USING INSAR TECHNOLOGY TO MONITORTEMPORAL SURFACEDEFORMATION

Yu Tang Huang[a] *and JozWu*[b*]
aGraduate student, Department of Civil Engineering, National Central University,
300, Jhongda Rd., Jhongli, Taoyuan 32001, Taiwan; Tel: + 886-3-4227151#57615;
E-mail: william36902580147@hotmail.com

bProfessor, Department of Civil Engineering, National Central University,
300, Jhongda Rd., Jhongli, Taoyuan 32001, Taiwan; Tel: + 886-3-4227151#57626;
E-mail: jozwu@csrsr.ncu.edu.tw

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ABSTRACT:

Synthetic Aperture Radar Interferometry (InSAR) technique is an application of the traditional radar image. It has been widely used to monitor the surface elevation. In recent years, it's also used to observe the volcano, earthquake and other natural disasters. The researches in Chi-Chi earthquake also have good results by using InSAR technique.

The quality of radar image, however, will influence the InSAR method. Due to a weak correlation among temporal and geometry, not only the interferogram is hard to recognize but also the surface deformation becomes hard to estimate. Because of this limitation, the Permanent Scatterer (PS) InSAR technique has been raised in the late 1990s. PSInSAR is a powerful tool for monitoring urban areas. However, the numbers of PS points are not enough in the mountainous area to acquire confident results.

This paper uses the statistics method to distinguish the target from neighbor pixels' backscatter. Combining the same targets' signals makes some of pixels exceed the coherence threshold of the PS point. The method can increase the density of measurement point in mountainous area. The final step is the least square method to estimate the surface deformation. Through this process, the more accurate and credible change detection map can be created.

1. INTRODUCTION

Since its introduction in the late 1960s, the synthetic aperture radar Interferometry (InSAR) technique has been widely use in topography. And the differential InSAR (DInSAR) technique also can successfully observe the surface displacement, like monitoring land subsidence in Italy (Berardino *et al*., 2002) and detecting the thrust dislocation cause by Chi-Chi earthquake (Chang *et al*., 2004).

However, InSAR technique is highly dependent on the quality of the images. The correlation between images will directly affect the recognizable of interference fringe. In recent years, there are two popular approaches to overcome the de-correlation limitation, small baseline subset InSAR (SBAS) method and permanent scatterer InSAR (PSInSAR) (Ferretti *et al.*, 2001). PSInSAR method is to identify and estimation the surface deformation on pixels which has high coherent over the whole time period of observation. Those pixels offer strong reflectivity values, it's also mean only slightly affected by temporal and geometricel de-correlation. They are probably man-made structures, boulders and non-cultivated, in other words the PS density in mountain or forest are quite low than urban areas (Ferretti *et al*., 2011)

Another drawback of both PSInSAR and SBAS methods is the requirement of phase unwrapping. And this will lead ambiguity error into the final result. Because the ambiguity error between two PS points, it will sometime fail to estimate the deformation. So how to increase the density of the measurement points and avoid the unwrapping errors are the most important challenge step in PSInSAR method when observation the mountain area.

This paper is organized as follows. After a description of the PSInSAR method and it's limitation in Section II, and use Kolmogorov-Smirnov (KS) statistics test to distinguish the neighbor pixels' backscatter and combine the same signals of targets to increase the density of the measurement points in Section III. Section IV provides the least squares (LS) approach to estimate the surface deformation of all the measurement points identified in the previous section.

2. PERMANENT SCATTERER METHOD

The starting point of this experiment is the acquirement of coherence and Interference maps, which can be performed by existing open source code program, like Delft object-oriented radar interferometric software (Doris) or repeat orbit interferometry package (ROI_PAC). We therefore use PSs approach to identify the stable and non-noised pixel. The purpose of PSInSAR method is to find the permanent scatterer, as corner reflector. And use the signal of the pixel, caused by the PS points, to analysis the surface deformation. The PS points can be identifying by coherence (Mora et al., 2003). The coherence γ cans be definition as follow:

$$\gamma = \left| \frac{\left\langle S_1 \cdot S_2^* \right\rangle}{\left\langle S_1 \cdot S_1^* \right\rangle \left\langle S_2 \cdot S_2^* \right\rangle} \right| \tag{1}$$

The S_1, S_2 are the complex master and slave image numbers. S_1^*, S_2^* are the conjugate of the complex. When there are N SAR images acquired in an ordered time sequence $(t_1 \quad t_2 \quad \ldots \quad t_N)$, used to create M interferogram and coherence map. And all the coherence number of the pixel are larger than threshold, we can define it as PS point.

The PSInSAR method can effectively to select the stable and reliable signal for following step. But in some cases, the coherence at the vegetation area is not so high to pass the threshold in some interferometric pairs of available dataset.

3. KS TEST TO SELECT MEASUREMENT POINTS

If the density of PS points was low, in other words the distance between two PS points is long. In that case, the phase difference of two measurement points will have ambiguity. The ambiguity is the biggest source in surface deformation estimation. So how to improve the density of measurement points was very important.

The statistical test can tells us, do two functions come from same population. We try to use KS test to identify does the neighbor pixel of target are the same kind of object, or not. If the target has enough number of neighbors which reflections from the same kind object. Than we can combine the phase of those points not only can make the phase stable, if we also combing the amplitude it will despeckle. And add those points as measurement points.

4. LS SOLUTION COMPUTATION

After identify the measurement points, the connection between each other must to create. Delaunay triangulation has been widely used for this purpose. The Delaunay triangulation can define a unique triangular network and make the connection consistency.

In each interferogram i, the line of sight (LOS) displacement of measurement point (l, s) can be described by a linear mean deformation rate $(v_k, k = 1, 2, \ldots, N-1)$ and the time span between two images. The LOS deformation $\left(\Delta r_{l,s}^{i}\right)$ during this time can be expressed as:

$$\Delta r_{l,s}^{\mathrm{i}} = r(t_{Mi}, l, s) - r(t_{Si}, l, s) = \sum_{k=1}^{C_i - 1} (t_k - t_{k-1}) v_k \tag{2}$$

where (l, s) are the pixel coordinate of the measurement point; r are the range distances between target and sensors; C_i is the number of SAR images acquisitions between master and slave image. The Equation (2) can also be express the phase correspond to the surface deformation $\phi_{\mathrm{defo},l,s}^{i}$.

$$\phi^i_{\text{defo},l,s} = -\frac{4\pi}{\lambda}\Delta r^i_{l,s} = -\frac{4\pi}{\lambda}\sum_{k=1}^{C_i-1}\left(t_k - t_{k-1}\right)v_k = \beta_i V \tag{3}$$

The λ is the radar wavelength. V is a vector of deformation rate, $\beta_i = -(4\pi/\lambda)\sum_{k=1}^{C_i-1}\left(t_k - t_{k-1}\right)$.

The phase related to the topographic $\phi^i_{\text{topo},l,s}$ can be described by the height error $\Delta h_{l,s}$:

$$\phi^i_{\text{topo},l,s} = -\frac{4\pi}{\lambda}\frac{B^i_{\perp,l,s}}{r^i_{l,s}\sin\theta^i_{l,s}}\Delta h_{l,s} = \alpha^i_{l,s}\Delta h_{l,s} \tag{4}$$

where $B^i_{\perp,l,s}$ is the perpendicular baseline between master and slave sensor, $r^i_{l,s}$ is the range distance from the master sensor to the target, $\theta^i_{l,s}$ and is the look angle.

The phase difference between two points located at (l,s) and (l',s') is given by:

$$\begin{aligned}
\Delta\phi^i_{l,s,l',s'} &= \alpha^i_{l,s}\Delta h_{l,s\,l',s'} + \beta_i\Delta V + w^i_{l,s,l',s'} \\
\Delta\Phi &= A\begin{bmatrix}\Delta h_{l,s\,l',s'} \\ \Delta V\end{bmatrix} + W \\
\Delta\Phi &= \begin{bmatrix}\Delta\phi^1_{l,s,l',s'} & \Delta\phi^2_{l,s,l',s'} & \cdots & \Delta\phi^M_{l,s,l',s'}\end{bmatrix}^T \\
A &= \begin{bmatrix}\alpha & \beta\end{bmatrix} \\
\alpha &= \begin{bmatrix}\alpha^1_{l,s} & \alpha^2_{l,s} & \cdots & \alpha^M_{l,s}\end{bmatrix}^T \\
\beta &= \begin{bmatrix}\beta_1 & \beta_2 & \cdots & \beta_M\end{bmatrix}^T \\
W &= \begin{bmatrix}w^1_{l,s,l',s'} & w^2_{l,s,l',s'} & \cdots & w^M_{l,s,l',s'}\end{bmatrix}^T
\end{aligned} \tag{5}$$

Once the function was set, the LS solution can estimate the height error and deformation rate.

$$\begin{bmatrix}\Delta h_{l,s\,l',s'} \\ \Delta V\end{bmatrix} = \left(A^T P A\right)^{-1} A^T P \Delta\Phi \tag{6}$$

And the parameter (deformation rate and height error) of each point x_i can also use LS solution to estimation.

$$\begin{aligned}
L &= UX \\
X^T &= \begin{bmatrix}x_1 & x_2 & \cdots & x_H\end{bmatrix} \\
x_i &= \begin{bmatrix}h_i & V_i\end{bmatrix}
\end{aligned} \tag{7}$$

H is the number of points, U is a design matrix depend on the Delaunay triangulation. X is the parameters at each point.

5. EXPERIMENT

We select the ERS1/2, and the track/frame are 232/3141showing below, image of our experiment. The present progress, we used the Doris to estimate the interferogram and the coherence.


Figure 1. The used in this paper

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