An Optimized Algorithm for InSAR Phase Unwrapping Based on Particle Filtering, Matrix Pencil, and Region-Growing Techniques

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***Abstract*—This letter presents a new phase unwrapping algorithm for synthetic aperture radar interferometry which combines a particle filter, a matrix-pencil (MP) local slope estimator, and an optimized region-growing technique. The advantages of the new method rely on the following contributions: The MP estimator provides better resolution to the local slope estimation, the particle filter enables simultaneous unwrapping and filtering without *a priori* statistics constraints, and the implemented region-growing technique adds diversity of unwrapping paths and ensures an optimum solution. Results introduced in this letter illustrate the main aspects of the new approach.**

***Index Terms*—Matrix pencil (MP), particle filter, phase unwrapping (PU), region growing, state space, synthetic aperture radar (SAR) interferometry.**

I. Introduction

In previous works, the authors presented some phase-unwrapping (PU) algorithms based on the use of state-space techniques, such as the grid filter [1] and the particle filter [2]. The skeleton of these algorithms incorporates two main stages that are executed for every pixel. The first one, known as prediction stage, makes use of the previously unwrapped neighbors and the information provided by a local slope estimator to obtain a prediction for the unwrapped phase at a certain pixel. The second stage, known as update stage, incorporates the measurement (interferometric phase) at the pixel. Then, a filter combines prediction and measurement to obtain the optimal solution for that pixel, based on their covariance matrices, thus providing filtering and unwrapping simultaneously.

Regarding the filter, there are several options with different performances and different features from the view point of the state-space approach. For instance, an extended Kalman filter can be employed [3], and it propagates (i.e., maintains for future use for the rest of pixels) only the adopted solution state and the covariance matrix. In case of applying a particle filter [2], the algorithm maintains both the solution state and a selection from the rest of state candidates (also known as particles). This selection is performed by a third stage known as resampling, and only the states whose associated weights are the highest are maintained.

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Finally, a search strategy can be incorporated to add the capability of selecting the best pixel among all the candidates to be unwrapped at each time.

Among all the versions of the algorithm presented so far, the 2PFPU, which states for the monoseed path following version of the Particle Filter PU (PFPU), was demonstrated in [2] to be a very robust PU tool. This solution combines a particle filter, a local slope estimator based on the mode of the power spectral density (PSD) [3], and a monoseed path following search strategy [4].

In this letter, an improved PU solution is proposed. This solution also makes use of a particle filter, like the 2PFPU algorithm, but it incorporates two important differences which improve the overall performance of the approach. First, the local slope estimator based on the mode of the PSD has been replaced by a matrix pencil (MP) based one, since more accurate local phase slope predictions are expected from such a superresolution approach and smaller estimation windows can be employed. Second, an optimized region-growing strategy is used to drive the PU paths. As described later, the region-growing approach used here is optimum because only the pixel whose cost function is the best among all regions will be unwrapped at every step. The whole resulting method is more robust than previous ones because it can unwrap zones which other PU approaches simply mask or fail to unwrap, as illustrated in this letter with some examples.

This letter is organized as follows. Section II introduces the basics and advantages of using a particle filter for PU. Section III justifies the use of the MP-based local slope estimator. The optimized region-growing technique is presented in Section IV. Then, Section V illustrates the performance of the new method with some examples from both synthetic and real interferograms. Finally, conclusions are drawn in Section VI.

II. Particle Filtering

The particle filter was introduced in [2] to simultaneously perform filtering and PU. The Extended Kalman Filter introduced in [3] shares the same objective. However, the particle filter was shown to achieve better results than the Extended Kalman Filter since the latter is limited to Gaussian models, whereas the particle filter (PF) can model any kind of noise distributions. Note that the noise present in real interferograms is a marginal density distribution of the Wishart one.

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