

SAR multi-track analysis in urban sites

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ABSTRACT: The relative low resolution ($\sim 25\text{m} \times 5\text{m}$ on the ground) of spaceborne C-band SAR data as acquired e.g. by ESA sensors ERS and Envisat can be significantly increased (up to sub-meter precisions) by processing coherently long series of images. Moreover, by analyzing the amplitude of the radar signal, the main radar characteristics of urban targets can be estimated and a system for automatic recognition of a set of scattering structures can be developed (ground level resonating scatterers as floor metal gratings, elevated (roof-level) scatterers as tiled or corrugated roofs, dihedrals, resonating dihedrals as metal fences, poles and trihedrals). Based on the identification of multi-track targets as poles, dihedrals and trihedrals, data acquired by different sensor tracks (ascending and descending passes and parallel orbits) can be jointly combined in order to increase the spatial density of urban scatterers. The density of measure points that can be achieved allows then the generation of accurate urban DTM's and a rough estimate of the buildings profiles at a very low cost. In this work we will show the results obtained by applying such technique in Milan and Shanghai.

1 INTRODUCTION

Nowadays, after 15 years since the launch of the first SAR satellites, a high number of spaceborne SAR images is available for almost the whole Earth surface. Many places are also imaged by SAR sensors from different acquisition geometries (from parallel tracks or from ascending and descending passes). Moreover, the number of operative satellites is going to increase and the new sensors that will be launched are characterized by high resolutions, multi-polarization capabilities, and variability of the antenna orientation. The C-band satellites are the European Space Agency (ESA) ERS-1 (dead in 1999), ERS-2 (loss of gyroscopes in 2001) and Envisat (expected to finish the fuel in 2010) or the Canadian Space Agency (CSA) Radarsat-1 (put in orbit in 1995) and Radarsat-2 (the launch is scheduled for this year), and they are differentiated by slightly diverse central frequencies and attitudes. There are then L-band spaceborne radars mounted on the Japanese JERS (dead in 1998) and ALOS satellites, and X-band sensors as the Italian COSMO Skymed constellation (Caltagirone et al. 1998) and the German TerraSAR-X, both expected to begin working in the current year. Thus, the presence of a high number of available SAR data and the prospect of having even more images at different resolutions acquired with different parameters push toward the development of new strategies of SAR data combination. The SAR data fusion on a common geographic layer is by its self an interesting task, but even more intriguing is to evaluate the possibility of developing interferometric analysis that jointly exploit different SAR data to monitor ground movements and to produce high quality digital elevation maps (DEM's). Such a goal would allow the continuity of the deformation measurements and could also permit the connection of the very

first new images acquired by the new satellites to data-sets of archived acquisitions with different resolutions. Precondition of such a work is the existence of SAR targets that are visible from the different platforms. Assuming that multi-angle multi-frequency SAR targets exist, the novel technique should then be able to super-resolve the system in order to accurately locate the targets detected in the low-resolution SAR data. Whenever the mentioned conditions are met, in line of principle, new high-resolution images could be connected to the existent data. In this work, summing up results obtained in the last years on the physical nature of urban Permanent Scatterers (PS) (Ferretti et al. 2001), we show that, by means of repeated low-resolution SAR images, it is possible to successfully implement super-resolution and thus to estimate the position of urban targets with 1m accuracy (Perissin & Rocca 2006, Perissin 2007). It becomes than possible recognizing some main typologies of urban scatterers and individuating multi-angle multi-frequency targets (Ferretti et al. 2005). Some strategies of combination of different SAR data are then described and first real data results obtained by combining data acquired from different parallel tracks and from ascending and descending passes are shown.

2 TARGET RECOGNITION

The processing chain that we developed for recovering information on the physical nature of urban targets from repeated SAR images consists of three main steps. The first one deals with the estimate of the precise 3D position of the target, the second one is the extraction of a set of features from the radar data that allow the characterization of the scattering structure. Finally, a system for the automatic recognition of some target typologies can be developed.

2.1 *Target positioning*

The target precise 3D position can be extracted from SAR data (ground resolution about 25m x 5m for ERS) by means of multi-temporal interferometric techniques. The interferometric phase in fact depends on view angle changes (normal baseline and Doppler centroid frequency) as well as on slight frequency shifts (as between ERS and Envisat sensors) (Perissin et al. 2006). By processing the phase of many images, the relative 3D location of PS's can thus be estimated up to sub-meter precisions. As an example, Figure 1 shows the 3D coordinates of PS's detected on the S.Siro Soccer Stadium in Milan from three different orbits, 2 descending and 1 ascending.

The quality of the obtained result suggested the exploitation of the estimated position of the scatterers to produce urban elevation maps. In particular, by analyzing the distribution of the height of the detected targets, it can be observed that most scattering structures lie on the ground (Perissin & Rocca 2006, Perissin 2007). This fact can be fruitfully exploited to estimate the urban DTM. By selecting the PS's on the ground, and by applying a spatial kriging, the height of the terrain is re-sampled on a regular grid and the noise is filtered out. Figure 2 shows the DTM of Milan in a color scale range of about 6m around the low-pass topography of the city (a slight slope from North to South). The blue depressions in the image correspond to the water courses. The red area in the middle of the image identifies the historic center.

By means of the estimated DTM, the scatterer height is then referred to the ground level, obtaining very precise measurements (with respect to the system resolution) of the buildings elevation. Thus, considering that the image swath on the ground is 100km, a first raw tomography of a wide urban area can be produced at a very low cost. Moreover, the height with respect to the ground is a first information of the target physical nature.

2.2 *Target feature extraction*

The second step of our algorithm is the extraction of a set of features from the radar data that allow the characterization of the scattering structure of the target at hand. To this aim we analyze two main radar characteristics of the targets: scattering pattern and polarimetric behavior (Ferretti et al. 2005).

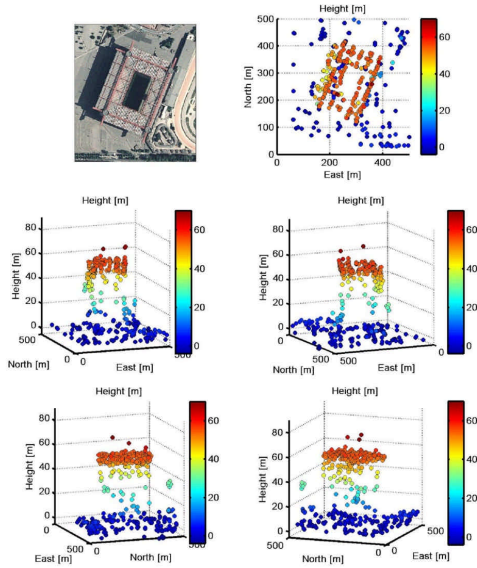


Figure 1. Aerial photo, planimetric coordinates and 3D views of PS's detected on the S.Siro Stadium in Milan from 2 descending tracks and an ascending one

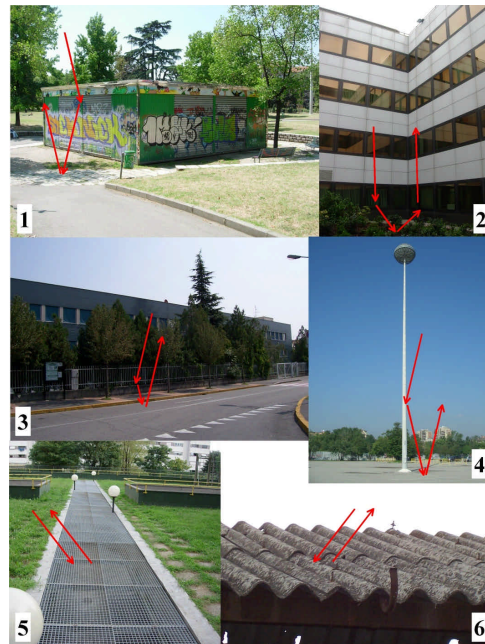


Figure 3. SAR target typologies in urban sites: 1) simple dihedron, 2) trihedron, 3) fence acting as resonating dihedron, 4) pole, 5) resonating metal grating, 6) backscattering roof

The target scattering pattern is analyzed by looking at the amplitude of the radar signal. The first information that can be extracted from the received amplitude is the Radar Cross Section (RCS). Then, many other useful hints can be derived by analyzing the variation of the RCS as a function of the acquisition parameters. Among them we take into account the geometry (normal baseline and Doppler centroid, DC), time and temperature. Variations of the RCS as a function of the acquisition geometry are related to the geometrical characteristics of the scatterer (extension and orientation in range and azimuth directions). The time domain has to be taken into account in order to identify possible temporary PS (Colesanti et al. 2003).

Finally, temperature-dependent RCS variations are used for detecting metal resonating structures (Bragg scattering) as gratings or fences. Such targets do not need to be physically oriented toward the sensor in order to be seen by the radar: the periodicity of their structure causes a resonance along the line of sight of the sensor. The distance between the periodic elements (in the order of magnitude of the wave length) is the key feature of the resonance and it causes RCS fluctuations as a consequence of thermal dilation.

The polarimetric behavior of the target is an other source of information on its physical nature.

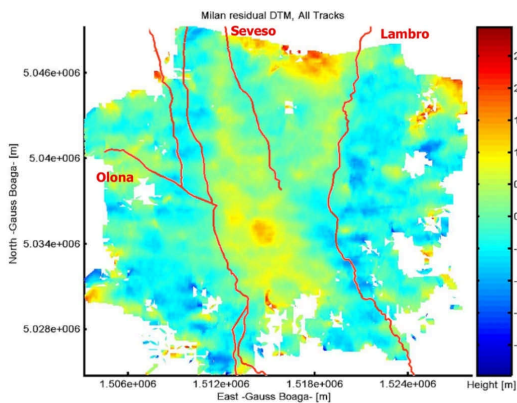


Figure 2. Milan DTM obtained from the height of PS's detected in three orbits (2 descending and 1 ascending) with the georeferenced watercourses of the city.

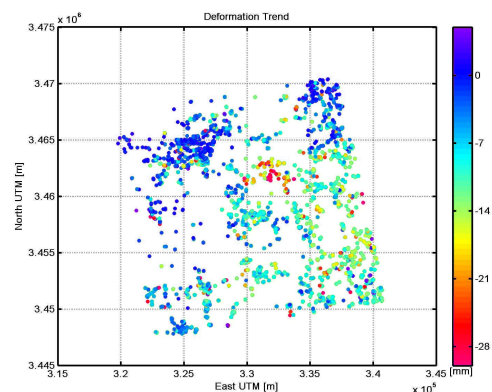


Figure 4. Deformation trend of multi-angle targets detected in Shanghai by combining data acquired by Envisat from two parallel tracks.

Rather than exploiting complex models, we analyzed it simply by means of an Envisat Alternating Polarization (AP) acquisition. In AP mode Envisat takes simultaneously 2 images with 2 different polarizations of the same area. Creating an interferogram between the two images (auto-interferogram), the interferometric phase depends only on the polarimetric response of the scatterers (Inglada et al. 2004). Thus the polarimetric auto-interferogram of a VV-HH acquisition can be exploited for discerning between odd and even bounces. A specular reflector (a mirror) behaves in the same way if illuminated with horizontal or vertical polarised signals, whereas a dihedral rotates the phase by π radians.

2.3 Target characterization and recognition

Based on the previously described set of target characteristics (height with respect to the ground, geometrical dimensions, resonance attitude, bounces parity-disparity), urban SAR PS's have been classified in 6 main typologies: ground level resonating scatterers as floor metal gratings, elevated (roof-level) scatterers as tiled or corrugated roofs, dihedrals, resonating dihedrals as metal fences, poles and trihedrals.

Table 1 reports the characteristics of each target typology (L_{rg} range width, L_{az} azimuth width, j_{AP} AP phase, RCS , k_T amplitude-temperature dependency, h height with respect to the ground). The last column is the percentage of detected targets in the urban site of Milan. Figure 5 shows some examples of targets in Milan as recognized in the validation campaign.

Table 1. Target Typologies

Target typology	Target characteristics						
	L_{rg}	L_{az}	j_{AP}	RCS	k_T	h	%
Roof	+	+	0	∞ dim	+	+	50
Grating	+	+	0	∞ dim	+	-	11
Dihedral	-	+	π	+	-	-	13
Pole	-	-	π	-	-	-	11
Fence	-	+	π	-	+	-	7
Trihedral	-	-	0	+	-	-	8

3 MULTI-MISSION MULTI-ORBIT DATA COMBINATION

Assuming that we are able to recognize the mentioned target typologies, some of them can be used as multi-mission multi-orbit SAR targets. A dihedral e.g. is visible under considerable incidence angle changes on condition that the sensor flight direction remains parallel to its edge. Thus dihedrals should be observable from adjacent parallel orbits. A trihedral has a wide scattering pattern both in range and azimuth, thus it should be seen by sensors with different attitudes. Poles are dihedrals with cylindrical symmetry and isolated poles should be imaged from 360 deg rotation and

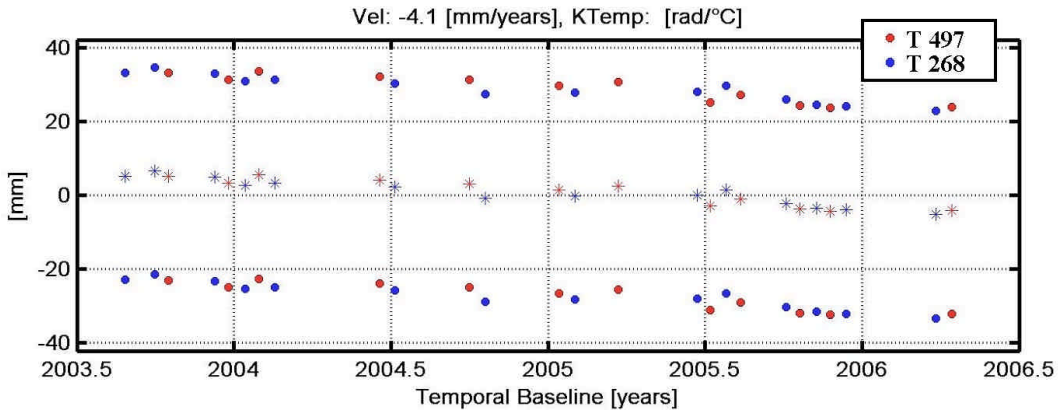


Figure 5. Example of displacement time series estimated from two parallel tracks with Envisat data. Blue dots Track 268, red dots Track 497.

different incidence angles (e.g. from ascending and descending passes). In the following we analyse three main strategies to exploit multi-angle targets to combine different SAR data.

3.1 *A-posteriori approach: data fusion*

The easiest way to combine SAR data acquired by two (or more) different sensors under different geometries is at the end of the two geocoding processes, on a common geographic layer, once the targets 3D positions have been independently estimated in the two data-sets. Obviously in this case the targets do not need to be observable by both sensors. However, there are two critical steps that have to be carefully taken into account in order to get reliable results: the orbital data correction and the handling of sub-pixel quantities. The first task is solved by using Ground Control Points (GCP's) with known geographical coordinates. Poles are the most suitable target typology to this aim because their electromagnetic barycenter (the intersection between the pole and the ground) can be very precisely estimated both with radar and conventional techniques, reaching tens of cm accuracies (Perissin 2007). Moreover, if isolated poles visible from both sensors can be found, the relative geocoding error between the two SAR systems can be accurately reduced. The second task is tackled by analyzing appropriately amplitude and phase of the radar signal as deeply described in (Perissin & Rocca 2006). Without estimating the targets sub-pixel position (e.g. by extracting the peak of radar signal amplitude) it is impossible to reach the sub-meter theoretic accuracy of the height estimate and, consequently, of the geocoding process. The results shown in figures 1 and 2 have been obtained in Milan using data acquired by ERS and Envisat from 2 parallel descending tracks and from an ascending one. The three data-sets have been precisely geocoded exploiting poles visible from all tracks identified by means of aerial photos.

3.2 *Coherent approach*

Whenever the acquisition parameters of two SAR missions have only slight variations in comparison with the system resolution (see (Perissin et al. 2006) for a quantitative analysis), an interferometric coherent approach can be developed. Usually, this is the case of two sensors with the same nominal orbit, as e.g. in the ERS-Envisat case (31MHz of carrier frequency difference) or in the ERS-2 case before and after the loss of gyroscopes (with high variations of normal baseline and Doppler centroid) or in the future Radarsat-1 and 2 combination (105MHz frequency difference, different attitudes (Rabus & Mccardle 2006)). Here the processing chain requires to co-register the two SAR data-sets on a common Master grid and then to compute interferograms with a common Master image. Classical interferometry is clearly unfeasible (unless the slight orbital fluctuation around the nominal track geometrically compensate for the mission differences (Gatelli et al. 1994)), still it is possible to carry out a PS analysis (Ferretti et al. 2001) on multi-angle targets as trihedrals, poles and, if the attitude does not change, dihedrals. The model for the interferometric phase must take into account the difference between the mission parameters, then the data of both missions are jointly exploited to estimate the targets height and deformation trend (as done in (Perissin et al. 2006)).

3.3 *Uncoherent approach*

The last strategy that we analyze is the combination of SAR data acquired with very different parameters (as e.g. from adjacent parallel tracks) to estimate the targets height and movement. In this case a coherent approach is not feasible for two main reasons. First, if the acquisition parameters are very different, it is not possible to implement a reliable co-registration between the two data-sets. Then, since the parameter diversity is exploited to estimate the target characteristics, a too wide lever arm can invalidate the estimate. The solution is found by adopting 2 Master acquisitions, one per data-set. The images of the two data-sets are then re-sampled on the corresponding Master grid and interferograms are computed. If one of the two data-sets has a sufficient number of images to carry out a PS analysis, the PS's so found can be geocoded and then re-projected in the SAR coordinate system of the second data-set. If the targets are visible also in the second data-set,

the estimated height and deformation trend will explain also the phases of the interferograms of the second data-set. The temporal coherence of the residual phases in the second data-set is the index to evaluate if the target is actually seen by the second satellite. The procedure can be implemented also in the case that there are not enough images in a single data-set to carry out a PS analysis. In this case the estimate of height and deformation trend is obtained from the two data-sets jointly (Perissin et al. 2007). Figures 4 and 5 show the results achieved in the test site of Shanghai by applying this approach to data acquired by Envisat from two adjacent parallel tracks (12 images track 268 and 14 images track 497). Figure 4 shows the deformation trend of multi-angle targets as estimated from the two data-sets jointly. Figure 5 reports a displacement time series of a detected target. Using data acquired from parallel tracks the revisit time has been halved.

4 CONCLUSIONS

In this work we have shown the possibility of super-resolving spaceborne C-band SAR data up to the development of a system for urban target automatic recognition. Six main urban target typologies have been characterized and a recognition process has been successfully implemented. Moreover, the identification of multi-track targets allows the combination of SAR data acquired with different parameters. Different strategies of data combination have been addressed and first results have been provided by analyzing data acquired from parallel tracks and ascending and descending passes in Milan and Shanghai.

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