Modern Synthetic Aperture Radar Systems

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Introduction

Synthetic Aperture Radar (SAR) is a side looking airborne radar sensor that provides high-resolution microwave images of selected ground areas. It is an all weather day and night sensor. Additional features include stand-off capabilities (long range) and fast coverage rate. Stationary ground targets are clearly visible upon a SAR image and can also automatically be detected. SAR sensors are used for reconnaissance and remote sensing applications.

A New generation of advanced SAR systems is presented. It features high performance reconnaissance and Zooming SAR modes as well as dedicated modes for display overlay of moving targets upon SAR images. It processes the radar raw data on-board and transmits SAR images via data-link. That on board processing capability greatly reduces the data link bandwidth. Those advanced systems operate upon fighter and transport aircrafts and upon unmanned vehicles (RPV's). A derivative of SAR for airborne fire control radars and for airborne maritime patrol applications is also presented.

Basic SAR Principles

SAR provides two dimensional range-azimuth images (figure 1). A high bandwidth waveform is used to obtain the desired range resolution. A range gated Doppler filtering process is used to obtain the desired azimuth (cross-range) resolution. The transmitted waveform bandwidth is typically few hundred MHz and the required Doppler resolution is few tens of Hz. As an example a 200MHz waveform corresponds to a range resolution of 1 meter. Doppler resolution of 0.1Hz corresponds to 1m azimuth resolution at 100Km range for x-band side looking SAR and at aircraft speed of V_{ac} = 200m/sec. Doppler resolution of 0.1Hz implies a coherent data collection time of $T_s \sim 1/\Delta f_d \sim$ 10sec. The aircraft motion forms a synthetic aperture whose length is $L_s \sim V_{ac} T_s$. To form a proper synthetic antenna, the aircraft deviation from a straight-line path should be measured and compensated for (to within a fraction of the radar wavelength). That motion compensation procedure is enabled thought the use of on-board motion sensing devices. Additional compensation is obtained through the use of auto-focusing techniques [1].

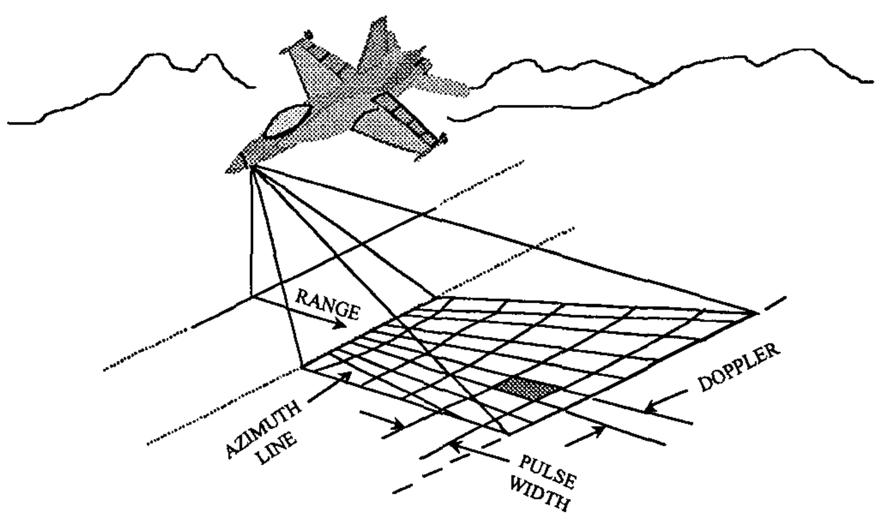

Figure 1. Basic SAR Imaging Geometry

Major System Components

A reconnaissance SAR system contains an airborne section and a ground station. The airborne section (figure 2) produces SAR images as well as coordinates of detected moving ground vehicles. That information is transmitted via data link to a ground station for intelligence assessment. In Modern airborne radars a single programmable waveform generator (based on DDS microwave components) is used to generate all the required radar waveforms. A programmable signal processor (PSP) performs the various real time processing schemes associated with the different radar modes of operations.

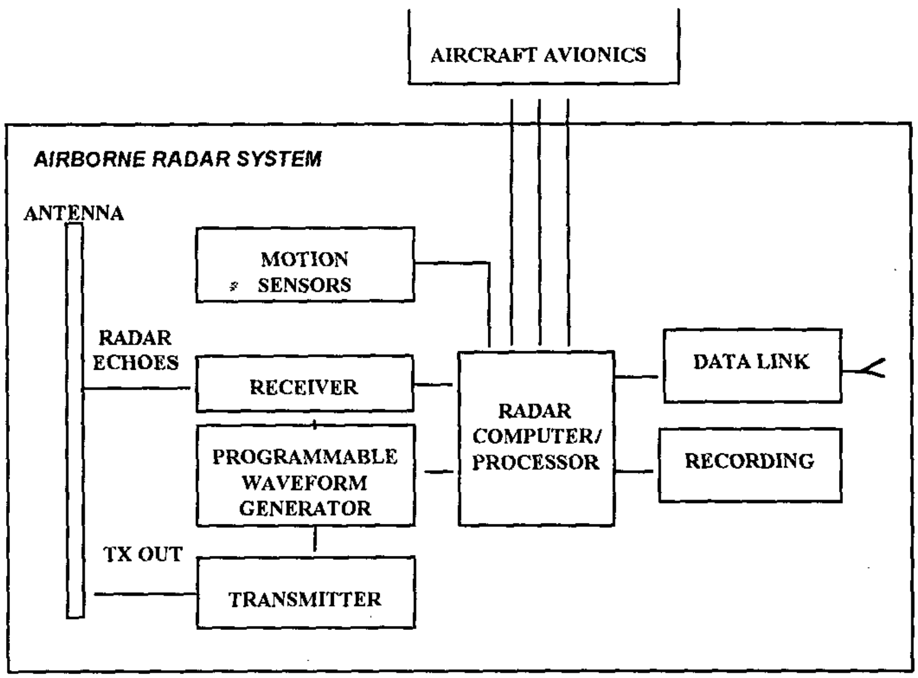

Figure 2. Airborne Section of a SAR Reconnaissance System

Basic Operational Modes

The basic operational modes for a SAR system include strip mapping for wide area coverage, Spot mapping which concentrates on smaller size designated areas (region of interests). A concurrent MTI mode display overlay moving target detections (as synthetic symbols) upon a SAR image. Additional modes include surveillance MTI (using a scanned antenna) as well as high-resolution SAR zooming modes. Each operational mode performs a different task and uses a different radar waveform (different range resolution requires a different waveform bandwidth). The various modes also requires different processing schemes and display configurations.

Type of SAR Systems

SAR systems operate in strategic and tactical manners. Strategic SAR systems perform reconnaissance over wide areas. The SAR images are transmitted to a ground station for intelligence exploitation. In tactical systems SAR is implemented as an additional air to ground mode upon a multi-mode fire control airborne radar. It produces SAR images over smaller areas. Those images are displayed to the pilot and constitute an important building block for the aircraft all weather capability. In maritime patrol applications inverse synthetic aperture (ISAR) is used for target classification [2]. In ISAR the synthetic aperture is formed inversely by target angular motion.

Related Theories

SAR is related to different theoretical fields. It can be viewed as a time shared phase array antenna and is therefore related to antenna array theory. Is is also related to basic radar signal processing schemes including the concept of range-Doppler processing and matched filtering (the image is the outcome of a two-dimensional matched filtering process). Along the synthetic aperture the imaged area is viewed from different aspect angles. The radar return at each pulse corresponds to the projection of the two-dimensional image over a line connecting the radar current position with the scene center. SAR processing produces a 2 two-dimensional image from set of projections. In that sense, SAR is related to back-projection and other tomographic algorithms. The SAR map is in essence the radar amplitude cross-section distribution $A(x,y)$ over the imaged area. The radar returns along the synthetic aperture constitute a two-dimensional received signal. A deterministic processed version of that signal is a two-dimensional spatial spectrum of $A(x,y)$ [3]. In that sense SAR processing can be viewed as a two-dimensional spectral estimation process and is related to the field of spectral estimation theory.

SAR Image Example

The example of figure (3) is a single look SAR image of the Golan Heights. The image is a portion of a strip map and was performed on-board, real time.

Figure 3. SAR Image Example

References

[1] R. Levy-Nathansohn and E. Yadin, "Performanc Evaluation of a Minimum ISLR SAR Auto-focusing Algorithm. The Third European Conference on SAR (EUSAR-2000), Munich, Germany, May 20000

[2] D. R. Wehner, "High Resolution Radar", Artech House, Norwood, MA., 1995

[3] W. G. Carrara, R. S. Goodman and R. M. Majewski, "Spotlight Synthetic Aperture Radar", Artech House, Norwood, MA., 1995