Two-dimensional phase unwrapping integrating deep learning and minimal cost flow

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InSAR can measure surface deformation in all-weather conditions and has been widely used to study landslides, land subsidence, and many geophysical processes. Since the phase of radar echo is measured in 2π rad modulo (wrapped), phase unwrapping is an indispensable step for InSAR, and its reliability directly determines the feasibility of deformation monitoring. However, temporal and spatial decorrelation often leads to severe noises, localized deformation or strong atmospheric turbulence may result in dense fringes, both making traditional unwrapping methods fail in acquiring continual unwrapped phases. Here, we present a deep convolutional neural network (DENet) to identify the probability of phase discontinuities between every two adjacent pixels in the interferogram and apply the probability as cost in the widely-used minimal cost flow solver to achieve phase unwrapping. To train the network effectively, we design a simulation strategy to generate sufficient training samples: the terrain-related phases are used as the background phases, and the deformation phases, atmospheric turbulence phases, and noises are superimposed to build the training samples. Unlike classical methods such as GAMMA and SNAPHU that use the coherence map as the quality index, we use the probability of phase discontinuities estimated by the DENet as the arc-cost of the minimum cost flow problem. We apply the proposed method to unwrap simulated and real interferograms and compare the results with 8 existing methods (including traditional and deep learning-based ones). On the simulated data set, the root-mean-square error (RMSE) of the proposed method is lower than all the 8 existing methods. We also test different methods to unwrap the real Sentinel-1 interferograms and verified the reliability using ALOS-2 data with a nearly identical acquisition period. Our results show strong robustness and stability when unwrapping very large interferograms with complicated phase patterns. The proposed method takes advantages of both deep learning and traditional minimal cost flow solver, which can effectively unwrap interferograms with low coherence and/or dense fringes, providing strong potential for large-scale SAR interferometry applications.