A Kalman Smoothing Approach for Surface Deformation Monitoring in Differential SAR Interferometry

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Abstract— **This paper presents a Kalman smoothing approach for estimating the temporal evolution of terrain deformations, using a chronologically ordered sequence of differential synthetic aperture radar interferograms spanning a long time interval. The proposed method assumes that the interferograms are formed with respect to the same master image and that the data pairs used to generate the interferograms can have orbital separations (i.e. baselines) up to the decorrelation baseline or even larger. The algorithm presented next applies to every highly coherent pixel (known as permanent scatterers) in the image and it is independent of the interferometric processing of the SAR images; so it is essentially a post-processing step. Since it's supposed that all the SAR images are available for batch processing, the proposed algorithm is naturally a smoother. The Kalman smoother reported thereafter can be exploited successfully to estimate the line-of-sight surface deformation of a vast area. This technique has been tested on simulated deformation data and it has demonstrated an excellent capability to track the ground deformation dynamics with a high accuracy.**

Index Terms—**Ground deformations, Kalman smoothing, synthetic aperture radar (SAR), differential SAR interferometry (DInSAR).**

I. Introduction

Differential synthetic aperture radar interferometry (DInSAR) represents a reliable and accurate remote sensing method to observe Earth surface deformation phenomena on a large scale and at low cost [1]. DInSAR was successfully used to monitor single deformation episodes, like the ones caused by earthquakes or volcanic events, for the monitoring of subsidence, landslides in alpine zones and soil instability, and for the measurement of glacier movements [2]. This technique is based on the generation of the interferometric phase of a couple of complex SAR images of the same scene, collected at different time instants and with different baselines. Since the differential phase is related to the scene topography and to terrain displacement, after the removal of the topographic component, an estimate of the displacement along the line-of-sight (LOS) to the radar sensor is possible in theory; the estimation accuracy of surface displacements can be of the order of the millimetre. The main limitation of DInSAR, especially for the retrieval of slow deformations, is the temporal and geometrical decorrelation; these are due, respectively, to the low coherence between two SAR images gathered at different times and with a large orbital separation [3]. Another limitation lies in the presence of phase variations caused by the fluctuations of the atmospheric refraction index as a result of the atmospheric inhomogeneities. Despite several potential errors may come out because of the aforementioned limitations, it has been shown [1] that a number of image pixels, hereafter called permanent scatterers (PS), that are coherent over long time intervals can be identified. The proposed algorithm, which is based on Kalman smoothing, applies to these pixels in the image. The permanent scatterers approach allows the generation of the interferograms even if the data pairs are characterized by large temporal and spatial baselines (even larger than the critical baseline [1]); in this way a full utilization of the available SAR images is possible, at the expense of the image pixel density. This paper is structured as follows. Section II describes the interferometric data processing needed to generate the data on which the smoothing algorithm can be used. Section III gives an in depth description of the proposed Kalman smoothing algorithm for terrain deformation monitoring. Simulation results are showed in section IV. Conclusions are addressed in section V.

II. Interferometric Data Processing

The technique presented next can be applied to the highly coherent pixels (PSs) of a chronologically ordered sequence of DInSAR interferograms, which are generated with respect to a common master image. For the applicability of the proposed algorithm, it's intended that the interferograms have been previously unwrapped and that the topographic component has been subtracted. As a result, the Kalman smoothing algorithm is independent of the interferometric processing itself, so it can be considered as a post-processing step applied to a set of DInSAR interferograms generated via an already available interferometric data processing technique.

III. Kalman Smoothing

Consider a set of $N+1$ SAR images of the same geographical area, acquired at the ordered times $\{t_0, t_1, \cdots, t_N\}$. From these images, a sequence of N interferograms can be generated with respect to the same master image that, for the sake of simplicity, is the image gathered at time $t = t_0$. As already stated, the data pairs are allowed to have baselines up to