

EFFECTS OF THE INTERVAL OF TIEPOINTS ON THE RELIABILITY OF SAR IMAGE CO-REGISTRATION

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ABSTRACT:

Spaceborne Interferometric Synthetic Aperture Radar (InSAR) has been demonstrated to be a potential tool for generating digital elevation models (DEM). The co-registration of SAR complex images is one of the most important processing procedures involved in InSAR. The quality of the co-registration significantly influences the final quality of any SAR interferometric generation, and thus the quality of DEM reliable results can never be achieved if the initial co-registration is not sufficiently reliable.

In SAR image co-registration, the distribution of tiepoint affects the quality or reliability of the results. Due to lack of well defined points, tiepoints are normally selected as the intersections of a grid cells. In this case, the grid interval of the tiepoint grid becomes the critical factor. Theoretically, the smaller the grid interval, (the more tiepoints), more reliable the registration. However, it is not always the case. In this study, some experimental investigations into the effect of grid interval on the co-registration results are conducted. 4 pieces of SAR complex images collected by ERS-1/2 are used for testing. Tiepoints with varying grid intervals have been used for co-registration. The results indicate that there is no single optimum grid interval for tiepoint grid but the grid with 8×8, corresponding to 205×34 pixels, always result in either best or very good in terms of both RMS and the coherence of interferograms.

1. INTRODUCTION

Spaceborne Interferometric Synthetic Aperture Radar (or SAR interferometry, abbreviated as InSAR) has been demonstrated to be a potential tool for generating digital elevation models (DEM). The co-registration of SAR complex images is one of the most important processing procedures (others being interferogram generation, phase unwrapping and geocoding) involved in InSAR to obtain good quality interferogram and high precise DEM. SAR images co-registration is based on patch match using a set of tiepoints, which are a set of selected conjugate image points on both images. The distribution of the tie points, which consists of 3 parameters as configuration, sampling size and point density, will affect the reliability of co-registration. As tie points are normally selected in a form of grid configuration (due to a lack of well-defined points), the only sampling parameters has been reduced to only one -- density, which can then be represented by grid interval. In other words, the interval of tiepoints has great effect on the reliability of SAR image co-registration. The question arising is "how much is the effect?" Theoretically, more tiepoints will result in more reliable registration. However, too many tiepoints would result in a dramatic increase in calculation but doesn't necessarily result in more reliable co-registration. Therefore, the critical issues become the search of most appropriate amount of tiepoints, or optimum interval of tiepoints so as to produce robust co-registration results.

From literature, it can be found that no thorough discussions on this issue have been conducted, though researchers from time to time state something like: "Tiepoints with feature should be selected", or "Tiepoint should be evenly distributed over the whole image". For a such reason, this project aims to investigate into the effect of tiepoint interval (and/or grid size) on the results of co-registration.

Firstly, the paper analyzes those problems in SAR images co-registration and discusses the concept of reliability in SAR images co-registration. Then the design of experimental testing is outlined. After that, the testing results are reported and analysed. A discussion is also made on some abnormal cases. Finally, some conclusions are made.

2. RELIABILITY OF THE CO-REGISTRATION OF SAR COMPLEX IMAGE

2.1 The Co-registration of SAR Complex Image

In SAR interferometry, two complex images are used, which are taken of the same scene but at different times. Therefore, their orientations could be quite different. Geometrically, they are in different coordinate systems. Therefore, there is a need of an operation to bring them down to an identical coordinate systems. There are two solutions, i.e. either to bring both down to absolute ground coordinate or to fit one image to the coordinate systems of the other. Normally, co-registration refers to the latter.

In order to bring one image to fit into the coordinate system of the other, the relationship between these two images need to be established. In InSAR practice, some sorts of polynomials are used as approximate models for the transformation between them. One a model is selected, the next step is to solve the coefficients of the model (polynomial). In this case, a set of reference points needs to be selected, which are the corresponding points on both images. Due to a lack of well-defined points on images, the normal practice is to select a set of tiepoints in a grid form from one image, called master image. Then a matching process is employed to find the points on the other image (called slaver image), which are the corresponding positions of the grid nodes on the master image. The cross-

correlation coefficient is a parameter for the evaluation of the matching results. The principle is: a window of, say, 3x3, pixels on the master image, there are many possible matching of windows of the same size, but the one matching with the highest cross-correlation coefficient is regarded as the true matching. Then the central pixels of the two windows are regarded as the corresponding pixels to be found.

Let $z_1(m, n)$ and $z_2(m, n)$ represent the two SAR complex images:

$$z_1(m, n) = a_1(m, n) e^{j\varphi_1(m, n)} \quad (1a)$$

$$z_2(m, n) = a_2(m, n) e^{j\varphi_2(m, n)} \quad (1b)$$

where $m=0,1,2,\dots, M-1$, $n=0,1,2,\dots, N-1$, the image size is $M \times N$. The cross-correlation coefficient γ is expressed as:

$$\gamma = \frac{|E(z_1 z_2^*)|^2}{\sqrt{E(|z_1|^2)E(|z_2|^2)}} \quad (2)$$

$$\gamma(m, n) = \frac{\left| \sum_{l=-(L-1)/2}^{(L-1)/2} \sum_{k=-(K-1)/2}^{(K-1)/2} z_1(m+l, n+k) z_2^*(m+l, n+k) e^{-j\varphi(m+l, n+k)} \right|}{\sqrt{\sum_{l=-(L-1)/2}^{(L-1)/2} \sum_{k=-(K-1)/2}^{(K-1)/2} |z_1(m+l, n+k)|^2 \sum_{l=-(L-1)/2}^{(L-1)/2} \sum_{k=-(K-1)/2}^{(K-1)/2} |z_2(m+l, n+k)|^2}} \quad (3)$$

$$\hat{\rho}(m, n) = \frac{\left| \sum_{l=-(L-1)/2}^{(L-1)/2} \sum_{k=-(K-1)/2}^{(K-1)/2} |z_1(m+l, n+k)|^2 |z_2(m+l, n+k)|^2 \right|}{\sqrt{\sum_{l=-(L-1)/2}^{(L-1)/2} \sum_{k=-(K-1)/2}^{(K-1)/2} |z_1(m+l, n+k)|^4 \cdot \sum_{l=-(L-1)/2}^{(L-1)/2} \sum_{k=-(K-1)/2}^{(K-1)/2} |z_2(m+l, n+k)|^4}} \quad (5)$$

2.2 Reliability in SAR Image Co-registration

Reliability is a widely used concept in engineering and industry. A generally acceptable definition given by the B.S.I. (British Standards Institution) is as follows (Dummer and Winton, 1986):

“Reliability is the characteristic of an item expressed by the probability that it will perform a required function under stated conditions for a stated period of time.”

In practice, the reliability of an engineering system or structure is much more complicated. Related to this study is a discussion of the reliability of the affected by check points in the case of experimental testing (Li, 1991). What is intended here is to adopt the concept of reliability into the context of SAR image co-registration.

In the case of InSAR, it is a pre-assumption that the RMS error of the residuals at tiepoints after least-squares adjustment is a good measure for the reliability. It implies that the smaller the RMS, the better or more reliable the registration. However, it is not always the case, as will be shown later. In some case, when

The expanded form of Equation (2) can be written as Equation (3), where $L \times K$ is the image patch size, $\varphi(m, n)$ is the phase difference between two images. It can be imagined that the computation would be heavy due to the involvement of φ . In order to reduce the calculation, an alternative solution has been in use, i.e. to use the power correlation coefficient $\hat{\rho}$ (Guarnieri 1997). The computation of $\hat{\rho}$ is shown in Equation (4). The relation between $\hat{\gamma}$ and $\hat{\rho}$ is as follows:

$$\hat{\gamma} = \begin{cases} \sqrt{2\hat{\rho} - 1} & \hat{\rho} > 0.5 \\ 0 & \hat{\rho} \leq 0.5 \end{cases} \quad (4)$$

The co-registration consists of two steps: the coarse co-registration and fine co-registration. Based on the orbital state vectors, the moments and the centers of the image, the coarse co-registration of two images, master and slaver images, is carried out. This is carried in order to facilitate the matching process during the search of tiepoints on the slaver image. What has been discussed above is the fine co-registration.

the RMS is small, the resultant interferogram could not good as identified visually. Therefore, good coherence in the resultant interferograms should also be a measure for reliability

It would be nice to set a set of parameters for the coherence of the resultant interferograms, so that the goodness of a interferogram can be evaluated numerically. However, this lies outside of this study. Indeed, in this paper, the RMS and visual appearance of interferograms are used together as a measure for the reliability of co-registration.

3. DESIGN OF THE EXPERIMENT

Of course, the reliability of SAR image co-registration may be affected by several factors such as image patch size; the mathematical models used (as they are approximate) and tiepoint interval. In this study, other factors are kept unchanged and therefore interval of tiepoints will be considered. As a result, a series of grids with different internals are used for the selection of tiepoints so that the relationship between the grid internal and co-registration results can be analysed.

| Image size (pixel) | Grid size (pixel) | Tiepoint interval | | No.1 Image | | No.2 Image | | No.3 Image | | No.4 Image | |
|--------------------|-------------------|-------------------|-----------|-------------|----------------|-------------|----------------|-------------|----------------|-------------|----------------|
| | | in row | in column | RMS (pixel) | Interfero-gram |
| 1760*400 | 4*4 | 411 | 68 | 0.0827 | | 0.0346 | | 0.0505 | | 0.0512 | |
| | 5*5 | 328 | 53 | 0.0735 | | 0.0344 | | 0.0440 | | 0.0490 | |
| | 6*6 | 273 | 44 | 0.0294 | Fig1.a | 0.0338 | Fig2.a | 0.0398 | Fig3.a | 0.0290 | Fig4.a |
| | 7*7 | 234 | 38 | 0.1442 | Fig1.b | 0.0151 | Fig2.b | 0.0385 | Fig3.b | 0.0481 | Fig4.b |
| | 8*8 | 205 | 34 | 0.0619 | Fig1.c | 0.0210 | Fig2.c | 0.0212 | Fig3.c | 0.0174 | Fig4.c |
| | 9*9 | 182 | 29 | 0.0965 | Fig1.d | 0.0301 | Fig2.d | 0.0070 | Fig3.d | 0.0641 | Fig4.d |

Table 1. SAR image co-registration data

It is understandable that the result of such an experiment would be scene-dependent. In order to minimise such dependency, 4 pairs of SAR complex images are used. They are located in Hong Kong. They are numbered by No.1, No.2, No.3 and No.4 areas, respectively. The image is obtained by ERS1/2. In the image, every pixel represents an area 4m*20m (4m in row and 20m in column). Therefore, in order to get a square area, the ratio of pixel number between row and column should be 5:1. All images are of the same size, the ratio is approximate 5:1, i.e. consisting of 1760*400 pixels. So all images are near q square area.

In the co-registration process, the bicubic function is used as transformation model as follows:

$$\begin{aligned}
 u &= a_0 + a_1x + a_2y + a_3x^2 + a_4xy + a_5y^2 + a_6x^3 + a_7x^2y + a_8xy^2 + a_9y^3 \\
 v &= b_0 + b_1x + b_2y + b_3x^2 + b_4xy + b_5y^2 + b_6x^3 + b_7x^2y + b_8xy^2 + b_9y^3
 \end{aligned}
 \tag{6}$$

where, (u, v) is the pixel's coordinate in slaver image. (x, y) is the pixel's coordinate in master image.

The tiepoint grids sizes vary from 4*4, 5*5, ... to 9*9. The number of tie points varies from 16 to 81. The corresponding grid interval varies from 411*68 (i.e. 411 pixels in row and 68 pixels in column between two) tiepoints to 182*29. The detailed information is provided in Table 1

As has been discussed previously, both the RMS errors and the resultant interferograms will be recorded for analysis.

4. TESTING RESULTS AND ANALYSIS

As discussed previously, the RMS and the quality of interferograms should be combined to analyze the results of co-registration. If the RMS is small, it proves the residuals at these tiepoints are small and thus the mathematical model fits through the tiepoints well. However, it doesn't necessarily mean that fitting outsides the tiepoints are also good. It is considered in this paper that only when RMS is small and interferogram quality is good, one could regard the co-registration result is good. Therefore, in this paper, some interferograms are also presented. More precisely, in each test area, not all but only four interferograms are included, one for the best, one next to

the best, the third the worse one and the forth the worst one. The results are also included in Table 1. The corresponding images are given in figures from Figure1 to Figure 4.

For No.1 image, when the tiepoint grid interval is 273*44, the RMS is the smallest and the resultant interferogram is best among all. However, when the interval is 234*38, the RMS is the largest and the resultant interferogram is very bad. When the interval is 205*34, the RMS is small and the resultant interferogram is next to the best. When the interval is 182*29, the RMS is large and the resultant interferogram is bad.

For No.2 image, when the interval is 273*44, the RMS is large, the resultant interferogram is bad. When the tiepoint interval is 234*38, the RMS is the smallest, but its resultant interferogram is bad. When the tiepoint interval is 205*34, the RMS is small and the resultant interferogram is best among all. When the tiepoint interval is 182*29, the RMS is small, and the resultant interferogram is next to the best.

For No.3 image, when the interval is 273*44, the RMS is large, the resultant interferogram is bad. When the tiepoint interval is 234*38, the RMS is large, the resultant interferogram is bad. When the tiepoint interval is 205*34, the RMS is small and the resultant interferogram is best among all. When the tiepoint interval is 182*29, the RMS is the smallest and the resultant interferogram is next to the best.

For No.4 image, when the interval is 273*44, the RMS is small, the resultant interferogram is best among all. When the tiepoint interval is 234*38, the RMS is the large, the resultant interferogram is bad. When the tiepoint interval is 205*34, the RMS is the smallest and the resultant interferogram is next to the best. When the tiepoint interval is 182*29, the RMS is the largest, and the resultant interferogram is bad.

The relation between the RMS and grid interval for all these four testing areas are given in Figure 5.

From these results, it is noticed that when the grid interval is 205*34, corresponding to the 8*8 grid, all of the four RMSs are small and all the corresponding interferograms are either very good or the best. Therefore, it might be said that when the grid interval is 205*34, the SAR image co-registration result is likely to be reliable, with these images.

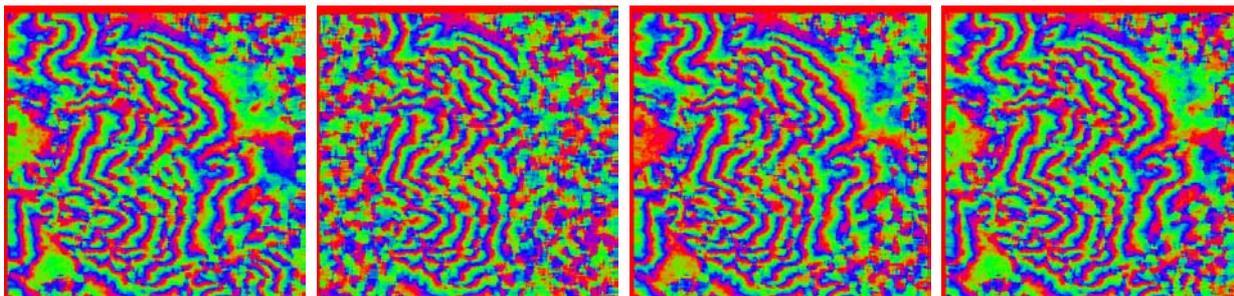


Fig1.a(tiepoint interval:273*44) Fig1.b(tiepoint interval: 234*38) Fig1.c(tiepoint interval:205*34) Fig1.d (tiepoint interval:182*29)

Figure 1. No.1 image interferograms in different tiepoint interval

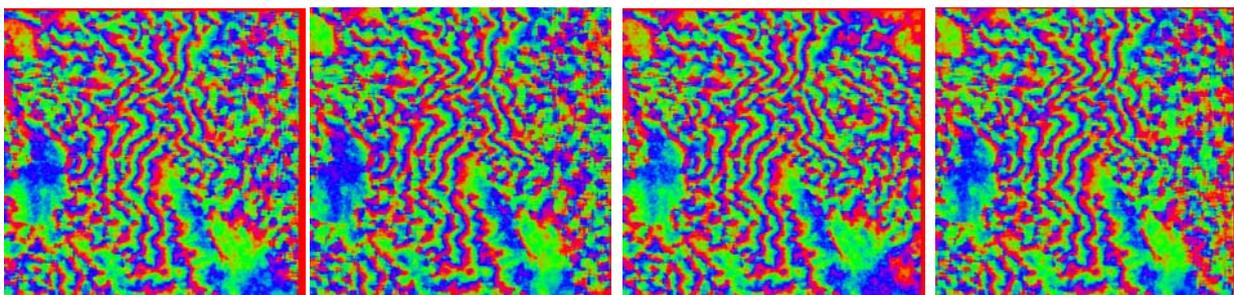


Fig2.a(tiepoint interval: 273*44) Fig2.b (tiepoint interval: 234*38) Fig2.c(tiepoint interval: 205*34) Fig2.d (tiepoint interval:182*29)

Figure 2. No.2 image interferograms in different tiepoint interval

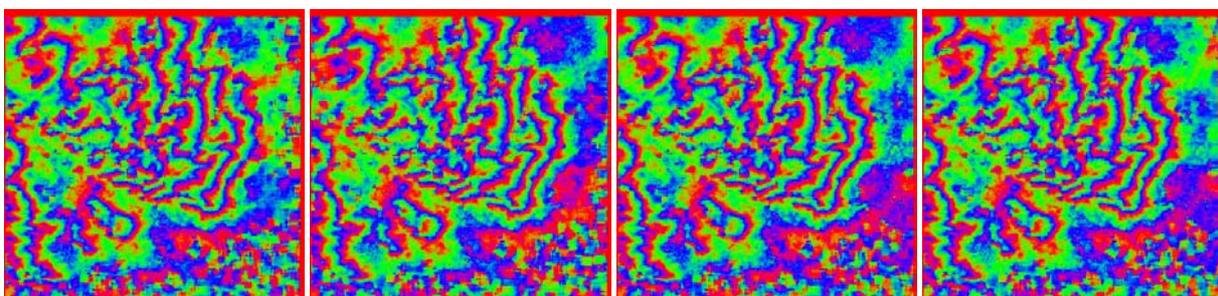


Fig3.a(tiepoint interval: 273*44) Fig3.b (tiepoint interval: 234*38) Fig3.c(tiepoint interval: 205*34) Fig3.d(tiepoint interval: 182*29)

Figure 3. No.3 image interferograms in different tiepoint interval

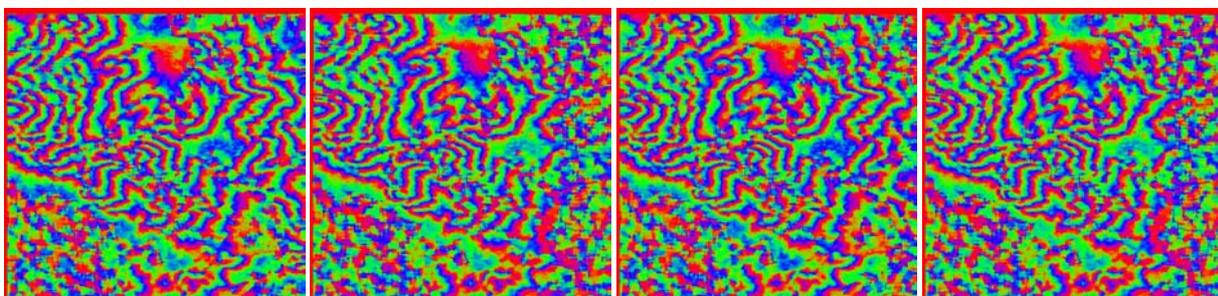


Fig4.a(tiepoint interval: 273*44) Fig3.b (tiepoint interval: 234*38) Fig4.c(tiepoint interval: 205*34) Fig4.c(tiepoint interval: 182*29)

Figure 4. No.4 image interferograms in different tiepoint interval

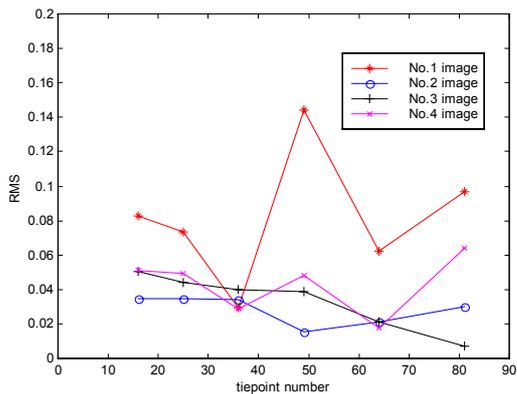


Figure 5. RMS in different tiepoint number

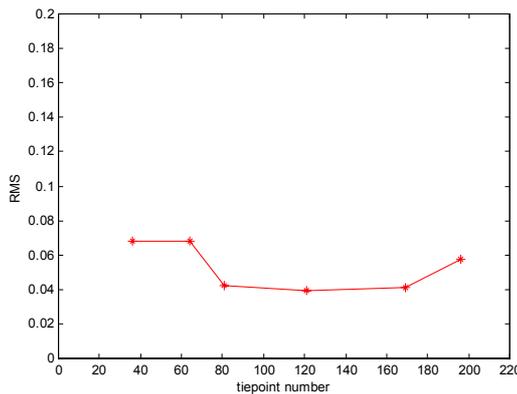
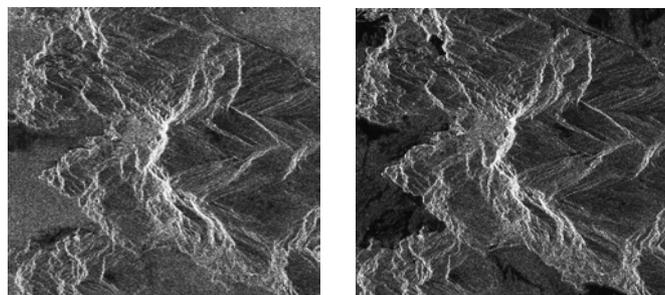


Figure 7. RMS in different tiepoint number

5. DISCUSSIONS

From the analysis of co-registration’s results, it was found RMS and interferogram are good when the grid interval is 205*34, the co-registration result is reliable. However, from Figure 5, it can be found that when the grid size is 6*6, the RMS is small for all these four images. However, surprisingly, the resultant interferogram for No.2 area is the worst, despite the good results for all three areas. In order to make the findings from this study more reliable, a pair of SAR images (Figure 6) with much larger are (2862*624) is employed for further investigation. The results of RMS are shown in Figure 7 and Table 2. The resultant interferogram shown in Figure 7.

These results are obtained with identical transformation model and patch size during the registration process. The only difference is the grid interval is larger in terms of number of pixels for the same number of grid lines. For example, the 4*4, 5*5, ... 9*9 are corresponding to 6*6, 8*8, ... 14*14. The above six different tiepoint interval are adopted. Its co-registration results are shown in table2. Four situations’ interferograms are respectively shown in figure8.a, figure8.b, figure8.c and figure8.d. Their tiepoint intervals are 411*68, 234*38, 205*34, 182*29 respectively. From the results, it could be found the co-registration result is good when the tiepoint interval is 205*34.



Master image obtained by ERS-2 Slave image obtained by ERS-1

Figure 6. Hong Kong Lantau SAR images

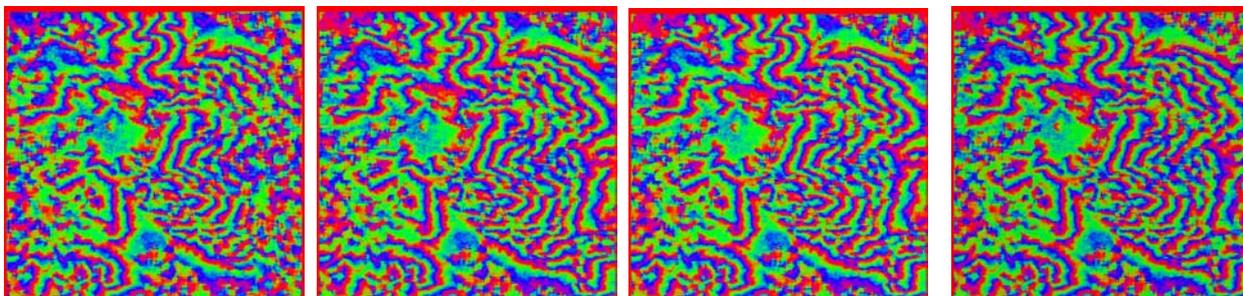


Fig8.a (tiepoint interval:411*68) Fig8.b (tiepoint interval:234*38) Fig8.c (tiepoint interval:205*34) Fig8.d (tiepoint interval:182*29)

Figure 8. Hong Kong Lantau SAR image interferograms in different tiepoint interval

| SAR image size(pixel) | Tiepoint Interval (pixel) | | Grid size (pixel) | Image RMS (pixel) | Interferogram |
|-----------------------|---------------------------|--------|-------------------|-------------------|---------------|
| | row | column | | | |
| 2862*624 | 411 | 68 | 6*6 | 0.0681 | Fig8.a |
| | 328 | 53 | 8*8 | 0.0680 | |
| | 273 | 44 | 9*9 | 0.0425 | |
| | 234 | 38 | 11*11 | 0.0395 | Fig8.b |
| | 205 | 34 | 13*13 | 0.0411 | Fig8.c |
| | 182 | 29 | 14*14 | 0.0577 | Fig8.d |

Table 2. Hong Kong Lantau SAR image co-registration data

6. CONCLUSION

In this study, some experimental tests have been carried out on the effect of the interval of tiepoints on the reliability of SAR complex image co-registration in InSAR. It has been argued that the RMS is not reliable sometimes for the evaluation of the registration result and thus suggested that the resultant interferogram should also be used as a measure.

Four pairs of images with a size of 1760*400 have been used for the testing. From these results, it has been found that the grid interval when tiepoint grid interval is 205*34, co-registration is reliable both in terms of RMS and resultant interferogram.

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