Persistent scatterer pair (PSP) Interferometry and Surface Reconstruction Techniques for Urban DSM from High Resolution Satellite SAR Acquisitions

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1. INTRODUCTION

Synthetic aperture radar (SAR) interferometry and radargrammetry are two well-known technologies for generating digital surface models (DSMs) from SAR data acquired from satellite or airplane. However, standard SAR interferometry and radargrammetry have strong limits for the derivation of DSMs over urban areas, due to the complexity of urban scenarios and the need for very high precision to reconstruct building shapes. Therefore, DSM or 3D models of urban areas are currently produced practically only based on photogrammetric or Lidar technologies. However, there are important reasons to consider also SAR data for the realization of urban DSMs. In fact, several areas in the world are not accessible by photogrammetric or Lidar technologies, due to frequent cloud coverage, or political or economical reasons. On the contrary, the existence nowadays of several high resolution satellite SAR missions can make available valuable data all over the world without the above mentioned limitations. In particular, the four satellites of the COSMO-SkyMed mission have been acquiring series of interferometric images over all main cities and sites of interest of the world.

In this work, we propose the realization of urban DSMs from high resolution satellite SAR data: advanced interferometry techniques can provide a cloud of points (persistent scatterers – PS) localized with metric precision in the 3D space; then surface reconstruction techniques applied to this point cloud are used to calculate the urban surface model. For the first step it is important to use advanced interferometric techniques able to provide a cloud of points as dense as possible. The second step remains critical because the PS points are in any case very sparse and not distributed homogeneously. However, a priori information on the distribution of the PS and on the structure of the urban scenario can be exploited to help the surface reconstruction.

2. INTERFEROMETRY TECHNIQUES

Persistent scatterer interferometry, founded on the idea (first introduced in [1]) of analyzing long series of full resolution SAR images, allows detecting and locate in the 3D space a set of sparse points that remain correlated at different acquisitions, named persistent scatterers (PS). More recently, we developed the persistent scatterer pair (PSP) method [2-4], based on the idea of both identifying and analyzing PS working only with pairs of points...
which makes the methods insensitive to spatially correlated signals such as atmospheric or orbital artifacts. In particular, the enhanced PSP algorithm searches for an optimized set of arcs connecting pair of points in order to fully test all the image pixels as potential PS, and significantly improves the already very good performance of the standard PSP approach. This makes possible to identify (and locate in the 3D space with metric precision) a large number of PS, corresponding to practically all SAR image pixels where you could expect a coherent signal, even when there are not strongly scattering structures and the sensed signal is low. The method is capable to select PS also in parts of the structures where standard techniques are not able to extract information (see Figure 1), and is very useful to build dense point clouds from which to reconstruct urban DSMs.

In order to assess the precision of the PSP measurements from COSMO-SkyMed data, we evaluated the statistics of the height measurements obtained from of 30 COSMO-SkyMed ascending Stripmap SAR images acquired from February 2011 to June 2013 in an area near Novara, Italy, with baselines spanning 1590 m on the flat roofs of two industrial buildings (see Figure 2). Results show that the standard deviation of the height measurements is about 0.7 m.

It is worth mentioning that another approach to consider in the problem of collecting point clouds for urban DSM is SAR tomography [5-6], a technique that allows detecting (and locate in the 3D space) PS points by processing the whole complex information of the SAR images. The tomographic technique requires a preliminary calibration of the data (that can be performed for example also with the PSP method), in particular to remove atmospheric components from the phase. Tomography is particularly important to analyze buildings in detail, since allows detecting different scattering mechanisms mixed in a single pixel of the SAR image, a frequent circumstance in urban areas.
3. SURFACE RECONSTRUCTION

The problem of surface reconstruction from point clouds has several applications (e.g., medical scanners, laser range finders, vision techniques, Lidar). The general problem is known as surface reconstruction from unorganized points, and several methods have been proposed to solve it [7], [8].

We have performed several experiments, on simulated and real data, for obtaining a 3D model from SAR-derived cloud of points, testing different surface reconstruction algorithms among which, Screened Poisson [9], Power Crust [10], Hoppe et al. [11]. Ball pivoting is a simple but effective algorithm that we mostly used for our preliminary tests. It computes a triangle mesh interpolating a given points cloud. The principle is very simple: three points form a triangle if a ball of a user-specified radius \( r \) touches them without containing any other point. Starting with a seed triangle, the ball pivots around an edge (i.e. it revolves around the edge while keeping in contact with the edge’s endpoints) until it touches another point, forming another triangle. The process continues until all reachable edges have been tried, and then starts from another seed triangle, until all points have been considered. The relatively small amount of memory required by the BPA, its time efficiency, and the quality of the results obtained compare favorably with existing techniques.

In general, for all types of surface reconstruction algorithms, the surface reconstruction from the PS point clouds generated by interferometry techniques is very difficult, because the PS points are very sparse and not distributed homogeneously. In order to improve the results, it is important to exploit the highest SAR resolution data and it is useful to exploit some a priori information on the distribution of PS (e.g., their tendency to accumulate along the borders of roofs and roads), and on the structure of the surface to be reconstructed (mainly vertical and almost horizontal surfaces).
4. FIRST TESTS

In order to verify the potential of the proposed method some preliminary tests were performed using COSMOSkyMed SAR data. The results (see Figure 3), obtained using stripmap data (3 m ground resolution) acquired over Rome, Italy, demonstrate the high potential of the proposed method for building urban DSM in areas of the world not easily accessible by photogrammetric or Lidar technologies (e.g. due to frequent cloud coverage, or political or economical reasons). More complete tests are in progress and will be included in the final paper and in the

Figure 3: Example of urban DSM and surface reconstruction of the Saint Peter area, Rome, Italy, obtained from an interferometric stack of COSMO-SkyMed image stripmap SAR images. The top images (at different zoom levels) highlight that the obtained DSM follows with a good detail buildings and streets (except for vegetated areas and water bodies). The bottom images show the PS cloud obtained for the Saint Peter basilica, and the corresponding surface reconstruction. It is important to note that these results were obtained with COSMO-SkyMed SAR data acquired in the stripmap mode (3 m resolution), and that much more details could be obtained with spotlight (1 m resolution) acquisitions.
presentation. In particular, the use of very high resolution COSMO-SkyMed spotlight SAR data (1 m ground resolution) will greatly improve the quality of the obtained urban DSM. Moreover, it is expected that the performance of surface reconstruction techniques can be improved by introducing in the processing a priori information on the distribution of PS and the typical structure of the urban scenario.

4. REFERENCES


