Literature Survey for EE381K Project

Inverse Synthetic Aperture Radar Imaging

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Abstract

High-resolution radar images can be achieved by employing SAR or ISAR techniques. It can be shown that SAR and ISAR have the same underlying theory but different configuration. Here the specific problem of aircraft ISAR imaging using ground-based radar is addressed.

As motion plays a critical role in ISAR, we study how the motion compensation should be done to focus the echoed data into a 2-D image. Besides the normal motion compensation, which uses the data sets themselves, here GPS aided motion compensation is also studied in detail, which uses GPS motion data of the aircraft as additional input. Comparisons of these two cases help to expose problems of the normal motion compensation and to form a better understanding of ISAR imaging process.

After giving problem definition and objectives of the project, this literature survey mainly summarize the existing work on ISAR imaging, with emphasis on the system model and motion compensation techniques. Then the implementation plans are put forward as the guideline for future work of this project.

Key words: ISAR, motion compensation, GPS data

1. Introduction

High-resolution radar imaging is interdisciplinary and has wide interests among many different areas. In radar remote sensing, synthetic aperture radar images are usually used to map the land of the terrain. In defense industry, inverse synthetic aperture radar imaging of moving objects is an important tool for automatic target recognition. The problem of radar imaging of an aircraft using ISAR is addressed in this project, with emphasis on motion compensation.

Both SAR and ISAR have the same underlying theory, the main difference is the geometry configuration. In SAR imaging, the radar is flying in the space, and the object is stationary, while in ISAR imaging, the object is moving and the radar is stationary. But only the relative movement between the object and the radar is important. So the ISAR imaging problem can be found to be equivalent to the more easily understood SAR imaging problem.

From signal processing viewpoint, radar imaging is a 2-D signal processing problem. To form an image, 2-D resolution must be defined for radar imaging. Here the two dimensional discrimination is realized by compression in range direction and synthetic aperture in the cross range direction. Actually, radar echoes are just 1-D time series, but it is convenient to format this 1-D signal into 2-D signal.

Radar images can be called as motion-induced images. Hence, in SAR and ISAR, motion is the problem and the solution (Carrara et al. 1995). In ISAR, the motion compensation is more challenging as we have no priori knowledge about the object, and in some cases the object like the aircraft can exert complex movement. It can be observed that the normal motion compensation might fail during some time of the flight.

To assess the normal motion compensation, we compared it against the GPS aided compensated images. We expect to get a better image with the GPS motion data as an additional input, we also expect to get a better understanding the ISAR imaging process.

2. Objectives

The objective of this project is to get a better understanding of the ISAR imaging by comparing the GPS aided motion compensation technique with the normal motion compensation technique.

With GPS data as an additional input, the GPS aided motion compensated image should be better, at least not worse than that of the normal compensated image. If this is not the case, a reason should be given regarding to the accuracy of the GPS data.

Also the reasons for the failure of the normal compensation technique might be exposed. And with the GPS truth data, some idea might come out to construct a modified motion compensation algorithm.

3. Review

Radar is important because it can provide all weather, day/night capability to generate a spatial, visual representation of the radar reflectivity of an illuminated scene. Thus it has a wide use from land use survey to automatic target identification.

Imaging radar typically provides a two-dimensional representation of scatters in the illuminated volume. Generally, we speak of radar resolution in the range and cross-range or azimuth directions. Range resolution is inversely proportional to the bandwidth of the transmitted signal. A wide bandwidth can be implemented by employing a frequencymodulated pulse instead of a simple pulse. In conventional real aperture radar, azimuth resolution is large, as it is inversely proportional to the electric size of the physical antenna aperture. A synthetic aperture array technique is used to improve the azimuth resolution. In synthetic aperture radar (SAR), the radar illuminates the object many times as it passes by. Then with subsequent processing, it is equivalent to illuminates the object one time but with the longer synthesized aperture.

Inverse SAR imaging, in its narrowest sense, refers to the use of target motion alone to generate a synthetic aperture for azimuth resolution. In practice, ISAR often includes antenna platform motion. The ISAR application of imaging a maneuvering aircraft is of primary interest in this project. Figure 1(a) illustrates the ISAR concept and geometry. It shows a stationary radar sensor illuminating a passing airborne target. The target's velocity and attitude changes (roll, pitch, and yaw) each contributes to the angular interval over which the radar sensor collects data from the target. Since only the relative motion is important for radar imaging, it is common to model the ISAR data collection and processing by treating it as an equivalent maneuvering SAR illuminating a stationary target. Figure 1(b) illustrates this perspective. Thus ISAR is very similar to a spotlight mode SAR.

Historically, literatures on SAR tended to be inaccessible to researchers outside the radar community. Munson and Visentin 1989 derived the strip-mapping mode SAR imaging equations using a signal processing approach. It is believed that future development in SAR/ISAR benefits from contributions from researchers in signal and image processing.

Soumekh 1992 treated the SAR/ISAR imaging problem as an inverse problem, and after presenting an analytical expression of the source/object interaction, he gave the inversion (imaging) strategy in the wavenumber domain. Such issues like sampling and resolution can be easily addressed.

Borden 1997 examined the limitation of such a point target model and its effect on ISAR image interpretation.

The motion compensation is a very crucial and active research area in ISAR imaging. Different from SAR, the motion of a non-cooperative target is unknown in ISAR imaging.

The target motion can be decomposed to a translational motion and a rotational motion.

In ISAR, the target rotational motion with respect to the radar line of sight contributes to the imaging ability, whereas the translational motion must be compensated out.

Wu et al. 1995 used a two-step approach to translational motion compensation, namely, an adaptive range tracking method for range bin alignment and a recursive multiple-scatter algorithm for signal phase compensation. The phase compensation performs both the motion compensation and automatic focusing.

The estimated aspect change provides the angular positions of the inverse synthetic array elements. In the case where the aspect change rate is varying due to maneuvering, an interpolation of the azimuthal data can be applied to obtain equally spaced samples.

After the compensation for the target translational motion and the estimation of the rotational motion, ISAR imaging simply becomes processing of a circular-arc aperture, which is amendable to the inverse Fourier transform.

Realizing the time-varying behavior of Doppler frequency shifts, Chen and Qian 1998 utilize a joint time-frequency transform to replace the Fourier transform as a means of radar image reconstruction to reduce image blurring. The standard motion compensation is necessary priori to the image reconstruction.

In a more recent paper, Logan et al. 1998 presented an estimation-theoretic approach for reducing motion effects in spotlight SAR imaging. The approach can be viewed as a multi-dimensional matched-filter.

No publication can be found using this GPS aided motion compensation. So this project is both initiative and difficult.

3. Plans

3a) System model

A system model should be developed for ISAR imaging from different prospectives, such as the traditional Doppler view point, the wave equation veiwpoint and the siganl processing view point. The radar signal at different stages of imaging can be described exactly for a point target. Based on the system model, examination and analysis of different phase terms would be given. Then the imaging process would be given in this framework. Issues like sampling and resolution can be expected to be resolved within the system model.

3b) Normal motion compensation

It is used as the reference for GPS aided motion compensation. So access and analysis of the normal motion compensation should be described in a concise manner.

3c) GPS aided motion compensation

First, the GPS data in original form should be transformed into a form suitable for ISAR imaging, there needs well defined coordinates transformation between the GPS data reference system, the aircraft flight system, and the aircraft local system.

Second, the GPS data should be matched into the radar echoes due to the different time reference and the different time interval between the two data sets.

Third, the GPS range data is used to range track in the range direction. The range track in the range domain is equivalent to phase adjustment in the range frequency domain.

And last, the GPS angular data is used to Doppler track in the cross range direction. This is due to the uneven angle intervals between successive radar echoes.

3d) Comparison, analysis, and conclusions

The GPS aided motion compensated ISAR images would be compared against the normal motion compensated images. With additional priori knowledge, ISAR images using the GPS aided motion compensation technique should have better quality. But if it is not the case, possible reasons like inadequate GPS accuracy would be examined.

In cases where the normal compensation technique fails, try the GPS aided motion compensated technique. Does it improve to some degree? This might expose the reasons for failure of the normal motion compensation technique.

If possible, comments on better understanding of the imaging process, a robust motion compensation technique or more realistic interpretation of the resulted images would be given.

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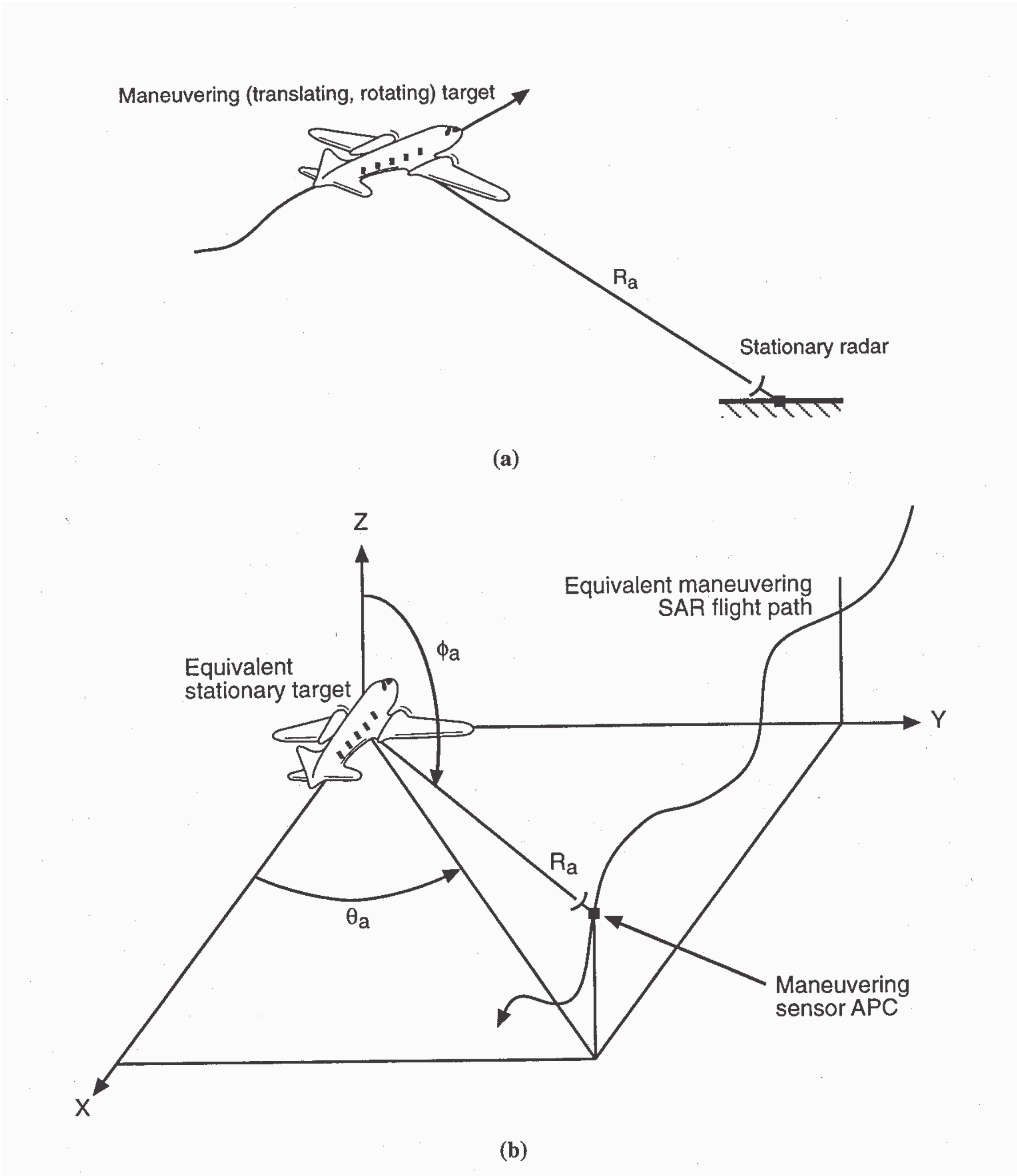

Figure 1. ISAR concept and Geometry perspective: (a) moving target (b) Maneuvering sensor (From Carrra et al. 1995)