Improving TanDEM-X DEMs by Non-local InSAR Filtering

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Abstract

The standard TanDEM-X product meets HRTI-3 DEM specification and comes with a sample spacing of 12 m. In this paper we apply non-local means (NL) interferogram filtering to the TanDEM-X data. Our version of the NL filter is a modification of the original formulation and provides better noise reduction. Based on simulations, phase noise reduction, coherence estimation accuracy and spatial resolution of our NL filter are compared to conventional filters. Finally, the first TanDEM-X DEM with 6m resolution and low noise level is presented.

1 Introduction

The major mission goal of TanDEM-X is the generation of a global digital elevation model (DEM) of global high quality (12 m posting) close to HRTI-3 standard [1]. For selected areas also 6 m DEMs, also referred to as FDEMs, similar to HRTI-4 standard will be produced. This requires however additional interferometric acquisitions with higher baselines. Table 1 lists the quality parameters of these two DEM standards.

	posting	absolute (90%)	relative (90%)
HRTI-3	12 m×12 m	10 m	2 m
HRTI-4	6 m×6 m	5 m	0.8 m

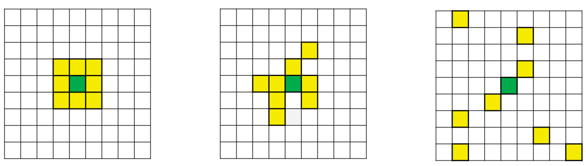
Table 1: Grid size and accuracies of HRTI-3 and -4 DEMs

InSAR processing of all TanDEM-X data is performed by DLR's ITP ("Integrated TanDEM-X Processor") [2] [3]. Since the data volume and processing load of the TanDEM-X ground segment is enormous, fast processing algorithms had been preferred in the development of the systems. In particular, the interferometric phase noise reduction required to meet the TanDEM-X requirements is performed by a conventional 5×5 or 7×5 boxcar filter depending on the range resolution. The purpose of our investigation is to design a more intelligent filter that results in better noise suppression and twice the resolution. We will call the resulting DEM a "6m DEM". The filter shall also deliver a less biased and less noisy coherence estimate to support phase unwrapping. This is however is not the standard processing for the 6m FDEMs in which additional TanDEM-X pairs are required as inputs.

We will use non-local (NL) filters [4][5] that have been shown to reduce phase noise while well retaining structures such as linear features and edges. Rather than averaging pixels in a local neighborhood such as rectangular windows, directional windows, or spatially connected adaptive regions, NL filters consider pixels in a large search area and weight them according to some similarity measure. The number of pixels to be averaged is much higher than with a moderately smoothing local filter. The similarity measure avoids "smoothing over edges" and helps resolution preservation.

In this paper, we present modifications of the original NL filter which render it more appropriate and efficient for massive processing of TanDEM-X data. Further, we investigate the noise reduction properties as well as the resolution and the coherence estimation accuracy of the new NL filter. We present a first 6m TanDEM-X DEM and demonstrate the increased quality compared to the standard TanDEM-X 12m product. Also future global InSAR missions like Tandem-L will greatly benefit from this type of filters.

2 Non-local InSAR Filtering



(a) (b) (c)

Fig 1 : Local vs. non-local concepts. Green: target pixel to be estimated, yellow: pixels considered to be similar to the target pixel. (a) rectangular window (local); (b) adaptive – but still local – window; (c) non-local window.

2.1 Non-local Concept

The NL-means concept proposed in [4][5] takes advantage of the high degree of redundancy of any natural image. It means that every feature (edge, point etc.) in an image can be found similarly many times in the same image. Inspired by the neighborhood filters as depicted

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in Fig 1(a) and (b), the NL-means concept re-defines the "neighborhood of a pixel *i*" in a very general sense as any set of pixels *j* in the image (local or non-local) such that a small patch around *j* looks similar to the patch around *i*. All pixels in that neighborhood can be used to estimate the value at *i* as shown in Fig 1(c).

Given a noisy image **v** on a discrete grid **I**:

$$\mathbf{v} = \{v_i \mid i \in \mathbf{I}\} \tag{1}$$

the estimated value $\hat{v}_{i,NL}$ of an image pixel is computed as a weighted average of all the pixels in the image:

$$\hat{v}_{i,NL} = \sum_{j \in \mathbf{I}} w(i,j) v_j \tag{2}$$

where the weight $w(i,j)$ depends on the similarity between the image patch around pixel *i* and the image patch around *j* and satisfies $0 \le w(i,j) \le 1$ and $\sum_j w(i,j) = 1$. In practice, not all the pixels in the image are used for averaging but only those in a sufficiently large search window. The measure of the patch similarity which leads to the weights $w(i,j)$ depends on the statistical model of the imaging process. In our case it is derived from the InSAR statistics.

2.2 Non-local InSAR Filtering

For the derivation of the weights in the InSAR case see [7]. The computation is iterative and results in estimates of amplitude, coherence and phase for each pixel. Since these parameters are estimated jointly the results are in general better than simple phase-only estimates. The SAR imaging process suggests, e.g., abrupt changes in phase are often accompanied by changes in amplitude and coherence. Hence, the different parameters mutually support each other's estimates.

2.3 Two Improvements

In this section we will describe two improvements of the NL filter that increase the noise reduction capability by including more pixels in the estimation process. The detailed description will be given in the final paper.

3 Quality Assessment

For the following simulations we used a patch size of 5×5 and a search window of 21×21.

3.1 Noise Reduction

To assess its best-case noise reduction power we applied the NL filter to interferometric simulations of a constant phase with varying coherence γ. In Fig 2 the noise standard deviation of the NL filter output is plotted as a function of γ together with the results of boxcar averaging. If the NL filter used all of the 21×21= 441 pixels of the search window with equal weights, the curve of Fig 2 would follow one for 441 looks. Since also the weights are estimates and hence stochastic, this limit will never be reached. Rather the curve follows approximately the one for 169 looks corresponding to a 13×13 boxcar filter.

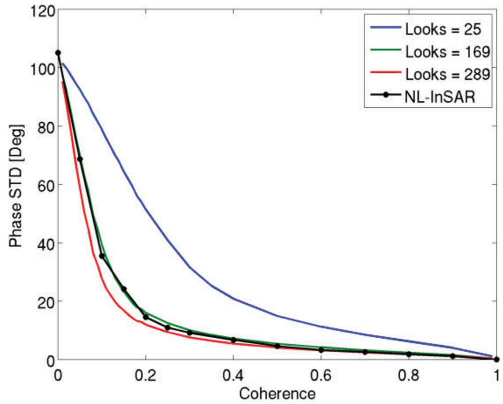

Fig 2: Phase standard deviation as a function of coherence for different number of looks and the NL filter.

3.2 Coherence Estimation

Coherence estimates based on small windows are not only noisy but also biased [6]. The latter aspect is particularly annoying since phase unwrapping needs information on low coherence areas. Fig 3 compares the coherence estimates of our NL filter with the traditional boxcar estimates. Again the advantage of using much more pixels in the NL estimator is evident.

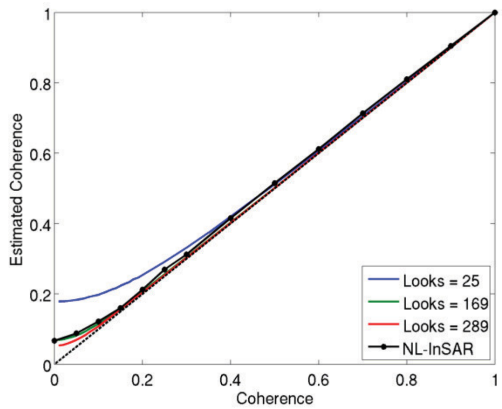

Fig 3: Coherence estimates as a function of coherence for different number of looks and the NL filter.

Fig 4 compares the coherence estimates at the test site Saint Lawrence River (near Montréal) shown in Fig 4 (a) using the 5×5 filter employed in the standard TanDEM-X processing chain (b), and the developed NL filter (c). From the optical image, one can observe that the test area is a mixture of water (incoherent), forest (medium coherence) and urbanized areas (high coherence). A good InSAR filter shall provide coherence maps with high dynamic range, i.e. very dark in water area and very bright in urbanized area. From Fig 4, it is evident that compared to the boxcar filter, the NL filter provides significantly less biased coherence estimates while preserving the fine details in the image.

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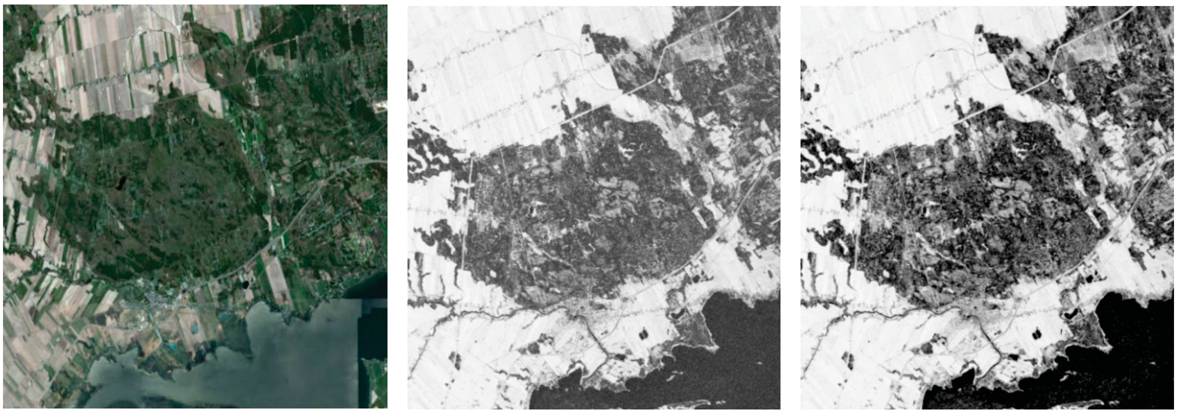

(a) (b) (c)

Fig 4. Comparison of the coherence estimates at the test site St Lawrence: (a) optical image © Google earth; (b) coherence estimate of the standard TanDEM-X processing chain based on 5×5 boxcar filter; c) coherence estimated by NL-means filter. The grayscale from black to white indicates a coherence value of 0 to 1.

3.3 Spatial Resolution

In the previous sections we have demonstrated that our NL filter is superior to a standard 5×5 averaging filter in terms of phase noise reduction and coherence estimation. Now we will demonstrate that the NL filter also provides a better spatial resolution. For this purpose we have simulated a target function representing step functions in phase, coherence and amplitude (see also [7]). Figure 5 shows the filter results from the boxcar filter and our NL filter. While the boxcar filter smooths the edges by about its size, i.e. 5 samples, the NL filter almost maintains the original step width of one sample.

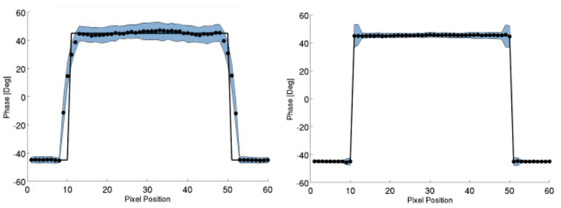

Fig 5: Phase step functions filtered by boxcar (left) and NL filter (right)

4 The First 6m TanDEM-X DEM

The 6m DEM generation is based on the aforementioned ITP at DLR. Interferometric data processing is performed including spectral shift filtering, high resolution image co-registration by fusing a coherent and incoherent correlation method, and resampling of the slave onto the master channel. Our improved NL filter is then applied. Single or dual-baseline phase unwrapping follows. Absolute phase offset (to get absolute height) is computed using a radargrammetric approach. Finally, this absolute phase is geocoded to get the desired 6m TanDEM-X DEM.

The first 6 m TanDEM-X DEM of a coal mine in Hambach, Germany is shown in Fig 6. Only a single interferogram with a phase-to-height conversion factor of -34.95 m/cycle is used in this experiment. To examine the quality of the DEM, a zoom into the Jülich city is shown in Fig 7 (b) and is compared to the standard TanDEM-X DEM with ground spacing of 12m shown in Fig 7 (a). Visual comparison shows that the 6m TanDEM DEM possess much more details, e.g. see the area marked with green boxes and remarkably much less noise which can be observed from the flat areas, e.g. the area marked with red boxes.

A similar experiment is performed on the test site Salar de Uyuni which has a totally flat salt lake area. The height noise measured over this area was about 0.68m for the boxcar filter and 0.25m for the NL filter, i.e. an improvement of 2.7 is achieved although the resolution is doubled in both dimensions.

5 Conclusion

We have shown that a higher quality DEM approaching the HRTI-4 standard can be achieved from the standard TanDEM-X acquisitions by applying NL filters on the interferometric complex data. The NL filter also gives us significantly less biased coherence estimates which serves as a very important input for phase unwrapping — the crucial step for DEM generation.

The downside of the NL filters is their computational hunger. Speeding up of these filters is a rewarding research and development task.

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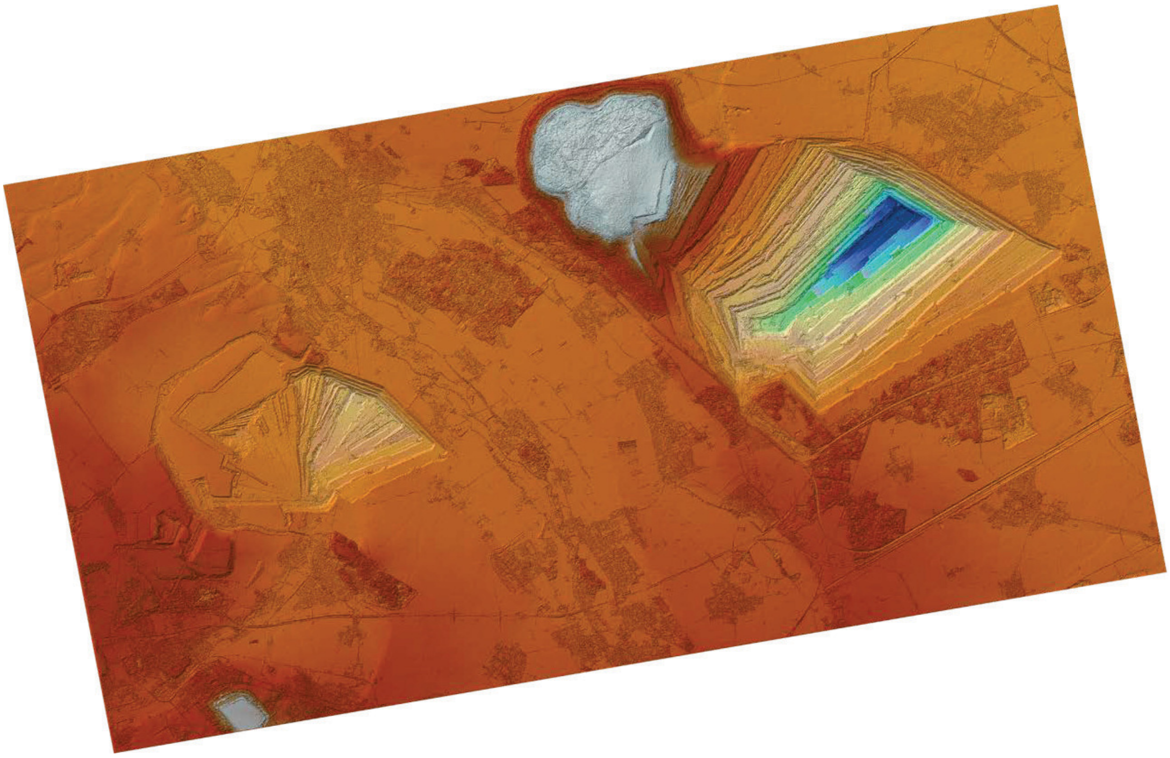

Fig 6: 6m TanDEM-X digital elevation model of a coal mine (Hambach, Germany).

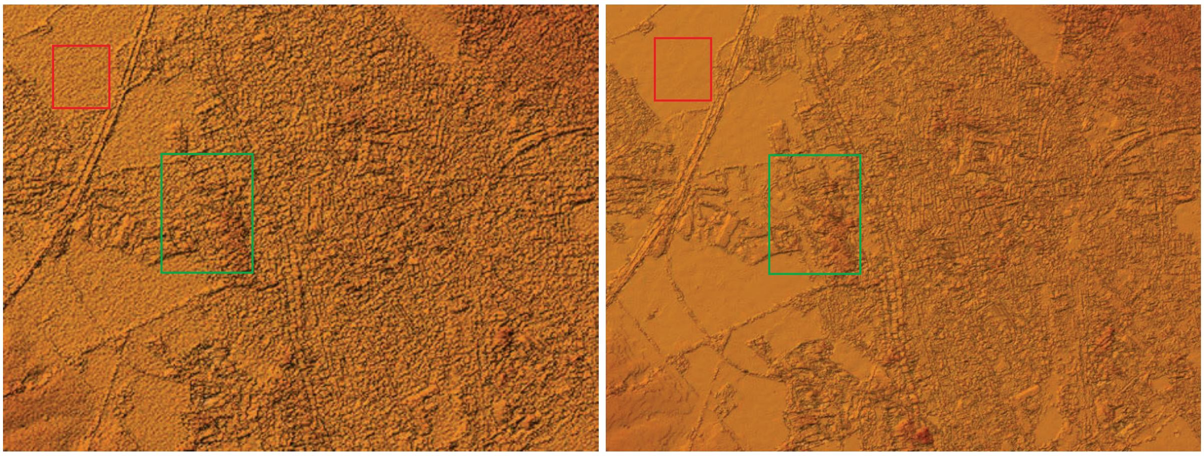

Fig 7 : Zoom in of the Jülich city (top left in Fig 6): Comparison of TanDEM-X DEMs with ground spacing of 12m (left, standard product) and 6m (right, see also additional noise reduction by NL filtering).

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