Estimation of Ground Surface Displacement from Microwave Radar Images by Using Phase-only Correlation

Yusuke Mizuno*, Tetsuya Takiguchi**, Yasuo Ariki**

* Graduate School of Engineering, Kobe University, Japan
** Organization of Advanced Science and Technology, Kobe University, Japan
E-mail: mizuno@me.cs.scitec.kobe-u.ac.jp, takigu@kebe-u.ac.jp, ariki@kobe-u.ac.jp

Abstract

In this paper, we propose a method to estimate ground surface displacement accurately from microwave radar images captured before/after an earthquake and also inspect the availability of the method. Phase-only correlation is used for sub-pixel image matching of small local regions between two input images with a high degree of accuracy. The proposed method is examined through the experiment using real satellite images.

1. Introduction

In recent years, an attempt to use satellite images in earthquake analysis has been performed. Especially, the observation through microwave radar has the advantage that the surface of the earth can be seen clearly even under forest because of its property, and is thought to be effective for investigating the crustal movement caused by earthquake. In this study, we propose a method to estimate the ground surface displacements with high accuracy by using phase-only correlation in matching images obtained from microwave radar before/after an earthquake.

2. Proposed Method

The proposed method is shown in Fig.1. Two input images captured by microwave radar before/after an earthquake are called master and slave image. First, the small localized region called reference region is set in the master image around a point of concern and larger localized region called search region is set around the same position in the slave image. Then, the size of the reference region is adjusted to the size of the search region by zero-padding shown in Fig.2. Image matching by phase-only correlation is applied to these two regions and the corresponding points between the master and slave image are found rapidly with high-accuracy.

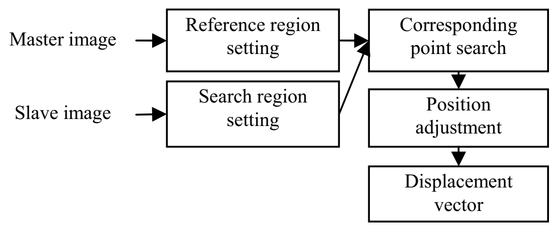

Figure 1: Processing flow in proposed method

Next, since two input images have general position gap because of the difference of recording situation like observing point, corresponding point of slave image is necessary to be projected from slave coordinate to master coordinate by Affine transform. The Affine parameters are computed by linear regression of corresponding points between two images. M-estimator is one of the robust estimation methods and it removes outliers of corresponding points and estimates the parameters correctly. In this way, the general position gap is adjusted and the displacement vector on master image is calculated.

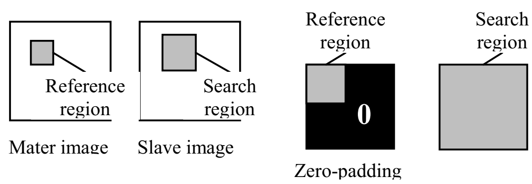

Figure 2: Reference and search regions

2.1 Phase-only Correlation

Phase-only correlation is a method to estimate the relative displacement between two images. By focusing on the phases of image signals, estimation with sub-pixel accuracy is possible. The summary of phase-only correlation is shown in Fig. 3.

ISSN 1975-4736 ©MITA 2009

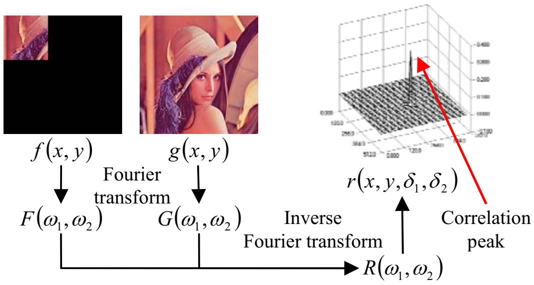

Figure 3: Phase-only correlation

The reference region in the master image is defined as $f(x, y)$, and the search region in the slave image is defined as $g(x, y)$. Two input regions have the same size $N_1 * N_2$ because of zero-padding. The cross-phase spectrum $R(\omega_1, \omega_2)$ is computed by Eq. (1). $F(\omega_1, \omega_2)$, $G(\omega_1, \omega_2)$ are the Fourier transform of two input regions. The phase-only correlation function $r(x, y, \delta_1, \delta_2)$ is derived by inverse Fourier transform of $R(\omega_1, \omega_2)$. The model of $r(x, y, \delta_1, \delta_2)$ is presented by Eq.2. $\alpha \cong 1$ and (δ_1, δ_2) represents sub-pixel displacement of between images. The correlation peak coordinate of $r(x, y, \delta_1, \delta_2)$ is evaluated based on the model and the relative position gap of two input images is estimated.

$$R(\omega_1, \omega_2) = \frac{F(\omega_1, \omega_2)\overline{G(\omega_1, \omega_2)}}{\left|F(\omega_1, \omega_2)\overline{G(\omega_1, \omega_2)}\right|} \tag{1}$$

$$r(x, y, \delta_1, \delta_2) = \frac{\alpha}{N_1 N_2} \frac{\sin\{\pi(x+\delta_1)\}}{\sin\left\{\frac{\pi}{N_1}(x+\delta_1)\right\}} \frac{\sin\{\pi(y+\delta_2)\}}{\sin\left\{\frac{\pi}{N_2}(y+\delta_2)\right\}} \tag{2}$$

2.2 Position Adjustment

The corresponding points $(x_2, y_2)^T$ in the slave image are adjusted by Affine transform to remove the general position gap and the displacement vector $(v_x, v_y)^T$ is calculated by Eq. (3), where the corresponding point $(x_1, y_1)^T$ is on the master image and $(x_2, y_2)^T$ on the slave image. Affine transform parameters A_1, A_2 are estimated to minimize the median of pixel errors by using Tukey's biweight, one of the M-estimator methods. This method is robust for local displacement by weighting the data depending on pixel errors of corresponding points. The weight is given by Eq. (4). μ_i represents the pixel error at i-th pixel and the data that have large error are given light weight and the estimation becomes to be robust for outliers or bad data. The weighting parameter w is median of μ_i. After repeat calculation, the parameters A_1, A_2 are derived.

$$\begin{pmatrix} v_x \\ v_y \end{pmatrix} = \begin{pmatrix} x_2' \\ y_2' \end{pmatrix} - \begin{pmatrix} x_1 \\ y_1 \end{pmatrix}, \quad \begin{pmatrix} x_2' \\ y_2' \end{pmatrix} = A_1 \begin{pmatrix} x_2 \\ y_2 \end{pmatrix} + A_2 \tag{3}$$

$$\begin{cases} w_i = 1 - \left(\dfrac{\mu_i}{w}\right)^2, & \mu_i < w \\ w_i = 0, & \mu_i \geq w \end{cases} \tag{4}$$

3. Experiment

Experiment data was captured before/after Iwate-Miyagi earthquake caused on June 14, 2008 in Japan. The experiment was performed by the proposed method using two satellite images. Fig.4 shows master image overlapped with displacement vectors. At this time, the parameter of Affine transform for the adjustment of general position gap was led by the method of M-estimator and the median of pixel errors was 0.16 pixel.

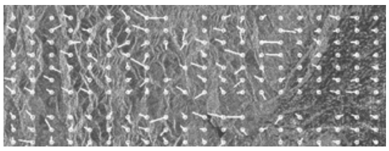

Figure 4: Displacement vector

4. Conclusions

This paper proposed the approach to estimate ground surface displacement with sub-pixel accuracy by using phase-only correlation. At the point of low reflection like rivers, the corresponding points could not be found and caused large error in displacement vector. Future work includes verification of the estimation accuracy.

References

[1] Sei Nagashima, Takafumi Aoki, Tatsuo Higuchi, Koji Kobayashi, "Improving Performance for Subpixel Image Matching Based on Phase-Only Correlation," The Society of Instrument and Control Engineers Tohoku Chapter. Japan, vol.218-15, 2004.

[2] Mikio Tobita, Makoto Murakami, Hiroyuki Nakagawa, Hiroshi Yarai, Satoshi Fujiwara, "Two-dimensional field of Three-dimensional Components of Deformations and Velocities, and Volume Change around Usu Volcano Associated with the 2000 Eruption by Matching of SAR Images," Geographical Survey Institute. Japan, No.95, 37-48, 2001