VALIDATION OF PS HEIGHT ESTIMATES BY MEANS OF PHOTOGRAMMETRY

Daniele Perissin

Politecnico di Milano, Via Ponzio 34/5, 20133 Milano, Italy, Email: daniele.perissin@polimi.it

ABSTRACT

The Permanent Scatterers (PS) technique is an operational tool in the context of spaceborne SAR interferometry for monitoring the displacement of radar targets with millimetric accuracy. Recently, the target localization capability of the PS technique has been subject of study and the possibility of generating DEM's and DTM's by means of the height of a sparse set of points has been evaluated. In this paper, for the first time the PS height estimate has been validated exploiting about 250.000 spot heights at street level derived from photogrammetric techniques in the urban area around Milan. The very high correlation between the two independent measures confirms the theoretical sub-metric accuracy of vertical positioning. A PS DTM has then been generated and compared to the spot heights together with the corresponding SRTM DEM, showing the very high improvement given by the PS technique to the freely available topographic data. The results have been obtained by processing about 300 ERS and Envisat images acquired from 2 descending tracks and an ascending one over Milan.

1. INTRODUCTION

The Permanent Scatterers (PS) Technique [1] detects, measures and monitors ground movement using satellite Synthetic Aperture Radar (SAR) data. Thus, the PS Technique takes conventional SAR interferometry (InSAR) a step forward, by identifying single coherent benchmarks (the PS's) and reconstructing their displacement history. PS's are stable "radar targets" that are located across the Earth's surface and that can be monitored by satellites. When PS's remain coherent within a multi-temporal radar data-set, it is possible to detect and measure millimeter variations in the sensor-target distance, over time. Indeed, the PS's comprise a sort of "natural geodetic network" for accurately monitoring surface deformation phenomena, as well as the stability of individual structures.

In recent time, the capability of the PS technique to precisely localize targets in the 3D space has been subject of study [2]. As a matter of fact, the theoretical precision of target positioning of the PS technique (about 1m) is much higher than the system resolution of the used sensors (20m x 5m on the ground for the ESA ERS and Envisat). Moreover, ESA SAR data archives guarantee nowadays an almost worldwide coverage and the data is accessible at a very low cost. Therefore, it is really interesting to evaluate the possibility of generating DEM's by means of SAR data that: 1) have higher accuracy than freely available height data as SRTM; 2) are much less expensive than the ones obtained with optical or LIDAR techniques.

The main problem to be tackled for creating DEM's by means of the PS technique is the spatial density of measure points. As shown in [2], in urban sites the problem can be solved by combining data acquired from different orbits. In extra-urban areas the task is more difficult because of the lack of coherence and it is still subject of research. In second instance, the quality of the elevation estimated by the PS technique has been not yet fully demonstrated. Indeed in [2] the PS DTM's estimated from different independent orbits have been compared and found in good agreement (dispersion of the estimate in the order of 1m), but up to now no cross-validation with external data has been provided. In this work, for the first time, a high-accuracy SAR PS DTM is compared to 250,000 spot heights at street level derived with photogrammetric techniques in the urban area of Milan. The results assess the very high potentiality of the proposed technique.

2. PRECISION OF PS HEIGHT ESTIMATE

As derived in [2] and [3], by exploiting the full ESA archive (ERS and Envisat data together), taking advantage of the variability of all acquisition parameters (normal baseline, Doppler centroid, central frequency, time and temperature), the interferometric phase can be used to estimate displacement and 3D coordinates of SAR targets. The theoretical precision of the estimate of the target height h can be expressed as a function of the number N of images of the dataset, of the dispersion of their normal baselines σ_{Bn} and of the phase noise $\sigma_{\Delta\phi}$.

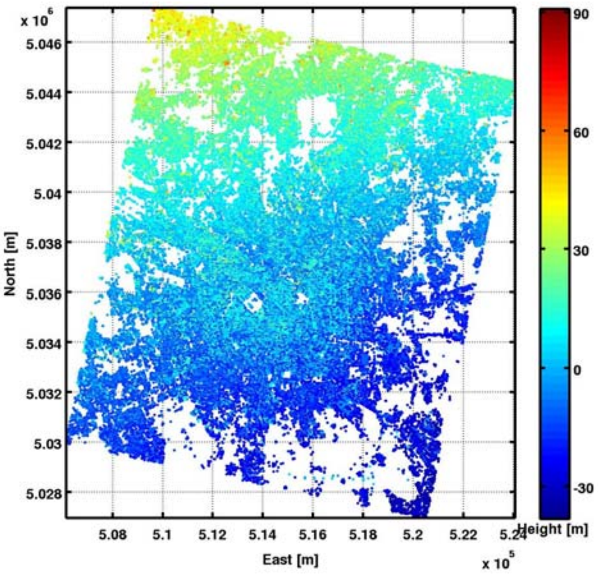

Figure 1. PS's detected in Milan from Track 208 (about 100,000 targets) in Gauss-Boaga coordinates. Color: PS ellipsoidal height with respect to a reference point.

$$\sigma_h^{\ 2} = \left(\frac{\lambda R_0 \sin\theta}{4\pi} \right)^2 \frac{\sigma_{\Delta\phi}^{\ 2}}{N\sigma_{Bn}^{\ 2}} \qquad (1)$$

where λ is the wave-length, θ the incidence angle and R_0 the sensor-target distance. Using N=60 ERS images (incidence angle θ=23°, baseline deviation σ_{Bn}=480m), a PS with coherence γ=0.8 can be theoretically positioned with 30cm of height uncertainty. It is worth

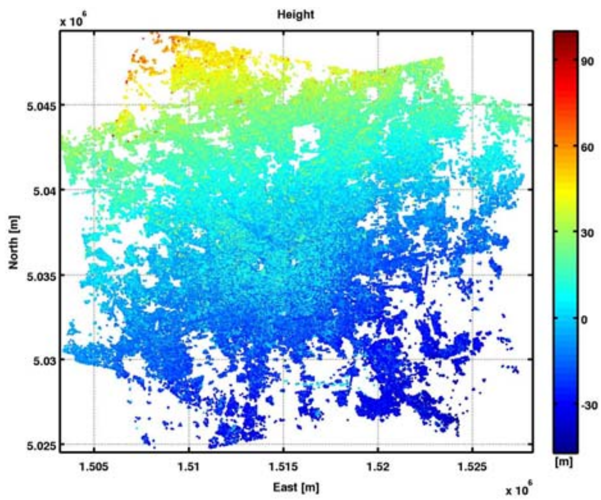

Figure 2. PS's detected in Milan from 2 descending parallel tracks (T208 and T480) and an ascending one (T487) (more than 300,000 targets). Color: PS ellipsoidal height with respect to a reference point.

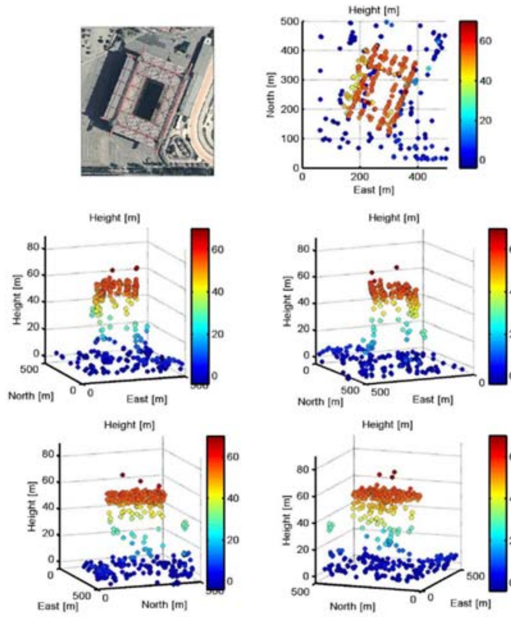

Figure 3. PS's detected on the Meazza soccer stadium, San Siro, Milan from 3 tracks. Color: PS height. Above: optical photo and PS planimetric coordinates. The other 4 images are 3D views.

noting here that, as analyzed in [2], such precision can be achieved only by adopting some processing tricks to avoid positioning artifacts and to correctly manage sub-pixel quantities. It has also to be pointed out that the implementation of the geocoding process is fundamental for avoiding spurious planes of the estimated DEM. Orbital uncertainty must be corrected in order to get reliable DEM estimates.

Figure 1 shows more than 100,000 PS's detected in

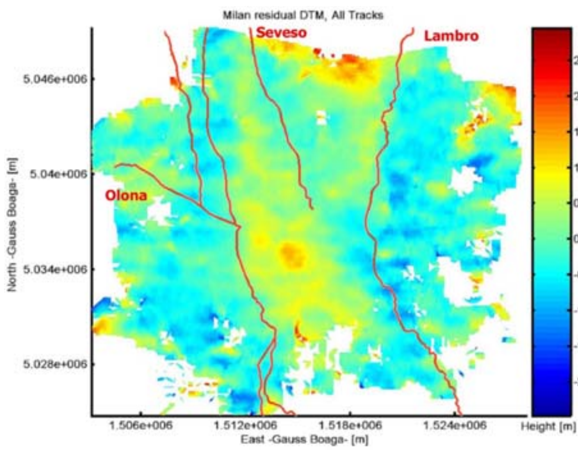

Figure 4. Milan DTM retreived from PS on the ground detected from 3 tracks. A second order surface has been removed to better appreciate details. Red lines: watercourses in Milan.

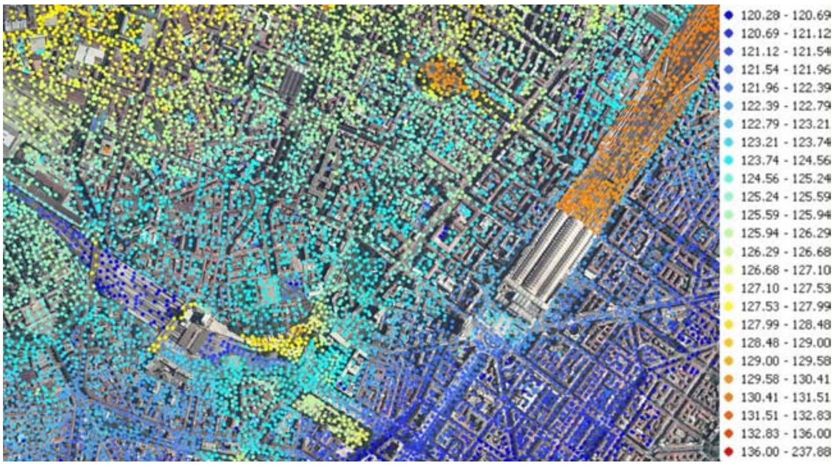

Figure 5. Spot heights derived from photogrammetric restitution in Milan.Color: geodetic height. The spot heights lie on streets, roads, flyovers, rail tracks.

Milan in 350km^2. The coordinate system is the Italian Gauss-Boaga. The color scale in Figure 1 denotes the height of the targets with respect to a reference point, highlighting the slope of the plane on which Milan lies but also many details of the city surface.

3. MULTI-TRACK COMBINATION AND URBAN DTM RETRIEVAL

As already mentioned, the main defect that stands out from Figure 1 is the relative low spatial density of the targets. The study on the physical nature of PS in urban sites, carried out in the last years [4], has allowed the recognition of multi-track targets as dihedrals and poles, which are very useful to connect data acquired by different orbits with sub-metric precision, thus increasing significantly the number of measurement points. As an example, Figure 2 shows more than 300,000 PS's estimated in 2 descending and 1 ascending tracks over Milan. The reached density is such as to appreciate details on the single building, as visible in Figure 3, where the PS detected in the 3 tracks are plotted in 3D coordinates around the Meazza soccer stadium, San Siro, Milan.

By analyzing the local distribution of the PS height in urban sites (without a-priori information on the topography), it was discovered that most targets lie on the ground. Discarding elevated points, it becomes then possible applying a spatial filtering and resampling the height data on a regular grid to retrieve a digital elevation map. Figure 4 reports the DTM estimated in

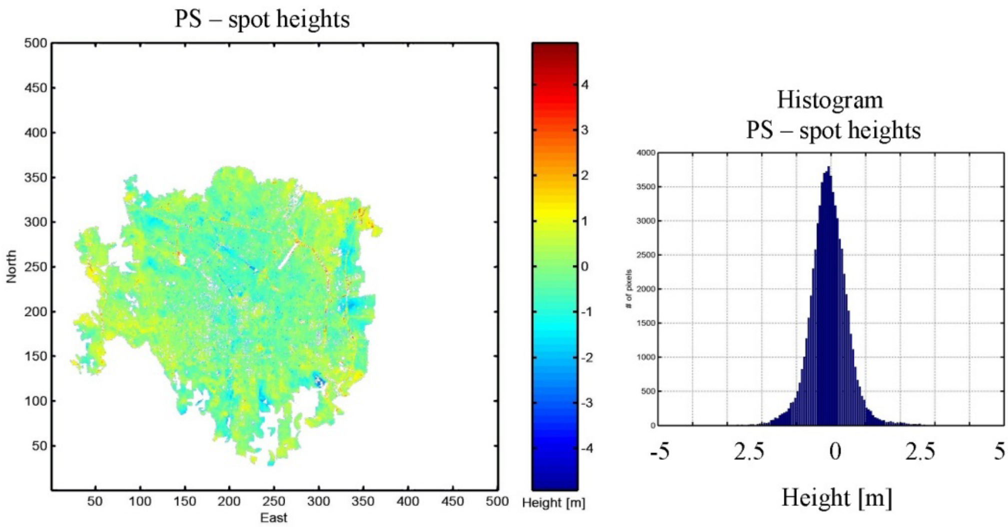

Figure 6. Difference between PS and spot heights DTM. Left: in planimetric coordinates. Right: histogram of the difference values.

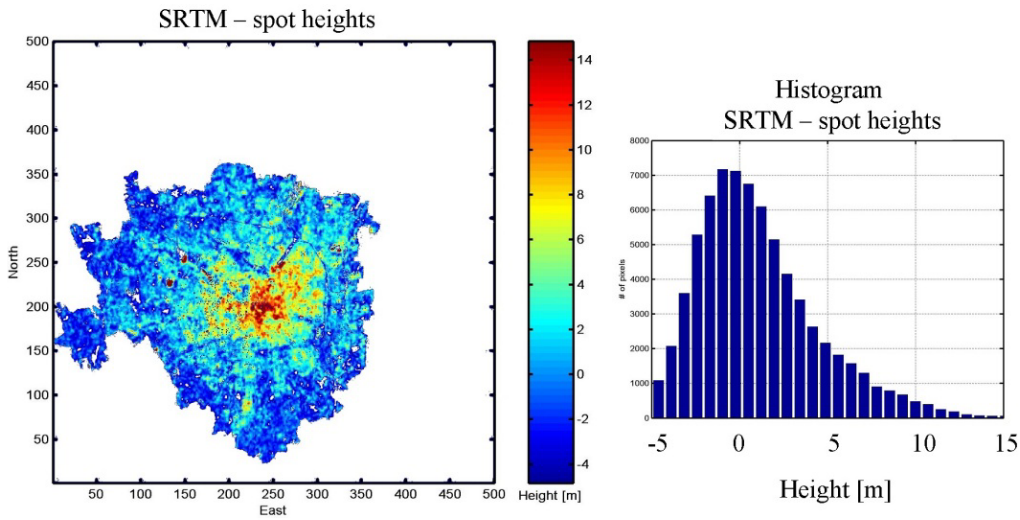

Figure 7. Difference between SRTM and spot heights DEM. Left: in planimetric coordinates. Right: histogram of the difference values

Milan, after removal of a second order surface for better appreciating the high-quality details. The color scale range of Figure 4 is -3÷3m. The red lines in the image are the main watercourses in Milan, and they are in correspondence of the blue depressions. The red prominence in the middle is the historical center of Milan.

4. PHOTOGRAMMETRIC SPOT HEIGHTS

By courtesy of the Territorial Information System Office of Milan municipality, the PS height results achieved in Milan could be compared to about 250,000 spot heights retrieved by means of photogrammetric restitution. To give an idea of the spatial resolution of such data, Figure 5 shows a close up near the Railway Central Station of Milan. The spot heights are plotted on an airborne optical image and their color is function of the geodetic height ranging values between 120m and 136m. The nominal accuracy of the elevation data is 20cm. A very interesting property of these spot heights is that they have been selected among the points at street level (considering also subways and flyovers). In fact, observing the image in Figure 5, on the left some road crossing Garibaldi railway and on the right the rail tracks on the back of the Central Station are easily recognizable. This property comes out very useful when comparing the height of the single scatterers to the spot heights.

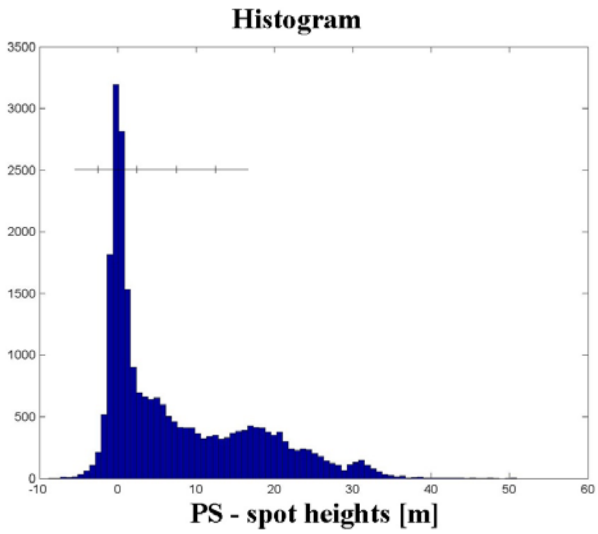

Figure 8. Histogram of the PS elevation referred to the closest spot height. The width of the main peak is the variance of the estimate of the PS height. Most PS's are at street level.

5. CROSS-VALIDATION

Two different strategies were chosen to compare PS and spot heights data. The first one is aimed to validate the digital terrain map retrieved with the PS technique as previously described (is it correct the assumption that we are able to select the targets that lie on the ground without a-priori information?). The second one achieves the purpose of assessing the accuracy of the height estimate of the single SAR target.

To reach the first objective the spot heights were resampled on the same grid of the PS DTM. Then the difference between the PS and the spot heights DTM's is computed pixel by pixel. Figure 6 shows on the left the difference in planimetric coordinates. Note that the overlapping area between PS and spot height is about one half the PS area. It is worth observing the quality of geocoding (no slope is evident). On the right of Figure 6 the histogram of the differences is reported.

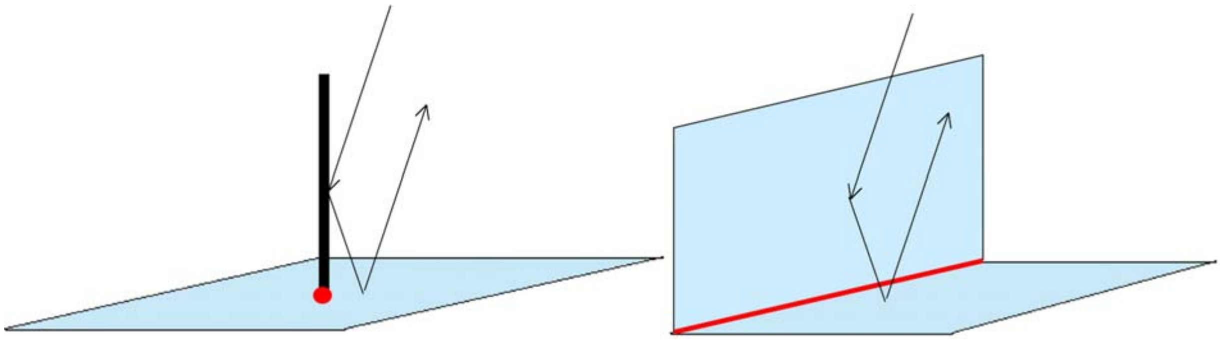

Figure 9. Examples of PS at street level in urban sites: poles and dihedrals. The electromagnetic barycenter of such targets is the intesection between the ground plane and the vertical structure (a point for a pole and a line for a dihedral). The PS technique estimates the height of the target e.m. barycenter.

The standard deviation between the two measures is in the order of ten cm. It is now interesting to make the same comparison with the freely available SRTM data. The result is shown in Figure 7. Again, on the left the difference is plotted in planimetric coordinates and on the right the histogram of the difference values is reported. As known, the accuracy of the SRTM height is about 10m. Moreover, Figure 7 clarifies that SRTM data interpolates the height values and do not extract the terrain level. On the contrary, Figure 6 validates the proposed technique for DTM generation by means of PS data.

The second goal is achieved by finding for each PS the spot height with planimetric coordinates nearest to it. Then the height difference between them is computed and the histogram of the difference values is shown in Figure 8. The first information we get from Figure 8 is the width of the peak: the accuracy of the height estimate of the single target is less than 1m. The second information is that the very highest part of urban PS's is at the same level of the spot heights. But these spot heights were selected among those staying at street level. This means that most PS's are on roads and streets and reveals again the multi-bounce nature of most urban SAR targets (dihedrals, poles, trihedrals [4]).

6. PHYSICAL CONSIDERATIONS

It is worth stressing the importance of the obtained results. The resolution of the SAR system (ERS case) is 20m x 5m on the ground. Considering a normal baseline range of 2km, the height of the resolution cell is about 10m [1], [2], [3]. Thus, a Permanent Scatterer could be formed by the interaction of elementary scatterers randomly distributed within a 1,000m^3 volume cell. The ensemble of elementary scatterers then shows an electromagnetic barycenter whose height is estimated by the PS technique. Under such a condition, the estimated height would be affected by a random error due to the unknown virtual position of the electromagnetic barycenter. The real height estimate would then be biased and the theoretical precision of 30cm derived in Paragraph 2 would not correspond to an actual accuracy. But what is being observed from the data, in accordance with the study on the physical nature of the targets [3], [4], is that only a little part of PS's derives from the combination of many scattering centers. Many PS's are basically dihedrals, trihedrals or poles. The barycenter of such targets is the intersection between the ground plane and the vertical structure, as shown in Figure 9. Thus, the height estimated by the PS technique has a physical correspondence. The results of the comparison between PS and spot heights (in particular Figure 8) confirm such interpretation. In case of poles (whose barycenter *is* pointswise), the PS analysis, being capable to localize a target within 1m^3 cube, realizes a physic super-resolution of a factor 1,000 with respect to the initial resolution. Finally, these considerations stress again the importance of knowing what kind of targets the radar looks at, to correctly interpret the data.

6. CONCLUSIONS

In this work for the first time a validation of the PS height estimate has been provided by means of photogrammetric data. Moreover, the capability of detecting targets on the ground and consequently to generate accurate DTM's with the PS technique has been assessed. 250,000 spot heights derived from photogrammetric restitution have been compared with more than 300,000 PS's detected from 3 different orbits (2 parallel descending and 1 ascending) around the city of Milan, showing high correlation.

7. ACKNOWLEDGMENT

The author is very thankful to the Territorial Information System Office of Milan municipality for providing the spot heights data, to ESA for ERS and Envisat images (COPEESAT project, id. C1F.1412) and to TRE TeleRilevamento Europa for focusing SAR data.

REFERENCES

[1]. Ferretti A., Prati C., Rocca F., (2001). Permanent Scatterers in SAR Interferometry, *IEEE TGARS*, Vol. 39, no. 1, 2001.
[2]. Perissin D., Rocca F., (2006) High accuracy urban DEM using Permanent Scatterers, *IEEE TGARS*, Volume 44, Issue 11, Pages: 3338 – 3347.
[3]. Perissin D., Prati C., Engdahl M., Desnos Y.-L., (2006). Validating the SAR wave-number shift principle with ERS-Envisat PS coherent combination, *IEEE TGARS*, Vol. 44, Issue 9, Pages: 2343 - 2351.
[4]. Ferretti A., Perissin D., Prati C., Rocca F., (2006). On the physical characterization of SAR Permanent Scatterers in urban areas, Proceedings of 6th European Conference on Synthetic Aperture Radar - EUSAR 2006.