BEYOND THE 12M TANDEM-X DEM

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ABSTRACT

The standard TanDEM-X product meats HRTI-3 DEM specification and comes with a sample spacing of 12 m.We apply non-local means (NL) interferogram filtering to the TanDEM-X data. 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. Simulations and tests with TanDEM-X data hint that the improved DEMs possess a quality close to the HRTI-4 standard. Also future global InSAR missions like Tandem-L will greatly benefit from this type of filters.

Index Terms— TanDEM-X, DEM, nonlocal means filter, HRTI-4

1. INTRODUCTION

The major mission goal of TanDEM-X is the generation of a global digital elevation model (DEM) of high quality (12 m posting) close to the 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.

InSAR processing of all TanDEM-X data is performed by DLR's ITP ("Integrated TanDEM-X Processor") [2]-[4]. 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".This is however is not the standard processing for the 6m FDEMs in which additional TanDEM-X pairs are required as inputs.The filter shall also deliver a less biased and less noisy coherence estimate to support phase unwrapping.

We will use non-local (NL) filters [5][6] 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 in 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 preserve resolution.

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 compare the 6m TanDEM-X DEM with the standard TanDEM-X 12m product. Simulations and tests with TanDEM-X data hint that the improved DEMs possess a quality close to the HRTI-4 standard. Also future global InSAR missions like Tandem-L will greatly benefit from this type of filters.

2. NON-LOCAL INSAR FILTERING

The NL-means concept proposed in [5][6] 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 such as boxcar and adaptive filters, 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 . Given a noisy image $\mathbf{v}$ on a discrete grid $\mathbf{I}$: $\mathbf{v}=\{v_i \mid i\in\mathbf{I}\}$, the estimated value $\hat{v}_{i,NL}$ of an image pixel is computed as a weighted average of all the pixels in the image:

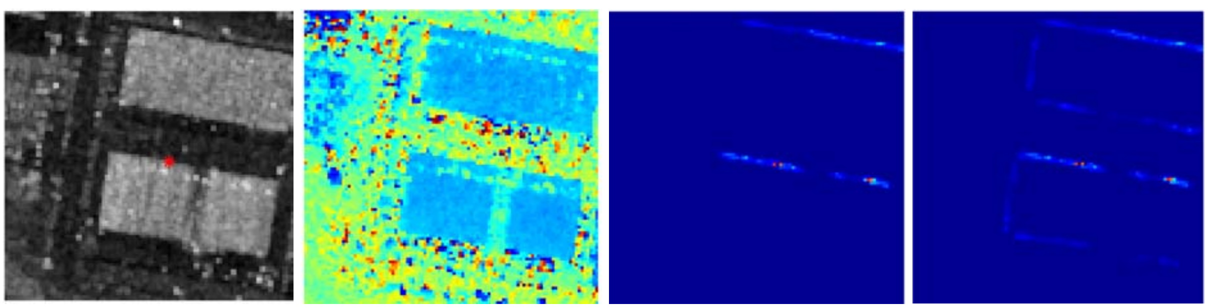
$$\hat{v}_{i,NL} = \sum_{j \in \mathbf{I}} w(i,j) v_j \qquad (1)$$

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.

For the derivation of the weights in the InSAR case see [8]. The computation is similar to an Expectation Maximization approach and, hence, iterative. It 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., that abrupt changes in phase are often accompanied by changes in amplitude and/or coherence. Hence, the different parameters mutually support each other's estimates. The filter used in this work is modified from that in [8]. The modifications increase the noise reduction capability of the filter by including more pixels in the estimation process while looking for similar pixels in a big window of a fixed size:

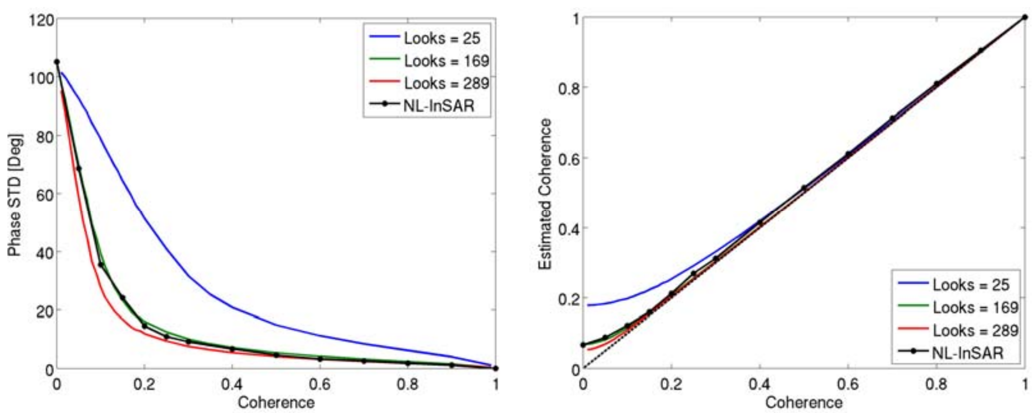
- Possible symmetric properties between the examined two image-patches are taken into account. An example is shown in Fig 1. Fig 1 (a) and (b) show the mean intensity and noisy interferogram of the input data. The red cross in Fig 1(a) represents the target pixel which is at the edge of a building block. For reducing the noise while preserving the spatial resolution, identifying more similar pixels for such edge pixels is very crucial. Calculating the similarity considering possible geometrical symmetries of image patches results in a larger number or similar pixels (light blue pixels shown in Fig 1d) than the original measure (shown in Fig 1c).
- The similarity measure reduces if the two patches have a constant phase offset. That means that in a flat phase interferogram more similar pixels are found than in a ramp of constant slope. In interferograms of natural terrain, however, similar patters may be found at arbitrary mutual phase offsets (e.g. on smooth slopes). In order to include also offset patches for noise reduction we compensate the mean height differences, and hence allow identifying more similar pixels.

In these manners, the resulting filter is more appropriate for massive processing of TanDEM-X data.



(a) Intensity **(b) Noisy interferogram** **(c) Weight map (original)** **(d) Weight map (improved)**

Fig 1: Example: improving similarity measure by considering possible symmetry in examined patches



(a) **(b)**

Fig 2: Phase STD (a) and coherence estimates (b) as a function of coherence for different number of looks and the NL filter.

3. QUALITY ASSESSMENT

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

- 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 (a) the noise standard deviation (STD) 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 (a) would follow one for 441 looks. Since also the weights are estimates and, hence, are stochastic, this limit will never be reached. Rather the curve follows approximately the one for 169 looks corresponding to a 13×13 boxcar filter, for high coherence regime it even reaches the one for 289 looks. The phase STD ratio for using 5×5 boxcar and the nonlocal filters at different coherence levels keeps consistent and is around 3.5.

- Coherence Estimation

Coherence estimates based on small windows are not only noisy but also biased [9]. The latter aspect is particularly annoying since phase unwrapping needs information on low coherence areas. Fig 2 (b) 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. The equivalent number of looks in terms of un-biased coherence estimation is 169~289.

- Spatial Resolution

To compare the deliverable spatial resolution, we have simulated a target function representing step functions in phase, coherence and amplitude (see also [8]). Figure 5 shows the filter results from the boxcar filter and our NL filter. While the boxcar filter smoothes the edges by about its size, i.e. 5 samples, the NL filter almost maintains the original step width of one sample.

4. 6M TANDEM-X DEMS

The 6m DEM generation is based on the aforementioned ITP at DLR [2]-[4]. 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 the absolute height) is computed using a radargrammetric approach. Finally, this absolute phase is geocoded to get the desired 6m TanDEM-X DEM.

Fig 4 compares the DEM quality of the standard TanDEM-X DEM (middle) and the improved NL TanDEM-X DEM (right). The test area is a mixed city-rural area at Jülich, Germany, as shown in the optical image (left). Only a single interferogram with a phase-to-height conversion factor of -34.95 m/cycle is used for in this experiment. Compared to standard TanDEM-X DEM, the 6m TanDEM DEM possess much more details and remarkably less noise which can be observed from the flat areas. A similar experiment is performed on the test site Salar de Uyuni contains 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. This ratio also fits well to our simulations.

Simulations and real data examples allow us to access the quality of the improved DEMs. Preliminary quality parameters are listed in Table 1 along with the two DEM standards mentioned above. Among the three parameters, the better than five meters absolute accuracy does not depend on the nonlocal methods, but on the generally very high absolute calibration accuracy of TanDEM-X. We expect with the improved DEM possessing a quality close to the HRTI-4 standard. To validate it in a general framework, it would require tests with massive TanDEM-X data at different terrains. Experiments on more test-sites named by potential users, e.g. Euskirchen in Germany, Marseille in France, Java in Indonesia and Weihai in China, confirm the improved DEM quality.

Table 1: Grid size and accuracies of HRTI-3, HRTI-4 and the improved TanDEM-X DEMs

	posting	absolute (90%)	relative (90%)
HRTI-3	12m×12m	10 m	2 m
HRTI-4	6 m×6 m	5 m	0.8 m
NL-DEM (preliminary)	3~6 m	< 5m	≤ 0.8m

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 drawback of the NL filters is their computational hunger. Speeding up of these filters is a rewarding research and development task. Our current work focuses on the quality assessments of the DEM quality in a general framework.

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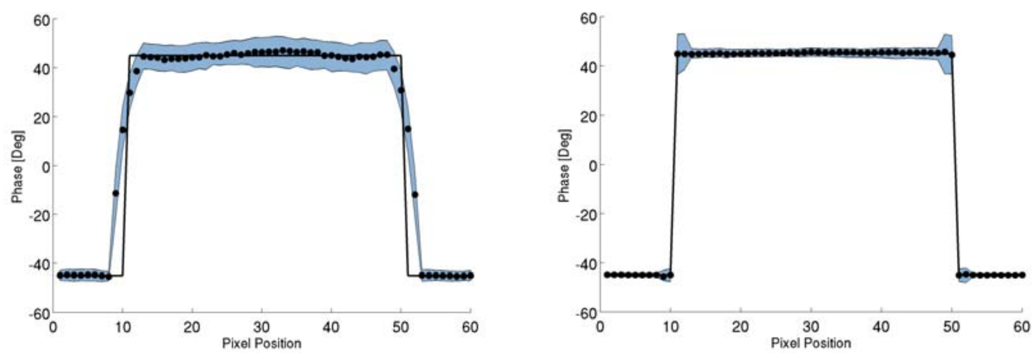

Fig 3: Phase step functions filtered by boxcar (left) and NL filter (right), grey: standard deviation of estimate

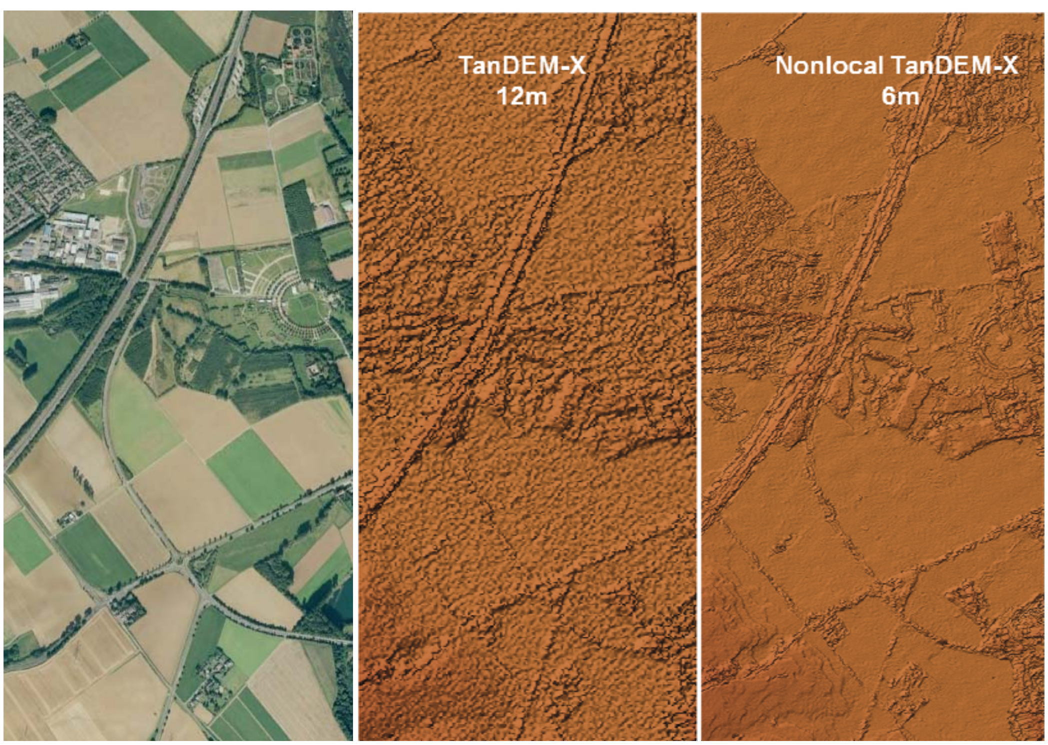

Fig 4: Jülich city area: Optical image ©Google (left), standard TanDEM-X DEM (middle) and improved nonlocal TanDEM-X DEM (right).