ADVANCES AND PROSPECTS IN SAR MISSIONS AND INSTRUMENTS

Steffen Suchandt, Michael Eineder, Nico Adam and Jürgen Holzner

German Aerospace Center, Remote Sensing Technology Institute, D-82234 Wessling, Germany

ABSTRACT

Current and future interferometric SAR satellite missions are faced with different strong requirements: precise orbit measurement, a large amount of data to be acquired and operationally processed and a high accuracy of the final products. The article gives an exemplary overview about experiences with the Shuttle Radar Topography Mission (SRTM) as one of the most advanced SAR missions. We focus on calibration and interferometric processing and address different aspects such as error influences, algorithms and computational environment.

1. INTRODUCTION

The SRTM project has two main objectives: firstly, to develop the technology of a space borne single pass radar interferometer and secondly, to process the acquired radar data to a precise and homogeneous Digital Elevation Model (DEM). The mission was successfully flown in February 2000 with two radar interferometers on board of the space shuttle Endeavour: the American SIR-C and the German/Italian X-SAR [1]. Here we concentrate on X-SAR mission and data.

2. RADAR INSTRUMENT

The SRTM instrument is shown in Fig.1. The transmit/receive antennas, that send radar pulses towards the earth and receive the echoes thereof were mounted in the cargo bay of the shuttle. They provided the primary channel SAR images. For single pass interferometry the echoes from the illuminated ground area must be simultaneously recorded from a slightly different position than that of the primary antenna. For that purpose a deployable 60 m long mast with receive-only-antennas on its tip extended from the cargo bay. The mast formed the mechanical baseline of the interferometer. For the mapping, the shuttle flew in a tail forward attitude and 59 degrees rolled off from bay down. This way the baseline was placed to its desired tilt angle of 45° against the local nadir. The interferometric phase that is measured by the instrument is given by:

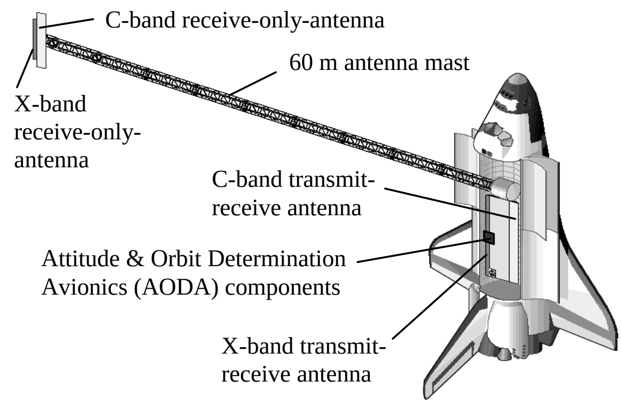

Fig. 1: SRTM interferometer configuration

$$f = \frac{2p}{l}\left(r_2 - r_1\right) \qquad (1)$$

with r_1, r_2, the distances of the primary/secondary antenna to the target and λ, the wavelength (3.1cm). In radar interferometry the exact knowledge especially of the baseline length and attitude is essential to obtain high quality DEMs. For precise measurements of these parameters, an *Attitude and Orbit Determination Avionics* (AODA) unit was used which combined several instruments [2]. Among these were an *Electronic Distance Meter* measuring the distance between primary and secondary antenna, i.e. the baseline length. With a *Target Tracker* the position of the outboard antenna within the shuttle's coordinate system was recorded. A *Star Tracker* and an *Inertial Reference Unit* were used to measure slow and fast variations of the shuttle attitude. Tab.1 lists the achieved geometry measurement accuracies.

Measured Parameter	Accuracy
baseline length	< 1mm
baseline roll angle	< 0.001° (~ 1mm at mast tip)
orbit position	< 1m

Tab. 1: Accuracy of measured geometry parameters

3. ERROR CONTRIBUTIONS AND CALIBRATION

The different sources of error that have to be considered in SRTM are summarized in Fig. 2. Many of them will also hold for other interferometric SAR instruments / missions. Since radiometric calibration is not essential for interferometry and DEMs, it is not discussed here. In the following, calibration is sketched for some of the errors.

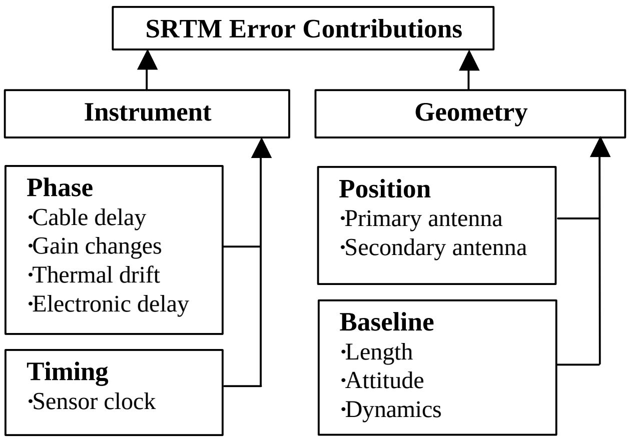

Fig. 2: Error contributions for SRTM

Phase variations due to cable delay and gain changes

The phase of the signal is the most important measure in radar interferometry, hence much attention must be paid to all instrument parts, that may disturb it. In SRTM, the mast cables caused phase variations of up to 2º due to thermal changes of 40 K. Frequency conversions for demodulation increased this phase error up to 144º, which corresponds to a height error of 72 m. The phase variations were monitored by tracking the phase of two calibration loops. Phase jumps due to receiver gain changes were measured the same way, but they proved to be negligible. For more information please refer to [3].

Electronic range delay

The electronic range delay of the radar instrument causes a systematic and constant error in the range coordinate at which objects appear in the radar image. It was determined using corner reflectors (CR). From the precisely known geographical coordinates of the CR, their nominal image pixel position could be predicted and compared to where they appeared in the image.

Timing

The radar instrument clock tended to drift away from the GPS based reference time. In order to fulfill the required pixel location accuracy, a time correlation pair was recorded each second. Fig. 3 shows the relationship between instrument time drift and reference time for one SRTM data take.

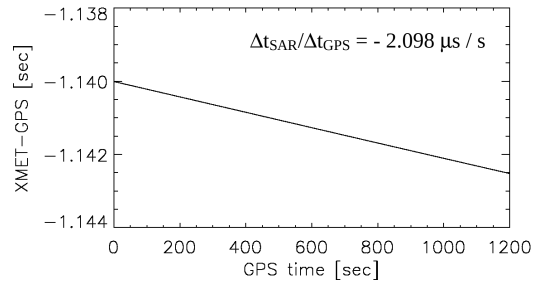

Fig. 3: Radar time drift vs. GPS time for one data take

Baseline attitude and dynamics

The exact measurement of the baseline attitude and the compensation of motion effects play a key role in using radar interferometry to create DEMs. The SRTM baseline was measured precisely, but its dynamics proved to be problematic. Thruster firings to correct the shuttle and baseline attitude caused the mast to oscillate at different frequencies and decay rates. The oscillations lead to a time varying velocity component of the secondary antenna in the line of sight. This causes an azimuth shift of the SAR impulse response function, i.e. the primary and secondary SAR image are mutually shifted by:

$$\Delta az_{motion} = \left(\frac{v_{los}}{2v_s^2} R\right) prf \qquad \text{[pixel]} \qquad (2)$$

with v_{los}, v_s, R and prf, the line-of-sight velocity, platform velocity, range and pulse repetition frequency (1674 Hz). Not only that, according to [4], this increases the phase noise, it also causes a systematic phase error, since a linear phase function with a gradient proportional to the prf and to the Doppler frequency f_{DC} runs through every point target [5]. Without a proper compensation of this motion phase term, interferograms could not be used to create high precision DEMs.

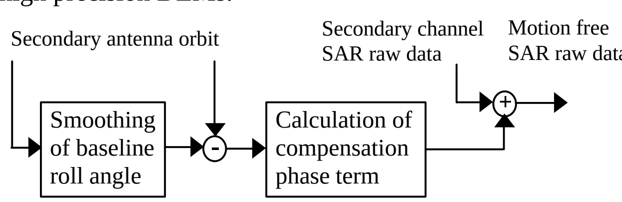

Fig. 4: The motion compensation concept for SRTM

Fig. 4 shows the SRTM motion compensation concept. The orbit of the secondary antenna is smoothed by filtering the baseline roll angle with a Gaussian filter (σ=20s, length=60s). Then, the phase term corresponding to the difference of both trajectories in the line of sight is computed and added to the SAR raw data of the second channel [6]. This way the problematic high frequency part of the motion phase term and azimuth shift is removed. The remaining part is handled later by co-registration.

4. INTERFEROMETRIC SAR PROCESSING

Interferometric processing combines the primary and secondary focused SAR image, to exploit their phase difference as a third coordinate (beside position along flight path and range). This way objects of the same range distance can be separated [7]. Fig. 5 shows the main components of the SRTM InSAR processor.

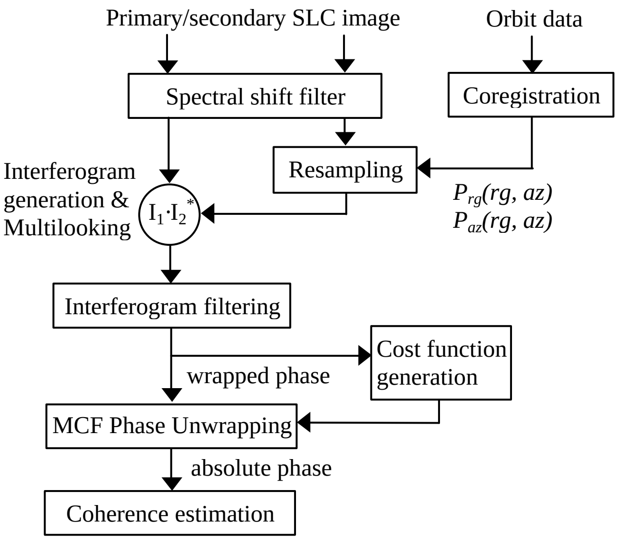

Fig. 5: Block chart of the SRTM InSAR processor

The inputs are the focused single look complex images (SLC) from the SAR processor. Spectral shift filtering is applied to keep only the common spectral components and to enhance SNR. The secondary image is resampled to the primary image geometry using resampling polynomials (P_{rg}, P_{az}). They are obtained by co-registration and express the mutual shift of both images at given image coordinates. The interferogram is formed by conjugate complex multiplication of primary and secondary image. In multilooking, noise is decreased by coherent pixel averaging and the phase image is subsampled. For further noise reduction, the interferogram is filtered. The interferometric phase, which is only known modulo 2π , is unwrapped then to obtain its absolute value. This is one of the most difficult tasks for which a Minimum Cost Flow (MCF) algorithm [8] is used. Finally the coherence, i.e. the magnitude of the complex cross correlation between primary and secondary image is estimated. Since coherence is a measure of the phase noise, it is used to estimate the height error.

Co-registration

Usually co-registration is done by maximizing the cross correlation between primary/secondary SAR image. The disadvantage thereof is, that the shift vector estimates may not be accurate enough when coherence is low. If the available orbits are precise enough, a data independent approach can be used, that derives the image shift vectors from the orbit data. The static range/azimuth shifts are calculated with zero Doppler iteration and geolocation. The residual dynamic azimuth shift due to antenna motion is obtained using (2). Fig. 6 shows the azimuth shift vectors of a SRTM ocean data take. While the shift estimates from cross correlation are very noisy, those from geometry co-registration are continuous and smooth.

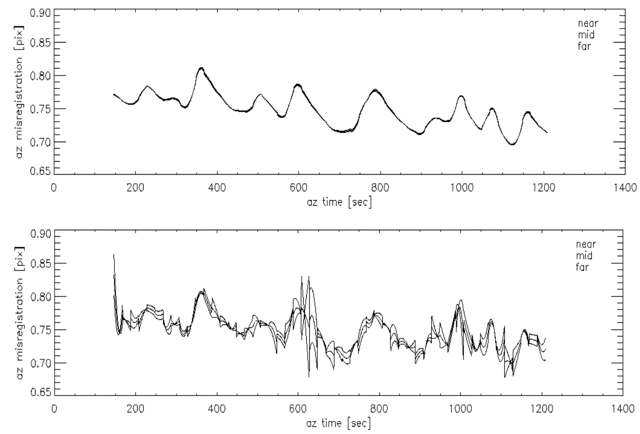

Fig. 6: Comparison of azimuth shift for geometric (top) and cross correlation co-registration (bottom)

Interferogram Filtering

For a sufficient reduction of the phase noise and thus of the DEM height error filtering is required. Here, a Gaussian filter of 2 x 2 pixel is applied for smoothing. Filtering is carried out on the normalized complex interferograms. The chosen filter is a good compromise between DEM quality, spatial resolution and computational requirements. Fig. 7 shows a comparison between (wrapped) DEMs of unfiltered and filtered data.

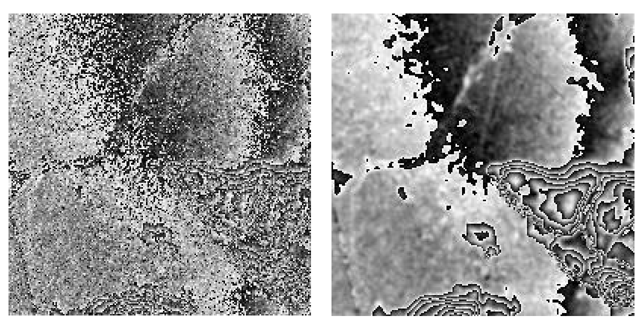

Fig. 7: Example of DEMs (wrapped) from an unfiltered (left) and a filtered interferogram (right).

5. DATA PROCESSING ENVIRONMENT

With high resolution SAR missions, the amount of acquired data increases significantly. In SRTM 3.6 TBytes of raw data were recorded. This will lead to additional 18 TBytes of interim and final image products and DEMs. In the following, we describe for SRTM, how such a huge amount of data is handled operationally.

All X-SAR data products are stored in a large scale robot archive which is used for remote sensing data of different missions. The archive hardware is supplemented by a software catalogue system, the *Product Library*, which provides inventory and versioning functionality. The versioning capability is very important for calibration purposes and for re-processing of the data with improved algorithms or orbit data. The operational processing of large amounts of SAR data requires a high degree of automation. In SRTM, the processing chain has four subsystems: tape scanning, data screening, SAR/InSAR processing and geocoding/ mosaicking. The invocation of the subsystems must be scheduled and timed and the needed input data as well as the computational resources must be provided. Therefore, a *Data Information and Management System* (DIMS) [9] is used, that is based on JAVA and CORBA technology. Although all data takes are divided to smaller interferometric data sets (IFDS), that cover a ground area of 50 x 170 km, the computational requirements are fairly high. The focused SLC images have a size of about 3000 x 40000 pixel, still being 3000 x 10000 pixel after InSAR processing. To achieve a tolerable processing time, about 90 % percent of the signal processing software had to be designed multithreaded. On a 12 x 250 MHz processor machine SAR and InSAR processing of one IFDS takes 30 minutes to several hours. The time depends strongly on the topography since phase unwrapping takes only a few minutes in moderate terrain but may be very slow in mountainous areas.

6. SUMMARY

The paper exemplary shows the data processing aspects of advanced interferometric SAR missions. Much of the experience of SRTM can be used for future SAR systems. Advanced radar interferometry missions and systems allow the production of homogenous digital elevation models of high precision and on a global scale.

7. REFERENCES

[1] Werner, M., “Shuttle Radar Topography Mission (SRTM) Mission Overview”, *Proceedings of EUSAR 2000*, VDE, Munich, Germany, pp. 209-212, 23-25 May 2000.

[2] Duran, R., Wong, E., Breckenridge, B., Shaffer, S., Duncan, C., Tubbs, E. and Salomon, P., “Metrology, attitude, and orbit determination for spaceborne interferometric synthetic aperture radar”, *Proceedings of SPIE AeroSense Conference on Acquisition, Tracking and Pointing XII*, April 1998.

[3] Werner, M., Haeusler, M., “X-SAR/SRTM Instrument Phase Error Calibration”, *Proceedings of IGARSS 2001*, Sydney, Australia, 2001.

[4] Just, D., Bamler, R., “Phase statistics of interferograms with applications to synthetic aperture radar”, *Applied Optics*, vol. 33, no. 20, pp. 4361-4368, 1994.

[5] Holzner, J., Suchandt, S., Eineder, M., Breit, H., Adam, N., “Co-registration – Geometrical Analysis and Verification for SAR Interferometry Under SRTM Data Conditions”, *Proceedings of IGARSS 2001*, Sydney, Australia, 2001.

[6] Adam, N., Eineder, M., Breit, H., “SRTM X-SAR Motion Compensation: Concept and First Assessment of the Interferometric Observation Geometry”, *Proceedings of IGARSS 2001*, Sydney, Australia, 2001.

[7] Bamler, R., Hartl, P., “Synthetic Aperture Radar Interferometry”, *Inverse Problems*, Issue 14, pp. R1-R54, 1998.

[8] Costantini, M., “A Novel Phase Unwrapping Method Based on Network Programming”, *IEEE Transactions on Geoscience and Remote Sensing*, vol. 36, pp. 813-821, 1998.

[9] Mikusch, E., Diedrich, E., Göhmann, M., Kiemle, S., Reck, C., Reißig, R., Schmidt, K., Wildegger, W., Wolfmüller, M., “Data Information and Management System for the Production, Archiving and Distribution of Earth Observation Products”, *Proceedings of DASIA 2000*, pp. 401-406, Montreal, Canada, 2000.