# Identifying urban SAR Permanent Scatterers for motion interpretation and multi-track data fusion

**Daniele Perissin and Claudio Prati**

Politecnico di Milano - Piazza L. da Vinci 32, 20133 Milano, Italy.
E-mail: daniele.perissin@polimi.it

## Abstract
The Permanent Scatterers (PS) technique is a processing tool in the field of space-borne SAR interferometry to detect terrain deformations with millimetre accuracy. Such an accuracy is achieved in correspondence of coherent targets, the so-called Permanent Scatterers. Recently the PS physical nature has been subject of study and a set of main target typologies (dihedrals, trihedrals, poles, roofs, metal gratings) has been found being recognizable by means of features extracted from the radar data. In this work we analyse the main applications that derive from the recognition of the PS scattering type: the interpretation of the deformation measurements, the increase of the temporal sampling rate (combining data acquired from parallel orbits by means of dihedrals), the increase of the number of measurement points (combining data acquired from ascending and descending passes by means of poles).
**Keywords**: SAR interferometry, target recognition, data fusion

## *Riassunto*
*La tecnica dei diffusori permanenti (Permanent Scatterers, PS) è un'applicazione avanzata nel contesto dell'interferometria SAR satellitare, in grado di monitorare fenomeni di deformazione con accuratezza millimetrica tramite l'osservazione di un limitato numero di punti di misura (i PS). Recentemente sono stati condotti studi sulla natura fisica dei PS che hanno permesso di discernere un insieme di principali tipologie di bersagli urbani (diedri, triedri, pali, tetti, griglie metalliche) e di sviluppare sistemi per il loro riconoscimento automatico. In questo lavoro vengono analizzate le principali applicazioni che derivano dal riconoscimento della tipologia di PS: l'interpretazione delle misure di deformazione, l'aumento del campionamento temporale delle misure di deformazione (combinando dati acquisiti da orbite parallele tramite i diedri) e l'aumento della densità spaziale di punti di misura (combinando passaggi ascendenti e discendenti tramite i pali).*
***Parole chiave**: interferometria SAR, riconoscimento dei bersagli, fusione dati*

## Introduction
The Permanent Scatterers (PS) technique [Ferretti et al., 2001], developed at POLIMI, is a tool for the interferometric processing of long series of SAR data. The PS methodology consists of identifying the targets (the so-called PS) that show an unchanged electromagnetic signature within the images of the analysed dataset. By means of such stable targets

the conventional limits of SAR interferometry (atmospheric artifacts and decorrelation) are overcome and slow deformation phenomena can be measured with millimetric deviation [Ferretti et al., 2000]. Moreover, the estimate of the 3D PS position with metric precision allows generating very accurate digital elevation models (DEM) [Perissin and Rocca, 2006]. Even if the PS technique is an operational tool since 2000, the PS physical nature is still subject of investigation [Ferretti et al., 2005a] and only recently first classification and recognition of the most common SAR targets in urban areas have been developed [Ferretti et al., 2005b]. In this paper we wish to focus the attention on the applications that become possible by knowing the physical nature of the targets.

## Target characterization and recognition

In order to characterize PS's, in [Ferretti et al 2005a] and [Ferretti et al 2005b] three main radar measurements for each target are analyzed: 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 [Perissin and Rocca 2006]. In fact, targets like dihedrals are usually at street level in urban areas (a dihedral consists of two orthogonal faces: very oft streets and something that lies orthogonally to the street).

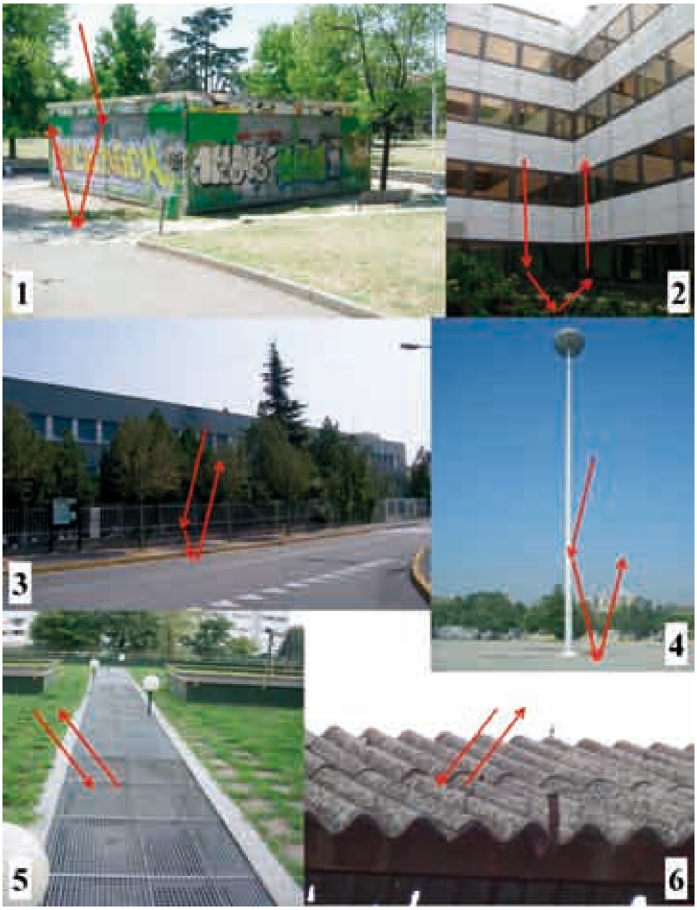


**Figure 1 - SAR target typologies in urban sites: 1) simple dihedral, 2) trihedral, 3) fence acting as resonating dihedral, 4) pole, 5) resonating metal grating, 6) backscattering roof.**

**Table 1 - Summary of the characteristics of the 6 recognized target typologies (+ means greater, - lower). Columns: cross-slant range width $L_{rg}$, azimuth width $L_{az}$, AP phase $\varphi_{AP}$, Radar Cross Section *RCS*, temperature-amplitude coefficient $K_T$, elevation with respect to the ground *h*.**

| | $L_{rg}$ | $L_{az}$ | $\varphi_{AP}$ | *RCS* | $k_T$ | *h* | % |
|---|---|---|---|---|---|---|---|
| **Roof** | + | + | 0 | ∝ dim | + | + | 50 |
| **Grating** | + | + | 0 | ∝ dim | + | - | 11 |
| **Dihedral** | - | + | π | + | - | - | 13 |
| **Resonating Dihedral** | - | + | π | + | + | - | 11 |
| **Pole** | - | - | π | - | - | - | 7 |
| **Trihedral** | - | - | 0 | + | - | - | 8 |

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 [Ferretti et al 2005b]. Amplitude variations as a function of the acquisition geometry depend on the physical extension and on 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) [Ferretti et al., 2005b]. Finally, the auto-interferometric phase of an Envisat alternating polarization acquisition allows one to discriminate between odd and even bounces of radar echoes [Inglada et al., 2004]. By jointly exploiting all these observations, six main typologies of urban SAR targets can be identified, as shown in Figure 1 [Ferretti et al., 2005b]: floor metal gratings, poles, simple dihedrals, resonating dihedrals, trihedrals and roofs (oriented mirrors, corrugated iron roofs, curved surfaces). Table 1 briefly summarizes the characteristics of each target typology and reports the percentage detected in the Milan site. Exploiting such information, a very simple system for the automatic recognition of the target typology can then be developed.
We are now interested in analyzing through some examples three main applications that derive from the knowledge of the physical nature of the targets.

## Main applications

### *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 [Ketelaar and Hanssen, 2003]. In Figure 2 an example of PS detected in the Milan site with a dataset 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 located near the center of Milan. Figure 3 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 (likely structure stabilization).

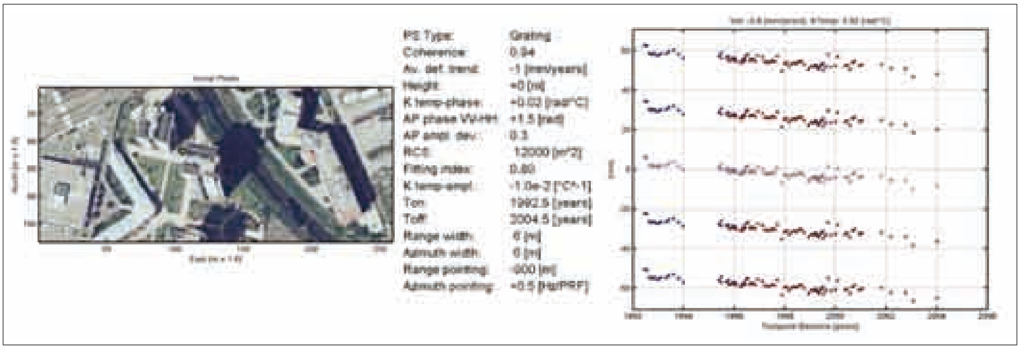


**Figure 2 - PS example in Milan (floor metal grating). Left: aerial photo with a triangle on the PS planimetric position. Centre: physical parameters detected by the radar. Right: displacement [mm] time [years] series.**

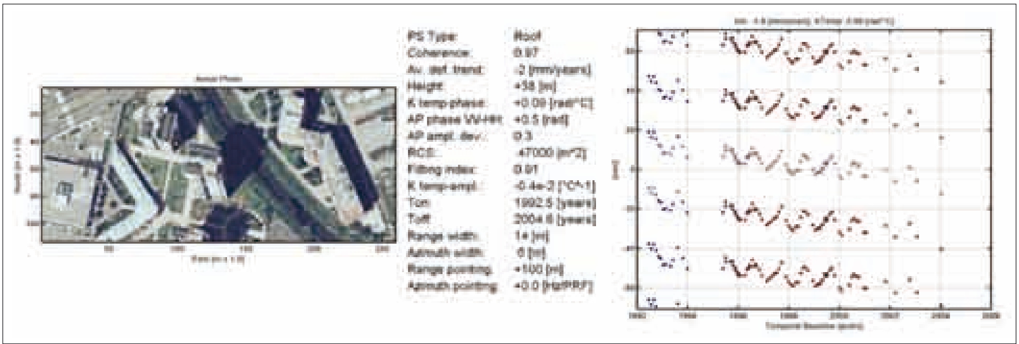


**Figure 3 - PS example in Milan (roof). Left: aerial photo with a triangle on the PS planimetric position. Centre: physical parameters detected by the radar. Right: displacement [mm] time [years] series.**

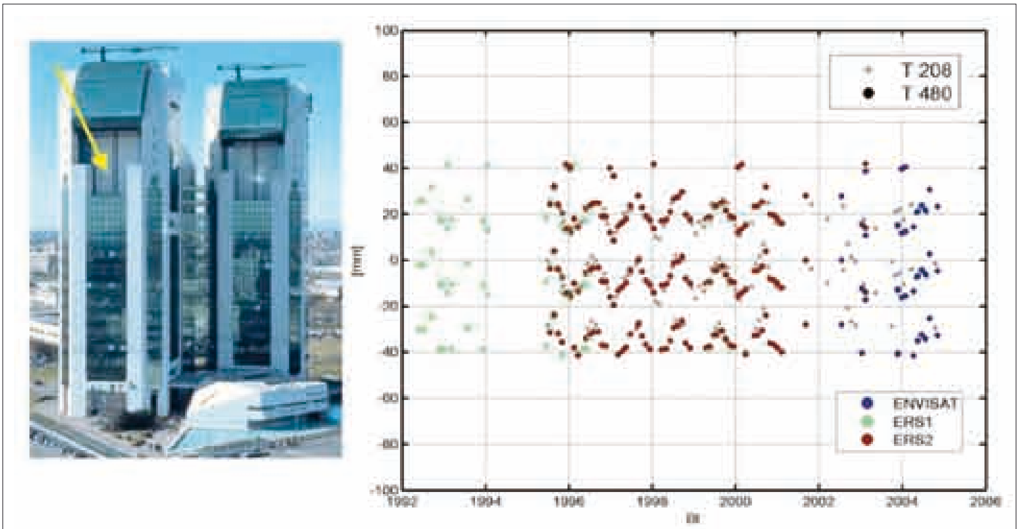


**Figure 4 - Elevated dihedral seen by different sensors in two different adjacent parallel tracks. Stars: track 208, dots: track 480; green: ERS-1, red: ERS-2, blue: Envisat.**

### *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 and, as a consequence, to increase the temporal sampling rate. Dihedrals, for instance, (or trihedrals, but not mirrors) are expected to be visible under different parallel tracks (or slightly different carrier frequencies [Perissin et al., 2006]).

Figure 4 shows an example of a dihedral reflector at an altitude of about 50 m together with its displacement time series measured by ERS-1 (green), ERS-2 (red) and Envisat (blue) 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 datasets confirms that measurements are relative to the same structure.

### *Increase of number of measurement 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 [Perissin and Rocca, 2006]. In fact, the electromagnetic barycenter of a dihedral coincides with its base (the intersection between the ground and the vertical structure). Therefore, its position can be precisely estimated both with classical and radar methods. An example of geolocation of PS datasets detected by two descending and one ascending tracks is reported in Figure 5.

The area covers about 2*x*4 km$^2$ in Milan downtown. The PS density is so high (about 800

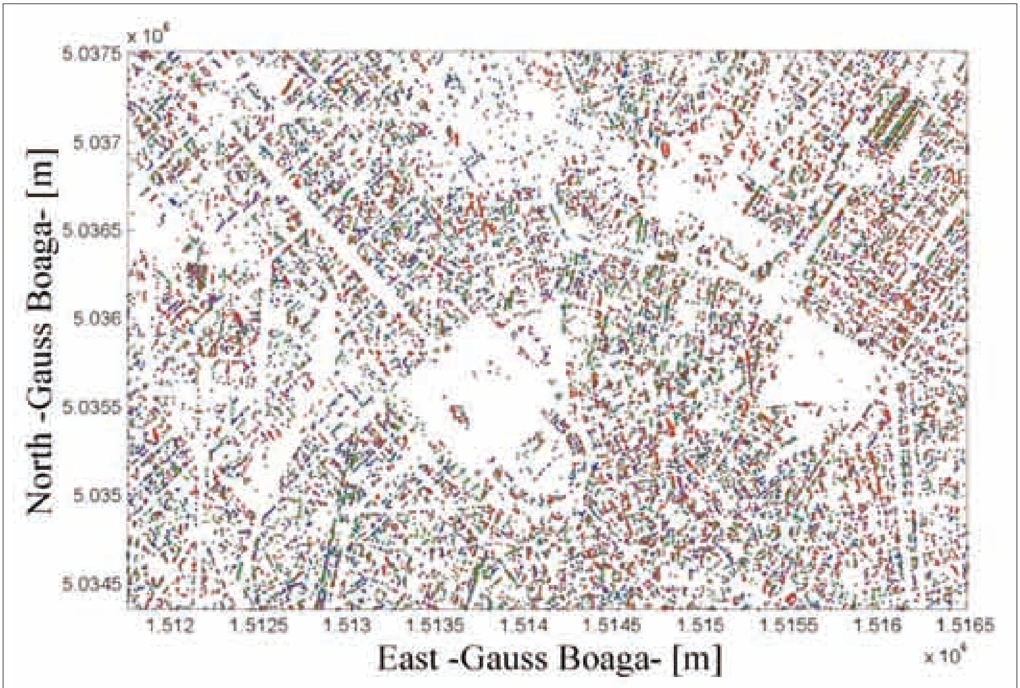


**Figure 5 - PS's detected in Milan in a 2x4km$^2$ area from two descending parallel tracks and an ascending one. Colours denote for each PS the respective track.**

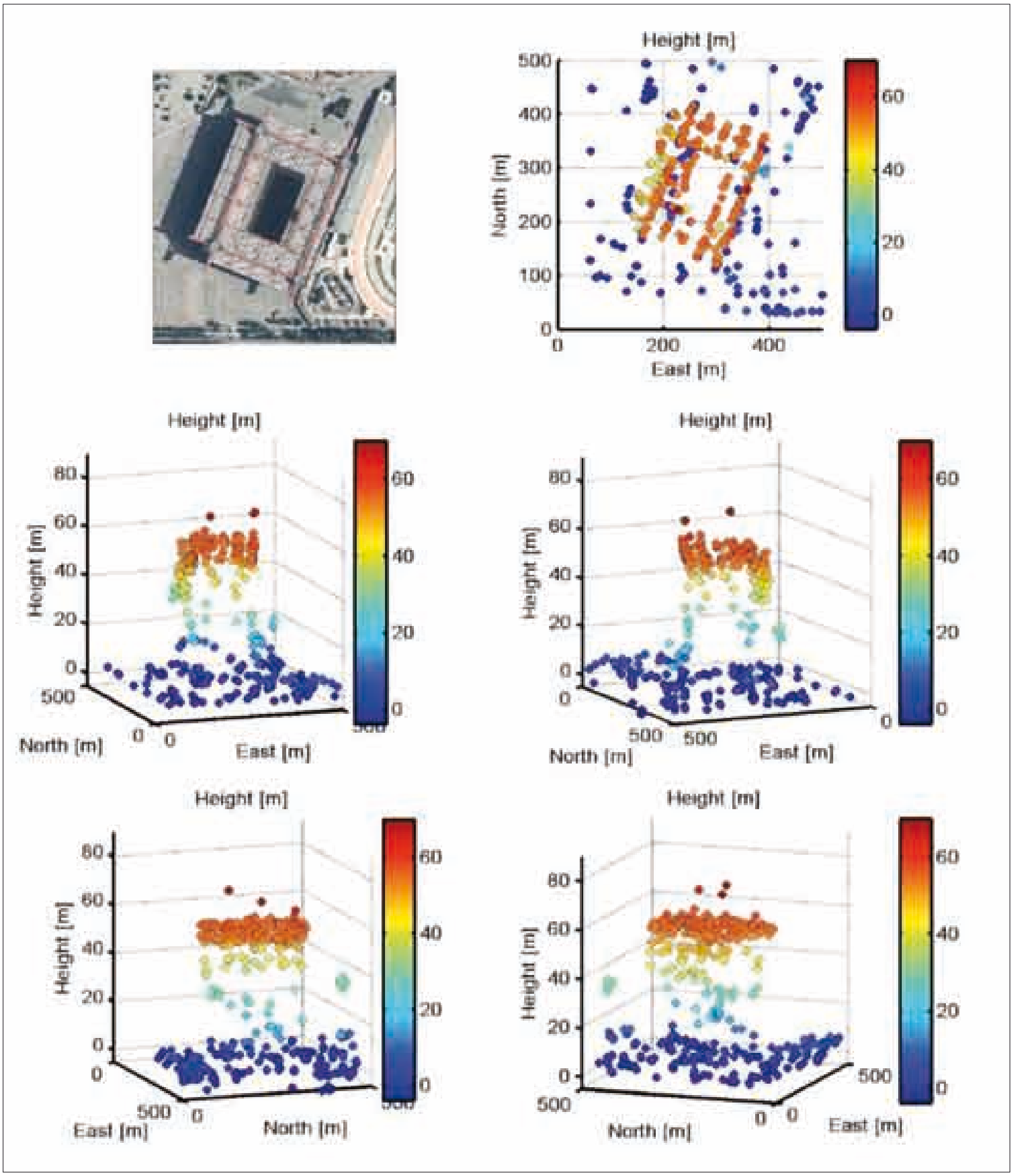


**Figure 6 - Meazza soccer stadium, S. Siro, Milan. Up left: aerial photo. Up right: planimetric coordinates of the detected PS's of two descending parallel tracks and an ascending one. The other four images are 3D views of the PS's. Colour scale: estimated PS height.**

PS per km$^2$) that it is possible to recover the "map" of this area simply looking at the PS positions, with no optical background. For each PS a precise elevation value is available as well: Figure 6 shows an aerial photo of the Meazza Soccer Stadium together with the planimetric coordinates and different 3D views of PS's detected on it from three different satellite tracks. Colour scale of Figure 6 is the PS estimated height. The details of the building highlighted by the PS location are remarkable.

## 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. Thus, it becomes possible to increase the temporal sampling rate of the deformation measurements (by combining data acquired from parallel orbits by means of dihedrals) and to increase of the number of measurement points (combining data acquired from ascending and descending passes by means of poles). Finally, we have shown that knowing the physical nature of the target we are looking at permits the interpretation of the deformation measurements.

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