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Design of an Integrated Platform for Modelling, Simulation and Validation of Motion Compensation Techniques in Inverse Synthetic Aperture Radar

Aniruddha Pal

PG Student, Dept. Of ECE, Nagaji Institute of Technology and Management, Gwalior, Madhya Pradesh, India

ABSTRACT: ISAR is an effective radar system which acquires high resolution images of targets such as aircrafts and ships ISAR technology utilizes the movement of the target rather than the emitter to form the synthetic aperture. For ISAR, synthetic aperture is formed by coherently combining the target returns from small aspect angles while target is moving. ISAR images are produced by using the rotation of targets and processing the resultant Doppler variations in slow time signal. Motion compensation technique in inverse synthetic aperture radar has been a very fascinating field of study. The target's relative motion with respect to the radar sensor provides angular diversity required for ISAR imaging. In practice the practical target like planes, helicopters and ships exhibit complicated motion during the flight. The complication of motion includes translational and the rotational motions like velocity, acceleration and jerk. The contributing factors are variable and unknown to the radar designer. Thus a number of algorithm and their effectiveness have been experimented. This procedure which tries to invert the unwanted effects of motion on the ISAR image is called motion compensation (MOCOMP). For analysis of the effectiveness of these motion compensation techniques an integrated platform is designed which is presented in this paper. This platform can be used to simulate, examine, model and validate motion compensation in case of inverse synthetic aperture radar (ISAR).

Keywords: Inverse Synthetic Aperture Radar (ISAR), Motion compensation, Translational Motion, Joint Time Frequency, Cross Correlation Method , Minimum Entropy Method

I.INTRODUCTION

The motion of target causes a change of the scattering centre with respect to the time. As the target moves the position of the point scatterer also changes .Thus the point scatterer's motion poses inaccurate information about the target. While the target is moving fast the scatterer may occupy several pixels on the image during the integration time. Thus the phase of the backscattered wave is altered and result in a change of ISAR image and the image is defocused in both range and the cross range. The movement of the target along the radar line of sight is called as translational motion. Translational motion is one factor which heavily affects the image quality of the radar. The position of the scatterers on the target along the range axis is shifted due to translational motion. Therefore the phase of the collected electric field data is misaligned along the pulses. Fourier transforms on the collected data results in the poor estimation of location of the point scatterers. Therefore the scatterer looks as if they walk over the range cells. This range walk phenomena negatively affects the performance of the image in the aspect of resolution, signal to noise ratio and the range accuracy. Therefore the targets image before the compensation is smeared in the cross range direction and defocused in range and cross range directions. The amount of the smearing and the defocusing depends on the amount of translational motion. For very slow moving targets the amount of smearing will be very less and like in the case of ships where as the translational motion causes detrimental effects in the case of high speed supersonic fighter aircrafts. For compensating the translational motion the algorithms are applied to overcome the range walk issue by trying to align range bins. This procedure of keeping the scatterers in the range cells is generally called as range tracking. Rotational motion also causes image distortion. Hence rotational motion is also required to be compensated by application of suitable algorithm. For rotational motion compensation Joint Time Frequency based applications are found very effective. Thus design of a modeling and simulation platform is an utmost requirement for the system designer for estimation and

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validation of a new design. In this paper design of an integrated simulation platform will be discussed and its effectiveness will be analyzed. The platform is designed in the MATLAB 2013 environment using both the Matlab m-files as well as MATLAB GUI.

II. RELATED WORK

There are many range tracking methods used by the various researchers. Cross-correlation method is one of the effective range tracking methods which calculate the correlation coefficients between the adjacent range profiles and tries to estimate the range walk between the range profiles [10, 11, 12].J.S Cho et al proposed the use of target centroid tracking algorithm which tries to estimate the radial motion of the target centroid point and to compensate in such a way that the range and the Doppler shift of the target centroid are kept constant. Another popular algorithm used by a school of researchers is prominent point scattering. Prominent point scattering algorithm at first selects prominent point on the target. Assuming that the phase components of these dominant point scatterers are known the translational motion error can be mitigated by un-wrapping the higher order phase components of the first prominent point as the second step of the algorithm. Range tracking procedures are capable of aligning all scatterer at their correct range cells but the Doppler frequency shift may still be varying with time in the phase of the received signal. The procedure that makes these Doppler frequency shift constant is called as Doppler tracking. There are many Doppler tracking algorithm proposed by different researchers. B. Haywood and R.J Evans [12, 13] proposed the dominant scatterer algorithm. T. M Colloway and G.W Donohoe proposed sub-aperture approach. Among other Doppler tracking algorithms cross- range centroid tracking algorithm, phase gradient autofocus and multiple PPP are important. Motion of the target which changes the aspect with respect to the radar line of sight (RLOS) is called as target's rotational motion. A small value of rotational motion is required to form range Doppler ISAR image but when the value increases, the Fourier based ISAR image degrades and causes blurring and shearing in the image. In a typical practical scenario the target usually has both the translational and the rotational motion. But the effect of the translational motion is more severe than the rotational motion component. Therefore the translational motion is compensated at first and then the rotational motion is compensated. V.C. Chen et al. suggested the JTF based methods to compensate the ISAR image. JTF based compensation technique has been found to be very effective to compensate the rotational motion. Another popular method to compensate the rotational motion is Prominent Point Processing (PPP).

III. MODELLING AND SIMULATION

Basically modelling is a process of producing a model. Model is a simpler representation of the construction and working of some system of interest. Although a model represents some system but generally it is simpler than the original system. But a model should closely represent the real system and incorporate most of its salient features. A model also should not be so complex that it is impossible to understand and make experiment with it. A good model should be a trade-off between realism and simplicity. A model complexity should be increased iteratively. An important issue in the modeling is the model validity. Model validity includes the experiment of the model with the different input conditions and comparing the output with the expected result. Simulation of a system is the operation of a model of the system. Simulation is basically a tool to evaluate the performance of a system, existing or the proposed under different conditions. Simulation is basically used before an existing system is altered or a new system is built. It is good option to optimize the system performance. This paper deals with the modeling and simulation of motion compensation techniques in Inverse Synthetic Aperture Radar. MATLAB as development platform

MATLAB 2013 has been taken as the software platform in this paper to develop and simulate different target models and to experiment with the motion compensation techniques. MATLAB is definitely a very strong platform in the field of radar signal processing. The GUI developed in this paper is also developed in the MATLAB environment. At the very first stage of the development, independent m-files are created for the motion compensation technique and then the GUI is developed. Respective icons are then linked through different callback programs.

A graphical user interface (GUI) is a graphical display in one or more windows containing controls, called *components* that enable a user to perform interactive tasks. The user of the GUI does not have to create a script or type commands at the command line to accomplish the tasks. Unlike coding programs to accomplish tasks, the user of a GUI need not understand the details of how the tasks are performed. GUI components can include menus, toolbars, push buttons, radio buttons, list boxes, and sliders—just to name a few. GUIs created using MATLAB 2013 tools can also perform any type of computation, read and write data files, communicate with other GUIs, and display data as tables or as plots. Figure 1 describes the basic aspect of design of GUI in the MATLAB environment.

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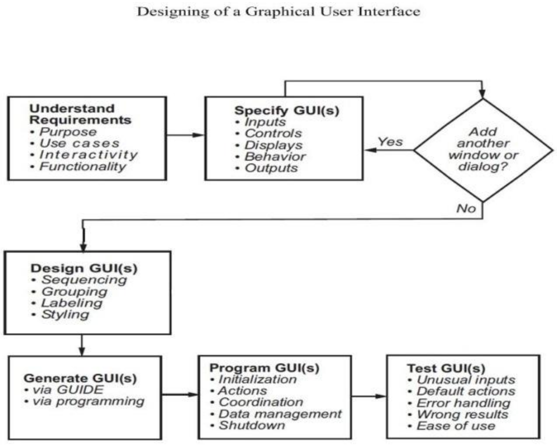

Fig. 1: Design of Graphical User Interface

IV.INVERSE SAR SIMULATION

A pioneer approach has been carried out in this paper to develop a simulation platform in the MATLAB 2013 environment to fetch the effectiveness of the motion compensation algorithms. Basically two different panels are developed in the GUI to simulate the two basic motion compensation techniques. In one panel different target models are developed to find out the efficiency of the translational motion. Three different target models are developed for each of the cross correlation algorithm and the Minimum Entropy Method. These models are then subjected to variable conditions and finally the effectiveness is discussed to recover the target in the presence of the translational motion. The other panel on the right hand side is designed for the JTF based application. For each of the JTF based method two targets are being considered. For the JTF based application Short Time Fourier Transform (STFT), Wigner –Ville Distribution, Pseudo Wigner Ville Distribution (PWVD), Smoothed Wigner Ville Distribution (SWVD), and Continuous Wavelet Transform (CWT) will be considered. A snapshot of the designed simulation environment is shown in figure 2.

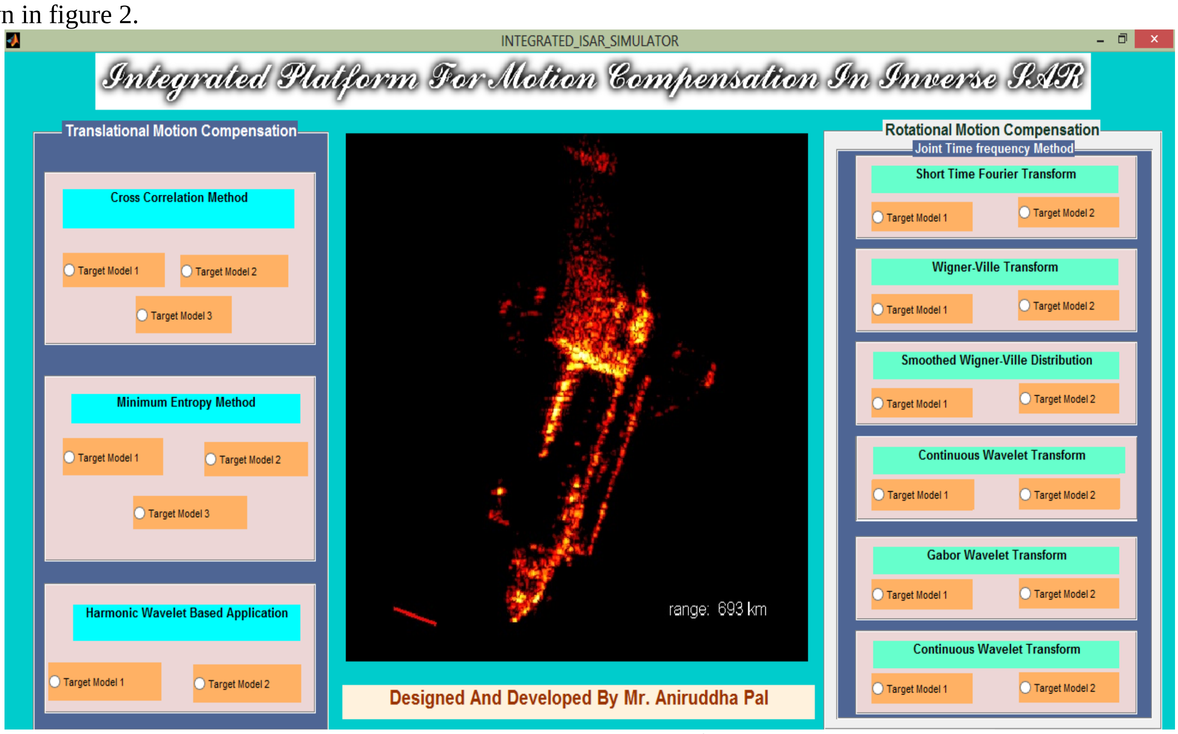

Fig 2: Designed integrated platform

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A. Simulation Of Cross Correlation Method

In the designed Simulation platform three targets are considered for the simulation and validation of the cross correlation method. At first these targets are being generated and then they are subjected to varying degree of translational motion as well as radar parameters. In the designed platform whenever the radio button is pressed the designed target and associated algorithm of motion compensation is executed through a callback program.

1) *Target Model-I*: At the very first instance a target model is designed in which there are point scatterers at the equal distances. For this purpose a square type point scatterer is being considered (refer figure 3). For simulation stepped frequency continuous wave type radar is being considered. When the model1 radio button is pressed the following figures are generated. Figure 4 represents the image of the target when compensation is not applied. As a result the image is blurred as well as distorted. For a non cooperative target this will be very difficult to recognize and identify the target Figure 5 represents the effectiveness of the cross correlation method. The figure significantly describes the fact that translational motion is being compensated and we can also recognize the target.

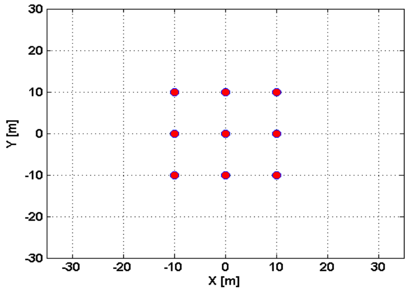

Figure 3: Target model-I

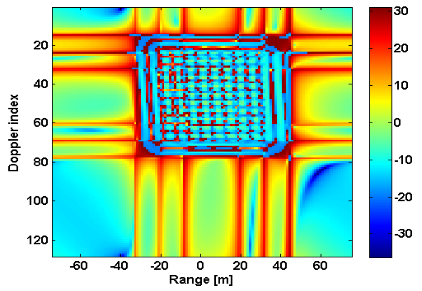

Fig 4: Target image when the compensation is not applied

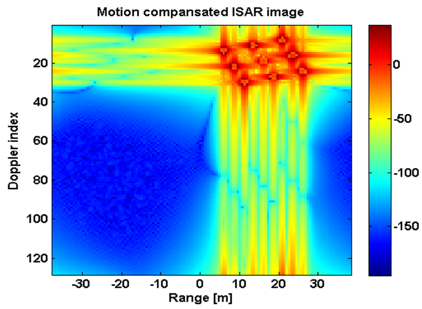

Fig.5: Motion Compensated ISAR image

2) *Model- II:* - In the same way when the model 2 radio button is selected the designed call back is executed and at first instance the target model is generated (ref fig 6). Then another figure is generated which clearly describes the effect of translational motion on the target (refer fig 7). At last the motion compensated ISAR image is generated (refer fig 8). If user wants to vary the condition then it is required to go back to the linked m-file and change the radar or the target parameters.

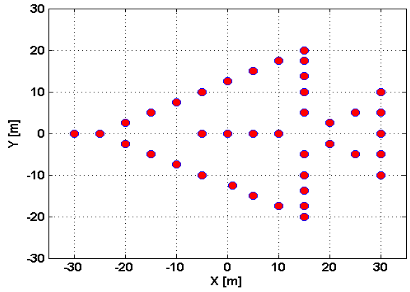

Figure 6:- Target Model-2

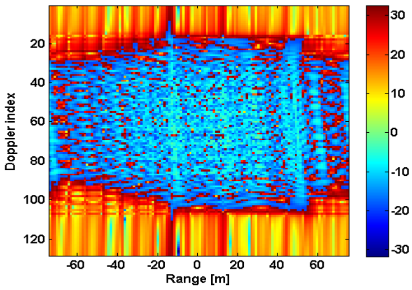

Figure 7: Uncompensated ISAR image

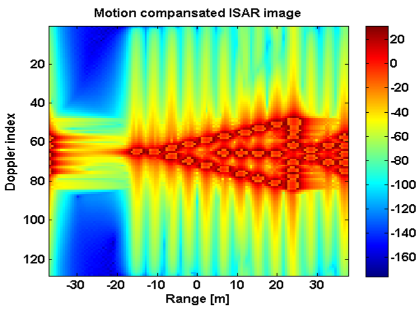

Figure 8:- Motion compensated ISAR image

B. Simulation Of Minimum Entropy Method:-

Minimum Entropy method is another very strong and effective motion compensation technique. In the designed simulation platform three targets are considered and the call back is generated. Again the operating condition and the target parameter can be set in the respective m-files.

1) Model-1:- If the model-1 radio button is pressed at first the target model is generated (figure 9). At the next instance the uncompensated ISAR image will be generated (refer figure 10). At last figure motion compensated ISAR image will be generated (refer figure 11).

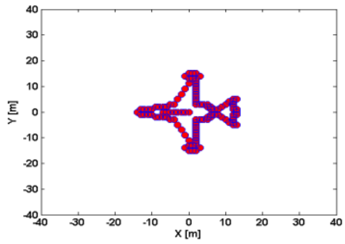

Figure 9: Target model-1

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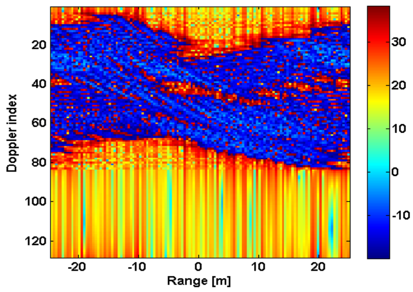

Figure 10:- Uncompensated ISAR image

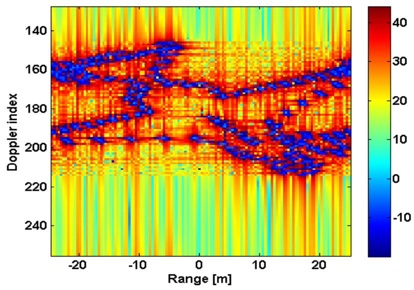

Figure 11: Target recovery after the application of minimum entropy method

In the left hand side panel of the simulator wavelet based application is used. On pressing of the radio button the Harmonic based wavelet theory is applied. The same way target and the radar parameter can be changed in the call back m-file.

C. Joint Time Frequency Based Application

The right hand side panel is designed for the estimation and the motion compensation of the target rotational motion. For the rotational motion compensation Joint Time Frequency Based Applications are considered. Joint Time Frequency (JTF) tools are in use to compensate the motion related problem in the ISAR imaging. JTF tools are also used in the field of radar signature and the target classification. JTF tools like Short Time Fourier Transform (STFT), Wigner Ville Distribution (WVD), Continuous Wavelet Distribution (CWD), Adaptive Wavelet Distribution (AWT), and Gabor Wavelet Transform are extensively used in the field of ISAR imaging.

1) Short Time Fourier Transform:-

Classical Fourier transform is a general expression and cannot establish a point-to-point relationship between time-frequency domains. To overcome this problem, it is easy to apply an inner product which is named as Short-Time Frequency transform (STFT) given by [10]

$$STFT(t,w) = \int s(\tau)\gamma_{t,w} * (\tau) d\tau$$
$$= \int s(\tau)\gamma * (\tau - t) e^{-jw\tau} d\tau$$

Where $\gamma(t)$ is the window function and since there is a short time windowing operation involved this is also called as windowed Fourier transform. Now the following target is considered and the effect of STFT is analysed. The square of the STFT is called as STFT spectrogram and it represents signal's energy distribution in the time Frequency plane. Figure 12 represents the target model taken for consideration in the application of STFT. Figure 13 depicts the effect of translational and rotational motion. Figure 14 depicts the effect of motion compensation technique if STFT is applied.

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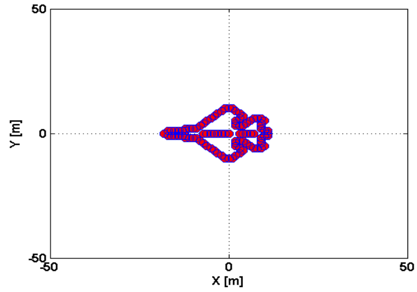

Figure 12: Target model for application of STFT

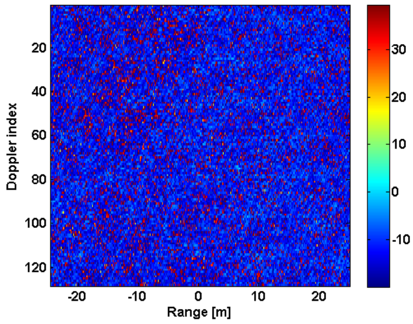

Figure 13: ISAR image due to translational and rotational motion

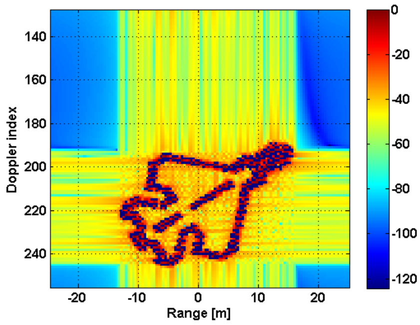

Figure 14: Motion compensated ISAR image

2) Wigner-Ville Distribution: -

This approach is based on the use of time dependent autocorrelation function for calculating the power spectrum. Standard autocorrelation is only a function of time lag τ. The Wigner-Ville uses a time varying autocorrelation function. To choose a suitable autocorrelation function, properties of time-dependent spectrum should be considered. Considering the same target model (figure 12) for wigner-ville distribution the motion compensation can be shown as follows (refer figure 15)

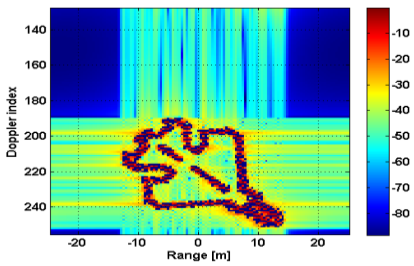

Figure 15: Motion compensation through the Wigner-Ville Distribution

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3) Smoothed Wigner-Ville Distribution:-

This technique is based on the smoothing operation of Wigner-Ville distribution with the purpose of reducing cross-term interference. A feasible method of reduce the cross terms is to use windows in both dimensions of time-frequency plane. Again taking the figure 12 as the model for smoothed Wigner-Ville distribution the compensated ISAR image is as follows (refer figure 16).

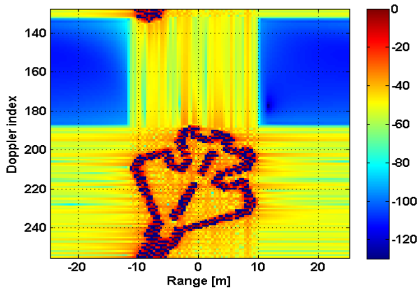

Figure 16: Smoothed Wigner-Ville distribution based motion compensation

4) Pseudo-Wigner-Ville Distribution

Pseudo-Wigner ville distribution (PWVD) is the windowed version of WVD. It is given by

$$PWVD_x(t, f) = \int_{-\infty}^{\infty} h(\tau)x^*(t - \frac{\tau}{2})x(t + \frac{\tau}{2})e^{-j2\pi f\tau}$$

Considering the model as in the figure 13 when pseudo wigner-ville distribution is applied then the resultant ISAR image is as shown in the figure 17.

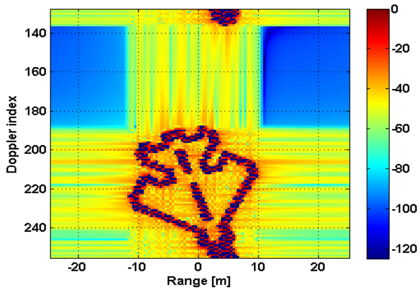

Figure 17: Application of pseudo-Wigner Ville distribution for rotational motion compensation

5) Choi -Williams Distribution

Cohen proposed a simple method to derive different time-frequency distributions which is called as Cohen's class. This method convolves different functions with time-dependent auto-correlation function and creates desired time-frequency distributions. These specific functions are also called as kernel functions of distribution series. For a correct time-frequency distribution interpretation, it must at least satisfy non-negativity and correct marginal properties for time and frequency.

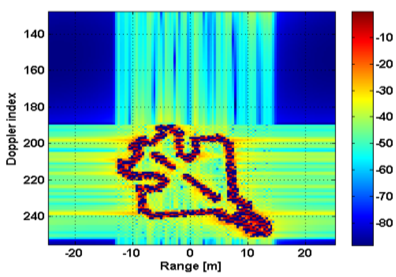

Figure 18: Choi-Williams distribution based motion compensation

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Choi-Williams distribution is a member of Cohen's class. Again considering the model as shown in figure 12 if the Choi-Williams distribution is applied then obtained motion compensated ISAR image is as follows (Refer figure 18).

V. RESULT AND CONCLUSION

Design of an integrated platform for the motion compensation technique is a pioneer approach to facilitate the students and the researchers to design and implement the Inverse SAR motion compensation algorithm. Individual model can be made in accordance with the present scenario design of fighter aircrafts and the same can be simulated, validated and the result can be analysed. In the designed platform some of the motion compensation algorithms are integrated however others can well be designed and added in the future course of time. The designed platform can simulate the cross correlation algorithm, minimum entropy method, JTF based applications which include Short Time Fourier Transform (STFT), Wigner Ville Distribution (WVD), Continuous Wavelet Distribution (CWD), Adaptive Wavelet Distribution (AWT), and Gabor Wavelet Transform and Choi- Williams Distribution. However there is enough opportunity to upgrade the model and to include the newly designed algorithms.

REFERENCES

[1] V.C Chen and H.Ling, "Time frequency transforms of radar imaging and signal processing". Arctech House 2002
[2] Wang ran, jiang yi-cheng, "ISAR ship imaging based on reassigned smoothed pseudo wigner-ville distribution", IEEE (2010),Antenna standards committee of the IEEE Antennas and Propagation Society IEEE standards definition of terms , IEEE Sed 145- 1993, The institute of Electrical and Electronic Engineering.
[3] Inverse Synthetic Aperture Radar Imaging With MATLAB Algorithms book by Ozemir
[4] Xiang Gu, Yunhua Zhang, "Effectiveness and Uniqueness Conditions for 2-D MUSIC Algorithm Used in ISAR Imaging" Synthetic aperture radar, APSAR. 2009, 2nd Asian-Pacific conference on digital object identifier.
[5] A. Karakasiliotis and P. Frangos "Comparison of Several Spectral Estimation Methods for Application to ISAR Imaging", Proceedings of RTO SET 080 Panel Symposiums, Oslo, Norway, pp. 1058–1067, 11-13 Oct. 2004.
[6] Lieu, Z.S., Wu, R., and Li, J. "Complex ISAR imaging of maneuvering targets via the Capon estimator" IEEE Transactions on Signal Processing, (May 1999), 1262—1271.
[7] Radar Handbook by Skolnik
[8] W.Haiqing, D.Grenier, G.Y.Delisle and D.-G Fang. "Translational motion compensation in ISAR image processing". IEEE transactions on image processing.4(11)(1995)1561-1571
[9] V.C Chen and H.Ling. "Time frequency transforms of radar imaging and signal processing". Arctech House 2002
[10] T.Kuchkkilic, ISAR imaging and motion compensation, M.S Thesis, Middle East University 2006.
[11] B.Haywood and R.J Evans, "Motion compensation for ISAR imaging". Proceedings for Australian symposium on signal processing and application, 1989.
[12] B. D Steinberg. "Microwave imaging of the aircraft", Proceedings on of the IEEE 76 (12) (1988)
[13] T. M Colloway and G.W Donohoe. "Sub aperture autofocus for synthetic aperture radar". IEEE transactions on Aerospace and electronic systems AES-30 (1994)
[14] Seung Yong Shin and Noh Hoon Myung, "The Application Of Motion Compensation Of Isar Image For A Moving Target In Radar Target Recognition", Wiley Microwave and optical technology letters / vol. 50, no. 6, June 2008
[15] Li Xi, Liu Guosui and Jinlin Ni "Auto focusing of ISAR Image based on Entropy minimization".
[16] M.J.Prickett, C.C.Chen, "Principles of Inverse Synthetic Aperture Radar (ISAR) Imaging", IEEE EASCON '80 Record, 1980, pp. 340-344.
[17] Marco Martorella, "Introduction to Inverse Synthetic Aperture Radar", Radar 2010 Tutorial Notes.
[18] D.R.Wehner, "High-Resolution Radar". Artech House, 1995.
[19] Lokenath Debnath, "Recent developments in the wigner-ville distribution and time-frequency signal analysis," *PINSA, 68, A, No.1, January 2002, pp. 35-56.*
[20] W. S. Cleveland. "Robust locally weighted regression and smoothing scatter plots". *Journal of the American Statistical Association* 74(368) (1979) 829–836.
[21] Wang ran, jiang yi-cheng, "ISAR ship imaging based on reassigned smoothed pseudo wigner-ville distribution", *IEEE (2010).*
[22] W.G.Carrara, R.S.Goodman, R.M.Majevski, "Spotlight Synthetic Aperture Radar: Signal Processing Algorithms", *Artech House, 1995.*

BIOGRAPHY

Aniruddha Pal received B.Sc degree from University of Burdwan, B.E. degree in electronics and communication engineering from Institute of Engineers (Kolkata), India, in 2008 and M.B.A degree in Marketing Management from Sikkim Manipal University, India in 2010. Presently he is pursuing M.Tech from Nagaji Institute of Technology and Management (NITM), Gwalior, MP, India. He has three research papers in international journal and in national conferences. His research activities are radar signal processing, image processing and pattern recognition.