High resolution SAR imaging along circular trajectories

Hubert M.J. Cantalloube, Élise Colin-Koeniguer, Hélène Oriot
Département Électro-Magnétisme et Radar
Office National d'Études et Recherche Aérospatiales
Palaiseau, France
Hubert.Cantalloube@onera.fr

**Abstract**—After a first series of full circle SAR acquisitions in L and P-bands during a 2004 joint FOI-ONERA campaign in Sweden, ONERA experimented in 2006 high resolution (15cm) polarimetric, full circle acquisitions in France and Germany using its X-band sensor. In order to cope with narrower antenna pattern and aircraft attitude fluctuations, a steerable antenna was used. Furthermore, an experimental setup for retrieving high accuracy trajectory was installed. This paper describes the processing of this signals.

**Keywords**—component; SAR image synthesis; autofocus; motion-compensation

I. INTRODUCTION

The French Aerospace Labs (ONERA) performed a few full circle SAR acquisitions during the 2004 joint FOI-ONERA LORRAM campaign in Sweden (after a partial circle acquisition test in the South of France earlier in the year).

This campaign allowed to experiment processing of such images [1] at P and L bands.

The processing options, namely flash-light SAR image geometry as introduced in [2] or tomographic-like polar format processing similar to that used in ISAR have been tested, and the weakness of the trajectory determination system (differential GPS hybridized strap-down inertial navigation unit) along such trajectories have been revealed. This weakness is caused by improper dynamical behavior of inertial units during long turning conditions and the loss of low elevation GPS satellite reception due to the high banking angle.

Due to the absence of strong point-like reflectors on the ground in the Northern forest area where the experiment was conducted, the phase-gradient (PGA)-like autofocus technique [3] used for very high resolution imaging could not be used for retrieving an accurate trajectory.

Furthermore, the P and L band antennae used for these test-flights are not steerable and (especially at L band the antenna pattern of which in narrower) this induced poor illumination of the circle center during trajectory corrective maneuvers.

In 2006, a new series of circular acquisitions was undergone on the RAMSES calibration test-pattern area and two industrial/airport areas in France and Germany.

The weakness of the 2004 acquisition campaign were taken into account:

- The trajectory measurement system was upgraded and an head-down display help for the pilots allowed a better fitting of the real trajectory to the circle with corrective maneuvers of less amplitude.

- The real-time trajectory hybridizing and the use of smaller X-band antennae allowed antenna steering to a coordinate-designated area (the circle center) thus maintaining proper illumination during the whole circle even though the X-band antenna pattern is much narrower than P and L-band ones.

- An appropriate set-up of corner reflector (18 on three 10m wide circles drawing an equilateral triangle around the circle center) as well as some tested devices (top-hat reflectors, transponder) allowed an accurate trajectory reconstruction (by phase-following and triangulation) and thus both focusing and asserting performance levels of different independent autofocus/trajectory hybridizing/smoothing algorithms.

One drawback of using X-band antennae (besides the 20 times increased requirement on trajectory accuracy) is that foliage/ground penetration effects are no more significant. However, due to the 3D aspect of the area (buildings) and the higher resolution (also a 20x increase), the tridimensional aspect of the circular SAR imaging can still be addressed.

X-band system was used in high resolution (0.1 m) and in full polar (0.15 m resolution) modes and a set of incident angle (depression from 60° down to 10°).

II. EXPERIMENTAL SETUP

The experimental setup contained two independent features: First a polarimetric and radiometric calibration set composed of a few triangular faceted corner reflectors (of edge size 0.4, 0.47 and 0.7 m) and two dihedral reflectors (1x0.63 m facets)
tilted by 22.5°. All these calibrators where aligned and oriented for simultaneous acquisition.

The second set, designed for trajectory accurate reconstruction consisted of three groups of six corner reflectors (0.67 m edged, triangular facets). The groups were spaced each other of 500-600m approximatively around the area of interest (center of the acquisition circle). Within each group, the corner reflectors were positioned on a circle of 10 m diameter each covering 60° of the 360° horizon line.

III. REFERENCE TRAJECTORY RECOVERY

The process starts from the dGPS-hybridized inertial trajectory (either the real-time or the post-processed one) on which the time varying lever-arm from the inertial unit to the antenna center of phase is applied (the time variations due to the antenna steering are recorded during the acquisition by the steering mechanism control computer). First, in order to measure precise nearrange gate distances (for each polarisation), we computed two flashlook images as the one in Fig. 1 taken at 180° distance along the circle.

Flashlook images are images obtained from a fixed integration interval and of which the azimuth (cross-range) axis correspond to the squint angle values covering the antenna pattern staying within the Doppler ambiguous range. Unlike the classical stripmap (pushbroom) images where the squint angle is constant and the integration interval varies along the azimuth (cross-range) axis. Of course, stripmap images are not relevant for imaging toward the center of the trajectory circle. Due to their wide Doppler range, flashlook images are more efficiently computed using fast (or semi-fast) factorized back-projection algorithms [4]. There exist frequency domain image synthesis techniques for circular SAR [5] using the full circular aperture, but they are designed for imaging of a human body “surface” (i.e. mapped on a vertical cylindrical surface) from a short range radar rotating below the floor (for airport safety applications). Compared to ours, this application is characterized by “small” data and “perfect” antenna positioning.

Knowing the altitude and the ground distance (10 m) between opposite trajectographic corner reflectors we can derive an accurate nearrange distance for say the horizontal polarisation with an accuracy in the range of that of the dGPS-inertial trajectory (around 10 cm, yielding a delay calibration in the ns range).

The other polarimetric channels are matched using corner reflectors echoes (for co-polar channels) or 22.5° dihedral calibrators (for all channels).

Next, narrow Doppler filtered range profiles are computed (for a rate much lower than the initial pulse repeat frequency PRF) for the 18 positions of each of the trajectographic corner reflectors. Fig. 2 illustrates the visual aspect of these range profile along time.

In order to save computation, we only computed the profiles for one (out of three) frequency agile steps of our waveform. It

---

Thanks for the French MoD directorate for armament (DGA) funding and for ETAS ground vehicle test-range, Anger, France for the ground setup and miscellaneous targets deployment.
degraded the range resolution by a factor of three (down to 45cm) but only the phase was needed for our purpose.

Figure 3. PFA computed images from the range profiles of one the 3 sets in fig. 2 before (left) and after (right) nearrange calibration. each image is the imaging-direction-color-coded superposition of 12 looks separated by 30°.

The phase tracking of the corner reflectors yields high accuracy measurement of the range or velocity to each of the three sets, hence an accurate 3D trajectory evaluation through an appropriate filtering technique. We used here either probabilistic phase gradient fitting or deterministic triangulation, because these algorithms are fast and accurate in absence of “false” fixed echoes (of course we knew our setup calibrator positions).

It worth noting that the prior nearrange calibration is important, because, if there is a nearrange error such as the one in the top row of fig. 1 (around 6m), it is not possible to separate the individual corner reflectors echoes in Doppler because their separation across range is not sufficient. Fig. 3 shows images obtained with the polar format algorithm of [2] from one of the three profiles before and after nearrange adjustment (looking direction is color coded). Note also that our setup was not optimal: pointing the main lobe of the corner reflectors tangentially to the circle instead of radially would have separated the dimming and raising reflectors in range instead of in Doppler. And Doppler separation is much more problematic than range separation: dGPS-inertial trajectory is accurate to about 10 cm, hence a 5 m separation provides an excellent isolation. But a 10 cm/s fluctuation on velocity causes 80 cm smearing if tangential and a 6 m cross-range position aberration if radial.

IV. POLARIMETRIC/RADIOMETRIC CALIBRATION

Polarimetric and radiometric calibration is performed by the Sarabandi technique (our SAR system use pulse-to-pulse switched polarisation transmit and simultaneous bi-polar receive). First the level and relative phases are measured on accurately oriented corner reflectors for the co-polar channels. The theoretical RCS for the calibrator is computed by integrating the geometrical (or physic) optic modeling of the corner reflector backscatter pattern, weighted by the antenna pattern and propagation along the trajectory stretch on which
the SAR image of the calibrator was synthesized. Of course, calibrator backscatter takes into account the sensor position relative to the calibrator axes, and the antenna pattern takes into account the aircraft attitude and the antenna steering position (provided by encoders on the antenna gimbals). Absolute radiometric calibration is derived from it for co-polar channels, and the phase shift with respect to the reference (e.g. horizontal polarisation) channel is measured.

Next, the relative amplitude levels and phase difference are measured on wide rough areas (forest) for the cross-polar channels. Assuming the rough areas are reciprocal (which they are on average) we can derive attenuation coefficients and phase shifts for cross-polar channels with respect to the reference. Phase shifts, however, are known up to $\pi$ Rd and a 22.5° tilted dihedral is used to determine which of the two value is correct.

We have a geometrical/physical optic model of the dihedral calibrators, but calibration using it instead of the measure on (assumed) reciprocal area proved excessively sensitive to calibrator orientation.

V. RESULTS

Resulting image focusing is assessed from the response of a corner reflector in the SAR image of which the integration interval is centered in the calibrator back scattering pattern main lobe. Figure 8 shows the response of the widest (0.7 m edged) corner reflector.

![Figure 7. polarimetric image of the rightmost car on fig. 6. Color coding is Red=cross-polar, Green=horizontal-polar and Blue=vertical-polar.](image)

![Figure 8. Image quality assessment from a 0.7 m edged corner reflector echo, before (top) and after (bottom) trajectory reconstitution from the three 6-corner reflector sets. The 0.7 m corner reflector—is at 250 m and 500 m distance from the trajectory recovery setup.](image)

REFERENCES


