COMPARISON OF INTERPOLATION METHODS FOR ISAR IMAGING

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ABSTRACT

The purpose of this thesis is to describe and compare different numerical methods that reconstruct focused ISAR images via interpolation of unevenly spaced samples. Parameters such as amplitude deviation, image entropy, as well as computational efficiency are used to contrast the different approaches presented. A point target model of a navy drone is used to compare these methods. Each method is also tested using experimental stepped-frequency ISAR data. It is shown that the conventional nearest neighbor and Euclidean approximations lead to small amplitude deviations. Linear interpolation also has a good performance in this regard. Likewise, cubic spline interpolation, Shannon reconstruction and weighted integration techniques yield similar results. Thus it is demonstrated that amplitude deviation is an insufficient figure of merit. Next, image entropy is used to determine which methods yield better image focusing. It is shown that the cubic spline interpolation and the Shannon reconstruction methods yield highly focused images devoid of artifacts within a 50 decibel range. In contrast, the approximation methods and linear interpolation yield poorly focused images with pronounced artifacts. As for computational efficiency, it is shown that cubic spline interpolation is second only to linear interpolation but has superior focusing capability.

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CHAPTER 1

INTRODUCTION

1.1 Motivation

Radar systems have been used for many years in different areas of our every day life. Their applications range from civil applications such as air traffic control or satellite-based terrain mapping to military applications for automatic target recognition. In contrast with optical applications where the system senses information without the need of a transmitter, most radar systems are implemented with highly sophisticated subsystems including a transmitter and a receiver with multiple signal processing stages. The transmitter and receiver can be designed in such a way that the data acquisition is maximized for specific applications. The data received requires a certain type of processing to recover information about the observed target. Such processing has to consider the physical attributes and motion parameters of the target, the characteristics of the environment (such as the presence of noise), or limitations on the actual radar system itself. Each of these factors constitute an important design problem

1.2 Goal

This thesis considers the problem of reconstructing ISAR images via sample interpolation when the data samples are collected in the spatial frequency domain as the target rotates. Multiple interpolation algorithms are implemented and their performance is evaluated.

1.3 Thesis organization

This section briefly describes the contents and organization of the chapters that form this thesis. Chapter 2 presents the theory of ISAR imagery and introduces concepts such as synthetic aperture and blurring. The process of polar sampling in ISAR is described and illustrated, and its implications are explained. The last section in this chapter discusses interpolation as a means to focus ISAR imagery.

Chapter 3 describes multiple interpolation methods that can be applied to ISAR imagery. These methods are classified into three different categories, and the differences between each category are clearly described. Approximation methods are introduced as the most basic approach to the problem. One-dimensional methods are then presented and an efficient algorithm is explained and illustrated. Finally, weighted integration techniques and their computationally expensive approaches are described.

Chapter 4 includes results obtained from the application of the seven different algorithms considered within this thesis to blurred data. Results are examined, and an algorithm comparison is made in terms of amplitude deviation, image spreading, computational efficiency and the introduction of artifacts. The image reconstruction algorithms are applied to both real and simulated data. First, the simulation of a point target model is introduced and described. Then, results for both real and simulated targets are presented and numerical comparisons are made; images of the blurred and deblurred targets are included. Finally, the appearance of artifacts is discussed and the importance of oversampling is noted.

Chapter 5 discusses conclusions drawn from the results presented in Chapter 4. An evaluation of the performance of the different methods is given, and recommendations are made. In addition, future research is suggested on interpolation techniques and their application to ISAR imagery.

Appendices are offered for the understanding of the sampling and reconstruction processes. Appendix A presents a proof of the Whittaker-Kotel'nikov-Shannon sampling theorem, which allows for a perfect reconstruction from evenly spaced data. Appendix B includes the listings of the Matlab codes corresponding to the algorithms implemented.

CHAPTER 2

ISAR IMAGING

2.1 Overview of radar systems

One of the most common applications of radar systems consists in the mapping of large regions of terrain from air-borne or space-borne systems. Such systems allow the user to obtain large amounts of information in non-optimal circumstances. Limitations such as nighttime or the presence of clouds can interfere with data collection for optical or thermal-based systems; however, radars are much less sensitive to these limitations.

A typical radar system has several stages, including a transmitter, a receiver, and a signal processor. The transmitter stage must include a modulator that relocates the desired envelope signal around a high-frequency carrier (usually in the order of GHz) before transmission. The receiver must demodulate the received echo to recover the modified envelope (baseband) signal that contains the target information. Figure 2.1 shows a block diagram for a monostatic radar system [1]. Basically, the desired signal for transmission has to be generated at baseband and then modulated to a carrier frequency f_c. This signal must be bandpass filtered to reduce noise, and amplified to satisfy transmission requirements, since the received echo power will be attenuated in the order of R^{-4}, where R is the range between the radar system and the target [2]. A duplexer will separate the signal to be transmitted at the antenna from the signal received. The received signal will be amplified and bandpass filtered before any processing, to reduce

the effects of noise introduced by the system. Finally a detector (such as an envelope detector or a quadrature detector) will attempt to recover some of the baseband. The resulting information can be digitized and stored for further processing.

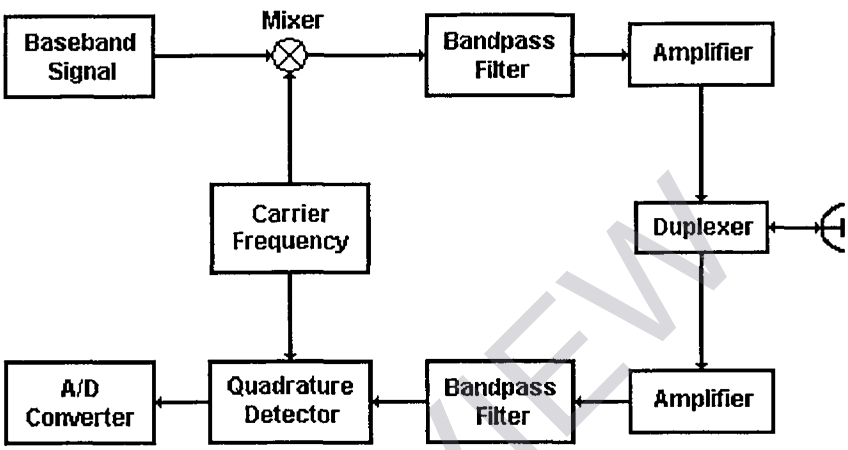

Figure 2.1. Monostatic radar system block diagram.

High resolution radars are capable of resolving small targets at large distances, and discerning the characteristics of different scatterers. This is achieved by processing information over long time intervals. This characteristic is useful in applications where the interest is not only in the actual physical characteristics of the target but also in its movement parameters for the time the radar illuminates the target (as in motion estimation applications).

2.2 Synthetic aperture concepts

Synthetic Aperture Radar (SAR) is one of the most widely used radar systems nowadays. Its applications include terrain mapping, global monitoring, surveillance and planetary imaging. The geometry for SAR mapping is shown in Figure 2.2. In this figure, the *range* is defined as the spatial dimension that runs parallel to the Line of Sight (LOS) of the radar, whereas the *cross range* extends normal to the LOS over the illuminated area.

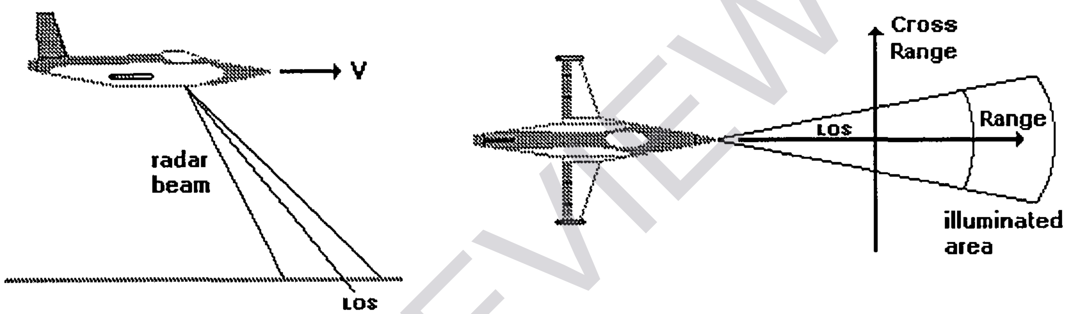

Figure 2.2. SAR geometry.

The selection of the transmitted signal itself constitutes an important problem in designing a radar system. The most basic radars use monotone tone pulses, expecting to receive an echo indicating the presence of a target. Some degree of resolution is achieved by reducing the pulse length to match the size of the expected target. The use of a train (or burst) of monotone pulses stepped in frequency greatly improves the resolution capability of the radar at the expense of added Fourier processing requirements. The range resolution obtained via frequency stepping is given by $\Delta r = c / 2n\Delta_f$, where n is the

number of pulses per burst and Δ_f is the frequency increment per pulse. In contrast, the resolution for a monotone pulse is $\Delta_r = cT / 2$, where T is the pulse duration. Clearly, narrower (thus better) resolutions can be achieved by increasing the bandwidth of the signal. In practice either stepped-frequency or linear FM signals may be used. The selection of one waveform instead of another is hardware dependent; however, both signals follow the same principles and constraints. For the purpose of this thesis, only wideband signals will be considered.

The main objective of modern imaging radars is to obtain two-dimensional images of either stationary or moving targets. Usually the transmitted signals behave as planar waves by the time they reach a target. Therefore two different scattering points located at the same range but at different positions in cross range (azimuth) will contribute simultaneously with some energy to the echo return and the radar will not be able to discern between two small scatterers and a single wide scatterer in cross range. Consequently, it is necessary to provide the radar system with an "aperture" or lateral view of the target. Since the antenna will only receive one-dimensional information every time the radar transmits a pulse, it is necessary to send several of such pulses at different views to obtain information in the cross range direction.

Figure 2.3 illustrates the concept of synthetic aperture. Suppose an airborne radar is illuminating the center of an area with two scatterers located at the same distance normal to the flight path of the plane but at different positions with respect to the center of the illuminated area in the direction parallel to the flight path. If the radar collects

information at three locations as illustrated, some of the range profiles will be different. At positions **a** and **c**, two scatterers will be observed; in contrast, at position **b** it would appear that there is only one scatterer.

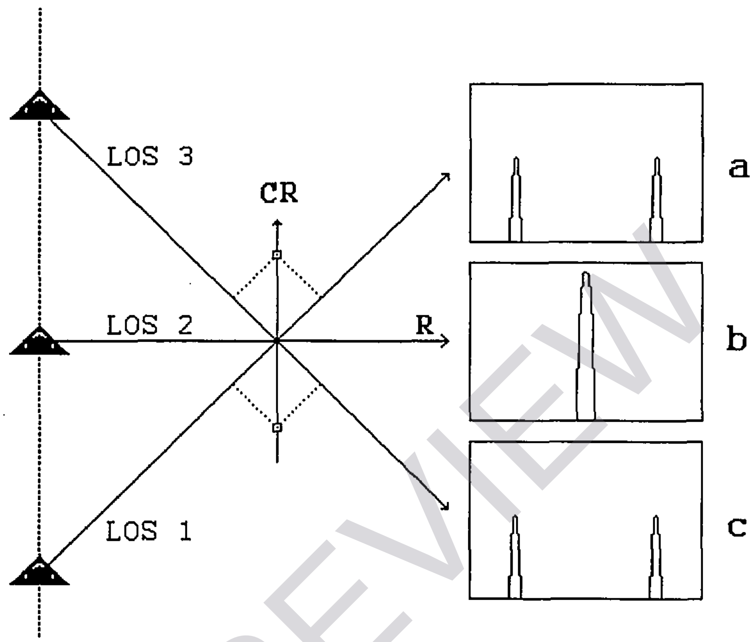

Figure 2.3. Illustration of synthetic aperture.

The discussion above illustrates the need for a radar that synthetically achieves an aperture to resolve scatterers in cross range. SAR achieves such task by extending the collection of data to several bursts of stepped frequency pulses or several chirp pulses. The design of the cross range signal processing stage for either method is very similar, as illustrated in Figure 2.4.