Virtual Research Presentation Conference

Fast 2D Phase Unwrapping for Large Scale Global Coverage Datasets.

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Program: (Spontaneous Concept)

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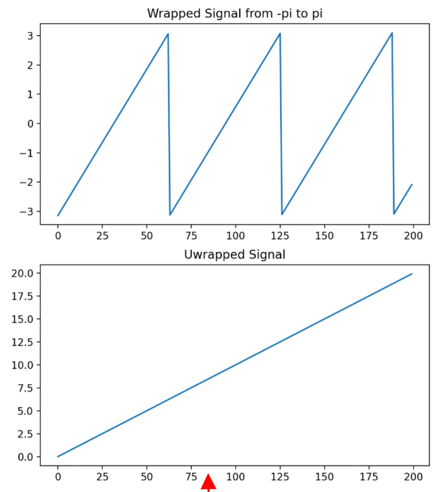
Tutorial Introduction

Phase of the returned signal is only defined between [$-\pi,\pi$)



Discontinuous wrapped signal unwrapped into a continuous one

Abstract

Interferometric Synthetic Aperture Radar [1,2,3] (InSAR) is a air and spaceborne technique adopted to measure centimeter level deformations using two different SAR acquisitions and computing the returned signal phase difference. The most time consuming step in InSAR processing is the 2D phase unwrapping where the discontinuous signal is turned into a continuous one (see Fig on the right). The generation of interferometric images could cost over $12M to the NISAR mission when performed on a cloud service and half of this cost is due to the unwrapping stage.

The current state of the art algorithm Snaphu [1] is very accurate but its complexity is $O(N^2)$ where N is the number of image pixels. Because of its complexity $O(N^2)$ downsampling each dimension of the image by two will result in a speedup by a factor $(2x2)^2 = 16$. However rare events such as earthquakes and volcano eruptions tend to create displacements that are large enough to induce errors if unwrapped at a resolution that violates the Nyquist-Shannon sampling theorem. We developed an approach that uses Machine Learning to determine at runtime if the image requires to be unwrapped at low or high resolution and that could potentially reduce the processing cost by a factor of three.

Problem Description

- New paradigm shift in InSAR processing.
  - Level 2 processing no longer limited to selected users and areas.
  - NISAR mission will provide not only Level 1 but also Level 2 and 3 products on global scale.
  - Processing fully performed on cloud environment i.e. pay as you go model.
  - Unwrap could be up to 50% of the interferometric image generation.
  - Any speedup of the unwrap stage will result in mission cost reduction.
- Compared to state of the art our approach provides at least 3x speed up.
- Estimated costs of the unwrap processing for the NISAR mission is about $6M. A 3x speed up will save $6M.

Methodology

- General Approach:
  - Exploit complexity of state of the art algorithm to perform unwrapping faster by downsampling inputs and upsampling the results.
  - Only rare events generate deformations that cause unwrapping errors when performed at low resolution.
  - Use Machine Learning (Random Forest [5]) to determine the likelihood of unwrapping errors when operation is performed at low resolution.
  - Use high resolution unwrapping only when there is a chance of unwrapping errors when performed at low resolution.
- Experiment:
  - Identified features that are strong indicators of a potential unwrapping error. Features selected are:
    - Image coherence (low values indicate poor signal and high chance of error. Earthquakes cause decoherence).
    - Rate of discontinuity in wrapped image (indicates a large displacement).
    - Maximum displacement in the unwrapped image at low resolution (large displacements in the low resolution image indicates potential even larger displacements in the high resolution one that the algorithm might have missed).
  - Used know events that caused unwrapping errors and created templates.
  - Applied random affine transform (rotation and stretching) and scaling (changing magnitude) on templates to generate new images with unwrapping errors.
  - Generated dataset with negative signals (i.e. images that DO NOT FAIL when unwrapped at low resolution) and positive signals from the templates (images that FAIL when unwrapped at low resolution). Negative signals 81% of the data. Positive signals 19% of data.
  - Split dataset for training and testing.
  - Trained Random Forest model to correctly classify the positive and negative signals in training set.
  - Computed performance metrics by applying model to unseen test set.

Precision P = TP/(TP + FP)	Recall R = TP/(TP + FN)	F1 = 2*P*R/(P + R)
0.999	0.961	0.98

Results

- In this project we were able to train a Machine Learning model that can accurately detect if an image needs the slow high resolution unwrapping or the fast low resolution one.

- When all the steps are taken into account i.e.
  - Downsampling
  - Processing at low resolution
  - Classify results with ML algorithm
  - Upsample if ML algorithm predicts no potential unwrapping errors or
  - Reprocess images at high resolution if ML algorithm predicts potential unwrapping errors

  the total speedup of the unwrapping stage is 3.1x (or ⅔ time saving).

- Given that the unwrapping stage is 50% of the InSAR processing the cost saving is ½ x (⅔) = ⅓.

- The saving for the NISAR mission processing costs could be of the order of $12M x ⅓ = $4M.

- Future work should focus on:
  - Collect an exhaustive set of events that cause failure in the low resolution unwrapping.
  - Reduce the False Positive rate (7%).

Publications and References

[1] Massonnet, D.; Feigl, K. L. (1998), "Radar interferometry and its application to changes in the earth's surface", *Rev. Geophys.*, **36** (4), pp. 441–500.

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[3] Hanssen, Ramon F. (2001), *Radar Interferometry: Data Interpretation and Error Analysis*, Kluwer Academic.

[4] C. W. Chen and H. A. Zebker, “Network approaches to two-dimensional phase unwrapping: intractability and two new algorithms," Journal of the Optical Society of America A, vol. **17**, pp. 401-414 (2000).

[5] Breiman L (2001). "Random Forests". *Machine Learning*. **45**(1): 5–32.