On the physical characterization of SAR Permanent Scatterers in urban areas

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Abstract

The Permanent Scatterers (PS) technique developed in late nineties by the Politecnico di Milano is a remote sensing tool capable of detecting and monitoring terrain deformation phenomena [1], [2]. Sub-centimetre accuracy is achieved on a sparse grid of radar targets, the so-called Permanent Scatterers. Even if the PS technique is used successfully since 1999, the physical nature of the objects exhibiting PS behaviour is still subject of investigation and research. Indeed, a good knowledge of the PS nature is an essential step to improve the interpretation of the radar measurements and to get a more precise topographic reconstruction. In this work we present the last results of this research program obtained by using more than 200 ERS (3 different acquisition geometries) and Envisat repeated acquisitions on the area of Milano (Italy). The characterization of the physical parameters of the PS would allow us to foresee their electromagnetic behaviour under different acquisition geometries, frequencies and polarizations, and we can develop feasibility studies on the integration of interferometric SAR multiple sensors (e.g. ERS and Envisat coherent exploitation [8]).

1 Introduction

The Permanent Scatterers (PS) technique [1], developed at POLIMI, is a tool for processing long series of SAR data. The PS methodology consists in identifying the targets (the so-called PS) that show an unchanged electromagnetic signature within the images of the analysed data-set. By means of such stable targets the conventional limits of SAR interferometry (atmospheric artefacts and decorrelation) are overcome and slow deformation phenomena can be monitored with millimetric deviation [2]. Moreover, the estimate of the 3D PS position with metric precision allows generating very accurate digital elevation models (DEM) [3]. Even if the PS technique is an operational tool since year 2000, the PS physical nature is still subject of investigation [4] and only recently a first classification of the most common SAR targets in urban areas has been produced [5]. In this paper we wish to focus the attention on the advantages of knowing the physical nature of the targets.

2 PS characterization

In order to characterize PS's, in [4] and [5] three main radar measurements for each target are analysed: 3D location, radiation pattern and scattering mechanism. The first useful information for PS characterization is the elevation of the target with respect to the ground, which can be derived from a fine estimate of the PS 3D position carried out in a multi-interferogram framework [3]. In fact, targets like dihedrals are usually at street level in urban areas. Then, studying the amplitude of the radar signal as a function of the acquisition parameters, useful information on the PS scattering pattern can be achieved [5]. Amplitude variations as a function of the acquisition geometry depend on the physical extension and the orientation of the target (e.g. corner reflectors appear as point-wise with a constant radiation pattern, whereas distributed targets have a more complex behaviour). Moreover, the amplitude dependence on the temperature at the acquisition time can be a key-feature of metal reflectors (Bragg-scattering) [5]. Finally, the auto-interferometric phase of an Envisat alternating polarization acquisition allows one to discriminate between odd and even bounces of radar echoes [6]. By jointly exploiting all these observations, five main typologies of urban SAR targets can be identified [5]: floor metal gratings, poles, dihedrals, trihedrals and roofs (oriented mirrors, corrugated iron roofs, curved surfaces). **Table I** briefly summarizes the characteristics of each target typology and reports the percentage detected in the Milan site.
We are now interested in analysing through some examples three main applications that derive from the knowledge of the physical nature of the targets.

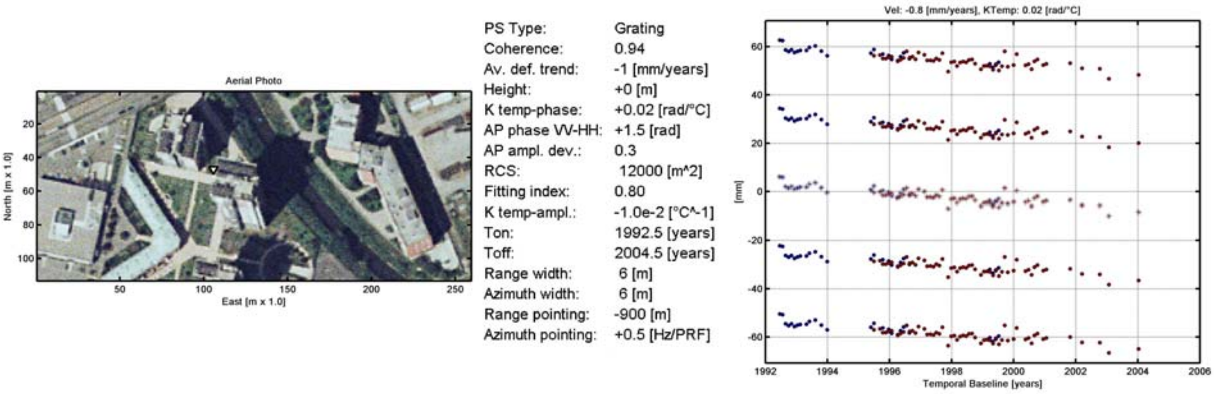

Figure 1. PS example in Milan (floor metal grating). Left: aerial photo with a sign on the PS planimetric position. Centre: physical parameters detected by the radar. Right: displacement [mm] time [years] series.

	L_{rg}	L_{az}	φ_{AP}	RCS	k_T	h	%
Roof	+	+	0	∝ dim	+	+	50
Grating	+	+	0	∝ dim	+	-	11
Dihedral	-	+	π	+	-	-	20
Pole	-	-	π	-	-	-	11
Trihedral	-	-	0	+	-	-	8

Table I. Characteristics of each target typology. Columns from left to right: range width L_{rg}, azimuth width L_{az}, AltPol phase φ_{AP}, radar cross-section RCS, amplitude-temperature dependence k_T, height with respect to the ground h, detected percentage in Milan *%*.

2.1 Interpretation of deformation measurements

Knowing the scattering mechanism and identifying which part of the building is reflecting the radar signal toward the sensor can be extremely useful to properly interpret displacement measurements [7]. In **Figure 1** an example of PS detected in the Milan site with a data-set of more than 100 ERS images is shown. The image on the left is an aerial photo with a mark on the PS planimetric position, then the detected physical parameters are listed and on the right the displacement time series are plotted (y-scale mm, x-scale years). The system recognizes the PS as a floor metal grating and the displacement shows a slightly negative linear deformation trend with respect to a reference point in Milan. **Figure 2** shows a PS with planimetric location very similar to that of the previous example, but in this case it is recognized as a roof. Looking now at its displacement two interesting features can be noted. The roof (at 38*m*) reveals the thermal dilation affecting the building and, in comparison with the grating, the fact that the building has a slow subsidence with respect to the surrounding terrain.

2.2 Increase of temporal sampling rate

The identification of the target typology seen by the radar makes it possible to properly combine data coming from different sensors. Dihedrals, for instance, (or trihedrals, but not mirrors) are expected to be visible under different parallel tracks (or slightly different carrier frequencies [8]). **Figure 3** shows an example of a dihedral reflector at about 50*m* height together with its displacement time series measured by ERS-1 (green), ERS-2 (red) and Envisat (blue)

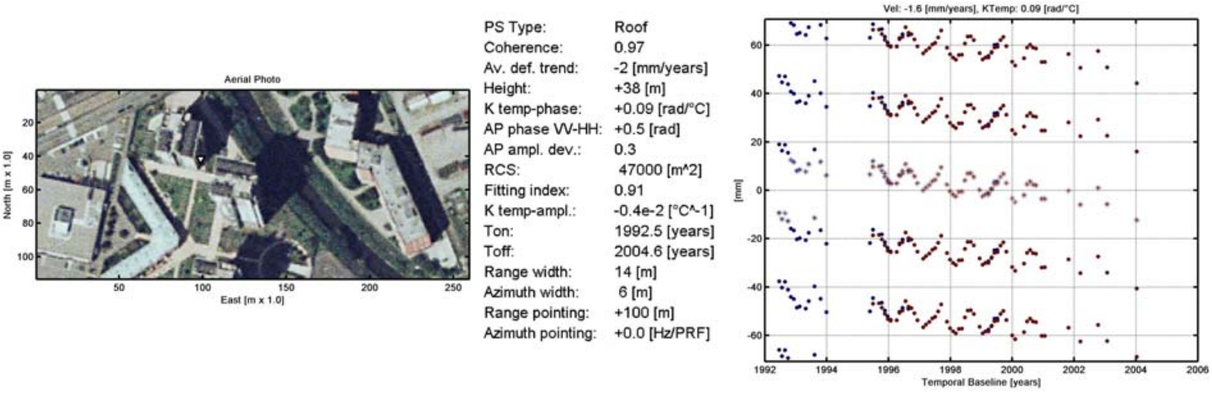

Figure 2. PS example in Milan (roof). Left: aerial photo with a sign on the PS planimetric position. Centre: physical parameters detected by the radar. Right: displacement [mm] time [years] series.

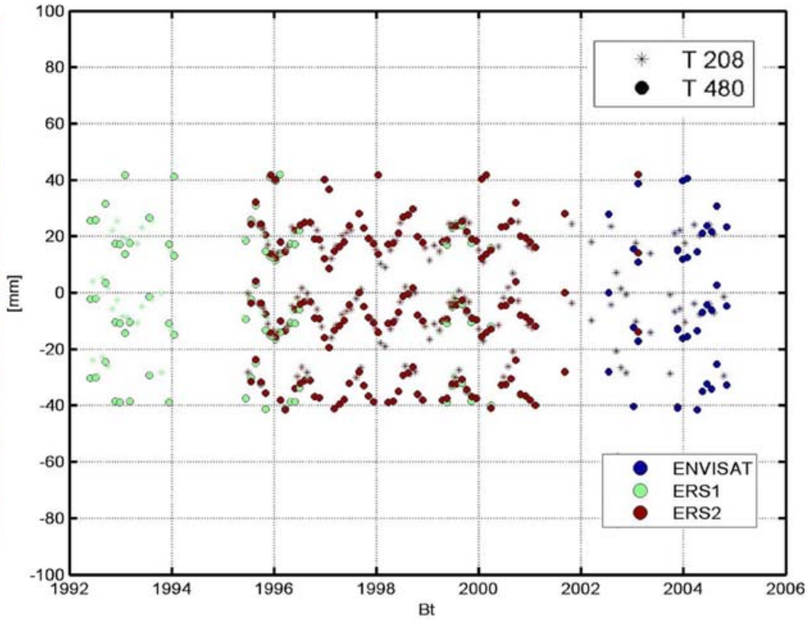

Figure 3. Elevated dihedral seen by different sensors in two different adjacent parallel tracks. Stars: track 208, dots: track 480; green: ERS-1, red: ERS-2, blue: Envisat

sensors from track 208 (stars) and from track 480 (dots). The two parallel tracks are 40*km* apart, the carrier frequency difference between ERS and Envisat is 31*MHz*. The extremely high correlation between the two data-sets confirm that measurements are relative to the same structure.

2.3 Increase of number of measure points

Targets like isolated poles (dihedrals with circular symmetry) can be observed not only from parallel tracks but also from ascending and descending passes. By means of poles, PS's acquired by very different orbits can be georeferenced with sub-meter relative precision [3]. An example of geolocation of PS data-sets detected by two descending and one ascending tracks is reported in **Figure 4**. The area covers about $2x4km^2$ near Milan downtown. The PS density is so high that it is possible to recover the "map" of this area simply looking at the PS positions, with no optical background. Of course for each PS a precise elevation value is available as well: in **Figure 5** shows an aerial photo of the railway station together with the planimetric coordinates and different 3D views of PS's detected on it from three different satellite tracks. Colour scale of **Figure 5** is the PS esti-

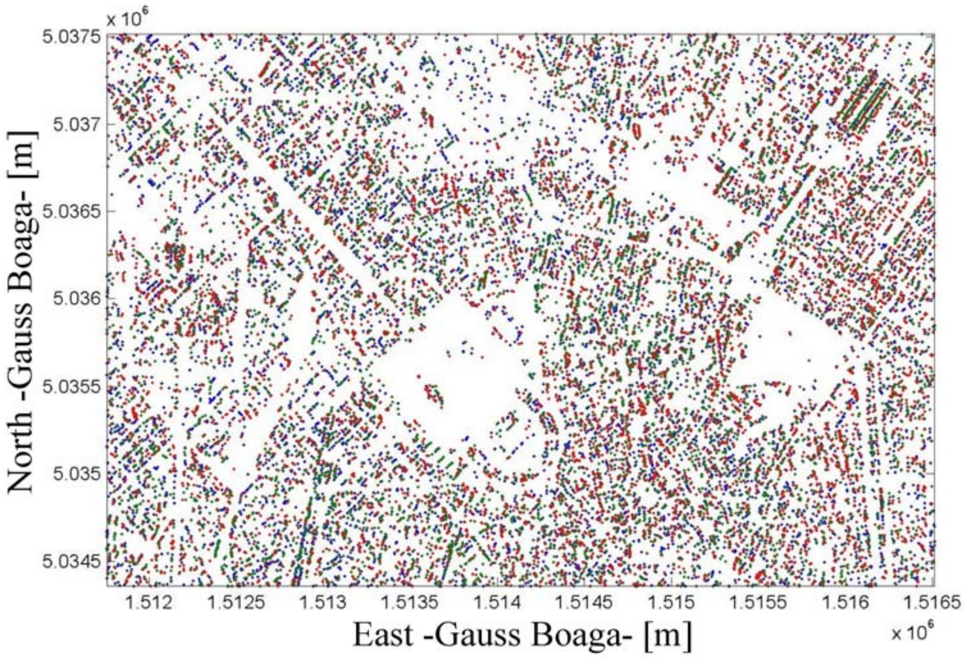

Figure 4. PS's detected in Milan in a $2x4km^2$ area from two descending parallel tracks and an ascending one.

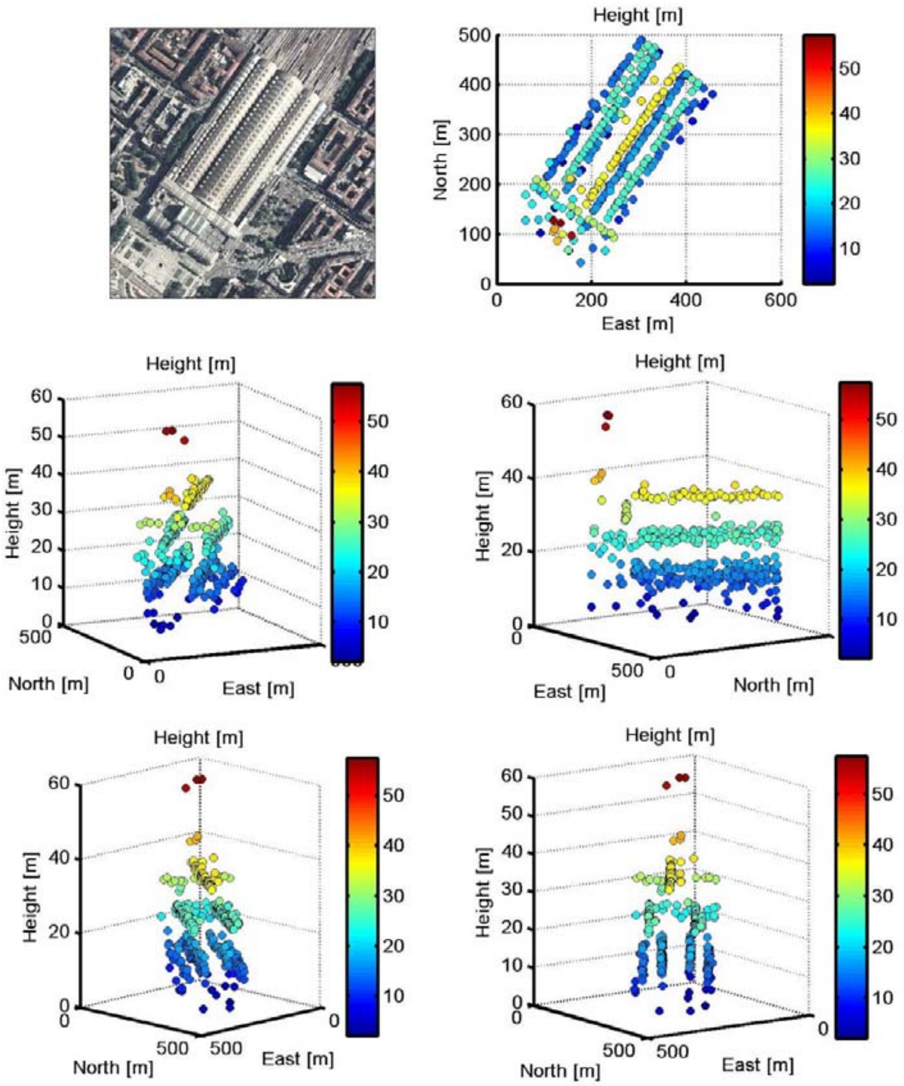

Figure 5. Milan railway central station. Up left: aerial photo. Up right: planimetric coordinates of the detected PS's of two descending parallel tracks and an ascending one. The other four images are 3D views of the PS's. Colour scale: estimated PS height.

mated height. The details of the building highlighted by the PS location are remarkable.

References

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