

Identification and quantitative estimation of noise based on gradients in InSAR images

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1. Introduction

In the 20th century, in many coastal cities in Asia, the population rapidly concentrated in cities, leading to excessive exploitation of groundwater, causing large-scale problems such as land subsidence and salt damage.

In the Kujukuri area in Chiba Prefecture, Japan, underground brine mining has a history of more than 50 years. Dissolved methane and iodine in water caused severe ground subsidence (Murai et al., 2010).

In the past two decades, through the use of interferometric synthetic aperture radar (InSAR) technology, land subsidence monitoring has been significantly improved.

InSAR images include x,y,z coordinate information; x and y represents the location, and z represents the displacement along the line of sight.

The presence of phase noise affects the quality of topographic information obtained from the interferogram. Noise includes temporal noise and spatial noise. Some trend analysis techniques used for time series analysis have removed temporal noise (Ansari et al, 2017). Traditional filtering methods such as median filtering and Gaussian filtering are not ideal because they smooth all the points of the InSAR image instead of smoothing the noise.

Several techniques have been proposed in the literature to reduce interferometric phase noise. One approach, applied to the complex interferometric signal, is the multilook filter (Seymour and Cumming, 1994). This technique, however, reduces noise at the expense of spatial resolution. Lee et al. (1998) used a local statistics filter applied to the real and the complex interferometric phase signal as well. Techniques for phase-noise reduction in the Fourier domain have also been proposed (Goldstein and Werner, 1997). All these techniques, however, involve the loss of image detail to a certain extent. If the noise can be identified, or the location and distribution of the noise can be found, and then applying these noise reduction methods, the effect will be better.

When the amount of noise is large, the one-time smoothing method is not enough to smooth the InSAR image. Then, multiple smoothing is required. However, the existing methods cannot infer the amount of noise, so they cannot provide a basis for multiple smoothing judgments.

There is a close relationship between spatial noise and spatial location, and gradient can reflect this relationship. Based on the direction of gradient descent, this research proposes a method that can identify the location of noise and infer the amount of noise, and combines and improves some traditional smoothing methods to smooth InSAR images.

2. Study area and materials

My study area is the Kujukuri plain in Chiba Prefecture, Japan, with an area of 23.72km^2 .

Since the actual InSAR image contains noise (no noise-free InSAR image cannot be obtained) and the precise land subsidence distribution is not known, this study uses a virtual verification method, in other words, a land subsidence model (Aichi, 2017) and a normal distribution noise model are used(Fig. 1).As for the model,the resolution is 10m*10m and 200*200 grids.As for the noise model,the standard deviation is 1.2E-03.

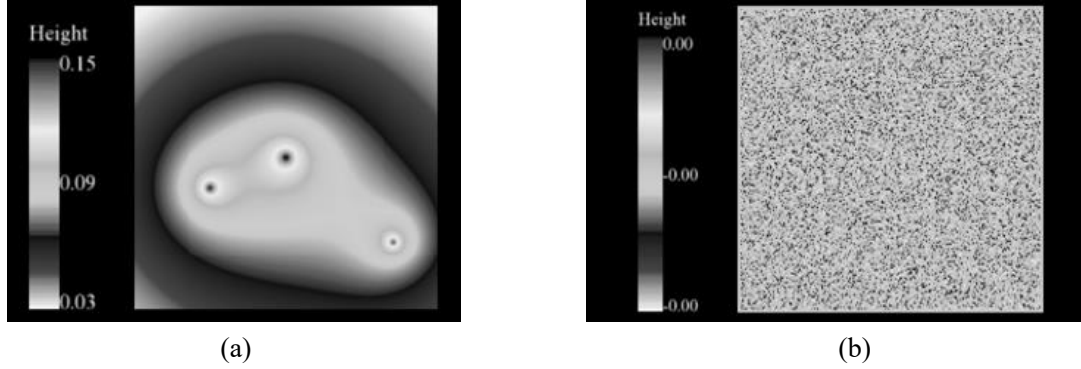


Fig. 1 Problem for a virtual verification. (a)Land subsidence model with 3 wells.(b)Normal distribution noise model with 100% amount of noise

3. Methodology

3.1. Methods of identifying the location and distribution of noise

This study used a combination of two methods to identify noise. Called method 1 and method 2, respectively, the purpose of method 1 is to identify noise, but the result of method 1 will produce many irrelevant points, and the purpose of method 2 is to reduce the amount of irrelevant points on the basis of method 1.

3.1.1. Method 1: Identify noise based on gradient direction

The principle of Method 1 is:

1. Calculate the gradient direction of each point of the InSAR image based on the 2D sobel operator(Formulas (1)~(3))(Kanopoulos et al,1988).

$$Sobel_X = \begin{bmatrix} 1 \\ 0 \\ -1 \end{bmatrix} * \begin{bmatrix} 1 & 2 & 1 \end{bmatrix} = \begin{bmatrix} 1 & 2 & 1 \\ 0 & 0 & 0 \\ -1 & -2 & -1 \end{bmatrix} \quad (1)$$

$$Sobel_Y = \begin{bmatrix} 1 \\ 2 \\ 1 \end{bmatrix} * \begin{bmatrix} 1 & 0 & -1 \end{bmatrix} = \begin{bmatrix} 1 & 0 & -1 \\ 2 & 0 & -2 \\ 1 & 0 & -1 \end{bmatrix} \dots\dots\dots (2)$$

$$\theta_M = \arctan(d_y/d_x) \quad (3)$$

2. (Assuming that the gradient descent direction is horizontal):

Calculate the average value of two points around the key point gradient descent direction(Formula (4)); calculate the average value of the two points around the key point gradient descent orthogonal direction(Formula (5)).

$$V_{average} = 0.5 \times (V_{left} + V_{right}) \quad (4)$$

$$V_{average} = 0.5 \times (V_{up} + V_{down}) \quad (5)$$

3. Compare the average value of the two directions with the key point value. If the formula condition is satisfied, the key point is regarded as a noise point(Formulas (6)~(7)).

$$V_{keypoint} < (1 - k) \times V_{average} \text{ Or } M_{keypoint} > (1 + k) \times V_{average} \quad (6)$$

$$k \in R, k \geq 0 \& k \leq 1 \quad (7)$$

Because the result of method 1 will find a lot of irrelevant points, it is necessary to use method 2 to reduce the amount of irrelevant points.

3.1.2. Method 2: Reduce the amount of irrelevant points based on the gradient angle map

Through the gradient angle map of the InSAR image, it can be found that the noise will greatly change the gradient angle value of the surrounding points. Method 2 is based on this theory to find abnormal points in the gradient angle map, and then infer the position of the noise points based on these abnormal points. The steps are as follows:

1. In the gradient angle diagram, construct 2 planes around the key points, calculate the normal vectors of the 2 planes, and compare the similarity of the normal vectors. Then, according to the conditional formula I defined, the ones that meet the conditions are regarded as abnormal points(Formulas (8)~(10)).

$$\theta = \arccos(a_1 * a_2 + b_1 * b_2 + c_1 * c_2) / (|Normal_1| * |Normal_2|) \quad (8)$$

$$\theta > K_\theta \&\& \theta < 180 - K_\theta \quad (9)$$

$$K_\theta \in N, K_\theta \geq 0 \&\& K_\theta \leq 90 \quad (10)$$

2. Create a "superimposed value point map" with all points starting at 0. For each abnormal point found, add +1 to the superimposed value of the surrounding 8 points. In theory, the superimposed value of noise points should be the largest, so according to the condition formula I defined, those that meet the conditions are considered noise points.

$$V \geq K_{\text{Superimpose}} \quad (11)$$

$$K_{\text{Superimpose}} \in N, K_{\text{Superimpose}} \geq 0 \&\& K_{\text{Superimpose}} \leq 8 \quad (12)$$

3.1.3. Find best coefficients of method 1 and method 2

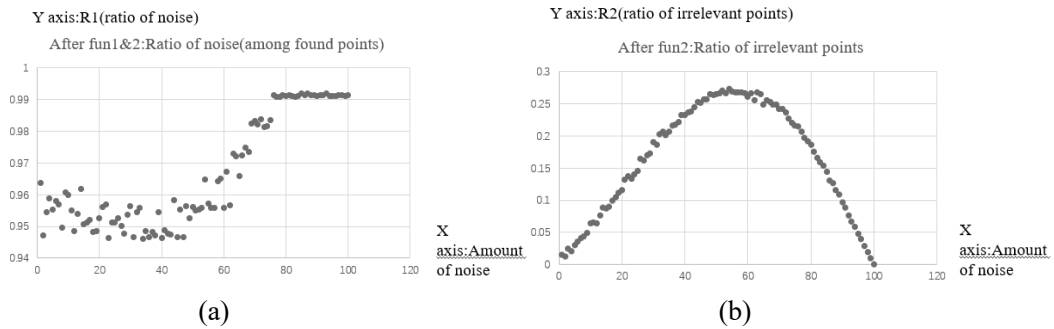
It can be found that there are three undetermined coefficients "k" in Method 1 and Method 2. According to the scope of k, this research increases the amount of noise from 1% to 100%, and studies the best value of k under different noise amounts. The evaluation method uses RMS.

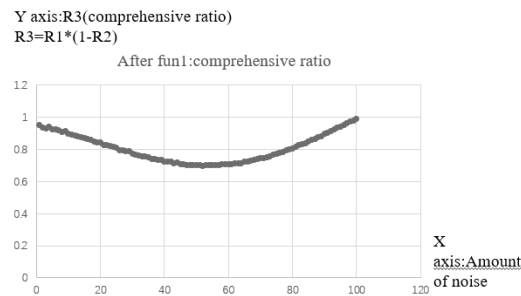
3.1.4. Infer the amount of noise

According to the data table of the best coefficients obtained in the case of different amounts of noise, in turn infer the amount of noise.

4. Results and discussion

The results of method 1 combined with method 2 are as follows(Fig. 3):





(c)

Fig. 3 Results(a)Result of R1.(b)Result of R2.(c)Result of R3

It can be seen that when the number of noise points is less than 60%, R3 (comprehensive accuracy) decreases, and when the number of noise points exceeds 60%, R3 increases. I think the overall accuracy rate is acceptable. The result of inferring the amount of noise is as follows(Fig. 4):

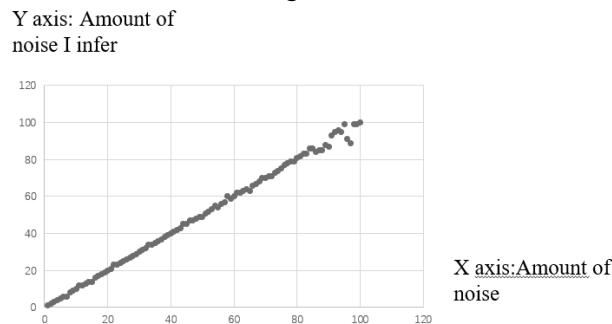


Fig. 4 The accuracy of the method of inferring the amount of noise

It can be found that, overall, the accuracy of the method of inferring the amount of noise is very high. But when the amount of noise is higher than 80%, the accuracy rate drops. The reason lies in Fig. 3(a). When the amount of noise is higher than 80%, the accuracy of the noise identified by methods 1 and 2 is almost close to 100%. Conversely, it is difficult to deduce the accurate amount of noise.

5. Conclusion

The combination of method 1 and method 2 can identify the amount and distribution of most noises, but the disadvantage is that the recognition rate cannot reach 100%.

The method of inferring the amount of noise is also very accurate, which provides a basis for the subsequent smoothing noise strategy. The disadvantage is that the accuracy will be affected by the standard deviation of the noise. So I think this content can be researched in the next step.

6. Reference

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