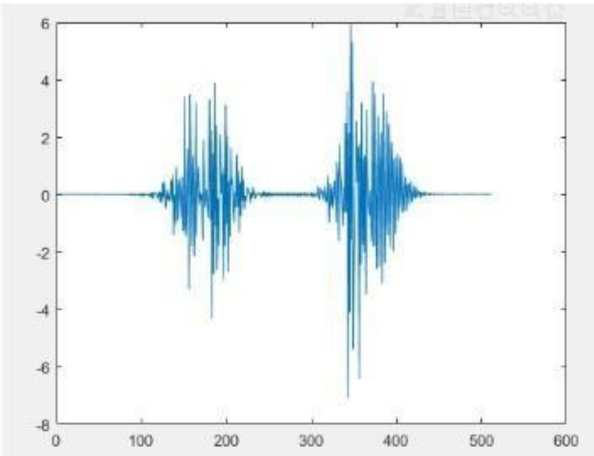


Fig. 9: g1(n) signal- integral using built-in function method

7. Conclusion

Doppler effect is the apparent shift in frequency due to the target velocity. If the target has mechanical vibration or rotation in addition to its translation, it might induce a frequency modulation on the returned signal that generates sidebands about the target's Doppler frequency shift. This is called the Micro-Doppler effect.

- We started with the concepts of Micro-Doppler effect and the various situations of a moving target (i.e., vibrational and rotational moving targets), which helped us to under- stand the mathematical parameters involving the Micro- Doppler signal [1]
- Our next focus was on the component separation method for removing cross components. We emphasized on FB Coefficients, which consisted of using a direct formula for separation of components. We also derived other methods which were found useful in the case of FB Coefficients, one of which was using the Hankel Transform method.
- We also attempted to optimize our code which in turn helped us to achieve better results with respect to the multicomponent signal [3]. With the use of bi-static radars, we aim to expand this model to real-time defence applications like tracking targets and estimate ranges.

8. Acknowledgments

The authors would like to thank Associate Prof. Sireesha B and Mr. Shrikant Sharma, Scientist E, Defence Research and Development Organization (DRDO) for their continuous help with in-depth discussions and helpful insights.

References

[1] V.C.Chen,L.Fayin,S.S.Ho, and H.Wechsler, "Micro-Doppler effect in radar: phenomenon, model, and simulation study." IEEE Transactions on Aerospace and electronic systems 42, no. 1 (2006): 2-21.

[2] P. Suresh, T. Thayaparan, T. Obulesu, and K. Venkataramaniah, "Extracting micro-Doppler radar signatures from rotating targets using Fourier–Bessel transform and time–frequency analysis." IEEE Transactions on Geoscience and Remote Sensing 52, no. 6 (2013): 3204-3210.

[3] R.B. Pachori, and P. Sircar, "A new technique to reduce cross terms in the Wigner distribution." Digital Signal Processing 17, no. 2 (2007):466-474.

[4] R.B. Pachori, and P. Sircar, "Analysis of multicomponent AM-FM signals using FB-DESA method." Digital Signal Processing 20, no. 1 (2010):42-62.

[5] K. A. Othman, P. F. S. A. Kamal, N. E. Abd Rashid, and R. S.A. R. Abdullah, "Study of Micro-Doppler effect on target spinning and precession for bistatic radar." In 2018 International Conference on Radar, Antenna, Microwave, Electronics, and Telecommunications (ICRAMET), pp.1-4. IEEE,2018.

[6] B. Boashash, and P. O'Shea, "Polynomial Wigner-Ville distribution and their relationship to time-varying higher order spectra." IEEE Transactions on Signal Processing 42, no. 1 (1994): 216-220.

[7] K. Gopalan, T. R. Anderson, and E. J. Cupples, "A comparison of speaker identification results using features based on cepstrum and Fourier-Bessel expansion." IEEE Transactions on Speech and Audio Processing 7, no. 3 (1999): 289-294.