Research on the Testing Methods for IBIS-S System

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Abstract. The basic theoretical principles and key techniques of the IBIS-S system, which is a micro-deformation monitoring system based on the techniques of GB-InSAR, are introduced. The accuracy of IBIS-S is much higher than that of traditional deformation monitoring devices, so it is necessary to test the accuracy and reliability of the system. Some comparison experiments are designed for testing the parameters provided by the manufacturer, and these tests verify the accuracy and resolution of IBIS-S. A Leica TCRP 1201 total station (with an accuracy of 1mm + 1ppm) and a stepping motor (with an accuracy of 0.001mm) are used for testing the monitoring accuracy of IBIS-S. The results from different tests show that the monitoring data of IBIS-S is very accurate and higher than the traditional total station. The results also indicate that IBIS-S can be applied in the micro-deformation projects of high-rise buildings, bridges and some other objects with a high accuracy.

1. Introduction
IBIS (Image by Interferometric Survey) is developed by IDS and University of Florence. The continuous micro-deformation monitoring with high accuracy can be provided by this system. The interferometric technique is applied in this system, and the target which is covered in the surveying area (even very far away) can be monitored day and night. IBIS-S is one of the three products which can be used for high-rise buildings health monitoring, dynamic/static load testing of highway bridges, and so on [1, 2]. The maximum range of monitoring is 1km, the range resolution is 0.5m, the sampling frequency can be up to 200Hz, and the micro-deformation more than 0.01mm can be detected accurately[3, 4]. Because of the very high accuracy for surveying, some necessary experiments should be designed to test the accuracy and reliability before the applications of this system.

2. Key techniques of IBIS-S
Deformation in the line-of-sight (LOS) direction of the radar can be obtained accurately by IBIS-S. The fundamental principles are that the high resolution information in range can be obtained with the technique of Stepped Frequency Continuous Wave (SF-CW) by transmitting Ku-band radar beam and the deformation of the target surface can be detected with the technique of interferometry by calculating the phase difference of the reflected echo signals in different time [5].
Large instantaneous bandwidth signals should be provided of traditional high-resolution radar, and thus a transceiver with a large bandwidth is necessary. However, the higher resolution can also be obtained by transmitting modulated longer period and smaller instantaneous bandwidth signals to synthesize a large bandwidth [6].

Increasing the spatial resolution can be realized by using short pulse width signals for a pulse radar, and the pulse can be composed with the technology of SF-CW which can provide high spatial resolution[7, 8]. The advantage of SF-CW is that high resolution can be acquired with reduced instantaneous bandwidth of digital signal processor. SF-CW signals are a serial of narrowband coherent pulses, and the intervals of the carrier frequency of each pulse are linear stepped. The synthesized pulse can be obtained by mixing, sampling and applying the inverse Fourier transform [9].

### 2.2. Interferometry

The principle of interferometry is that the deformation in the direction of line-of-sight of the radar can be calculated by the phase difference of the echo signals with different time. If we assume the phase difference of the reflected signals in different time is $\Delta \phi$, the displacement of the target will be [10]

$$d = \frac{\lambda \cdot \Delta \phi}{4\pi} \quad (1)$$

### 3. Experiment schemes

A stepped motor and a Leica total station (TCRP 1201) are used in the experiments to test the accuracy of IBIS-S. The accuracy of the stepped motor is 0.001mm and 1mm+1ppm for TCRP 1201. A corner reflector (CR) is fixed on the stepped motor to reflect the movement of the motor.

#### 3.1. Test 1 – Single corner reflector

Test 1 is designed for testing the monitoring accuracy and sensitivity of moving targets for IBIS-S. Figure 1 shows the scene of Test 1. A stepped motor is placed in the direction of IBIS-S with a distance about 16 m, and a corner reflector is fixed on the stepped motor (Figure 2). The displacements can be controlled accurately by the stepped motor, and IBIS-S and TCRP 1201 are used for monitoring. Experiment plans are listed in Table 1, where Cnt means the number of movements, Interval means the time between each step of movement, and “+” means that the CR moves close to IBIS-S and “-” means the opposite.

#### 3.2. Test 2 – Two corner reflectors in different range indexes

Test 2 is designed to test whether the monitoring results of one CR will be interfered by the adjacent CR which is in the neighboring range index. Two stepped motors are placed in the direction of IBIS-S with the distances about 14.5 m and 16 m (Figure 3), and thus the two corner reflectors are in neighboring indexes in the LOS direction of IBIS-S. The two corner reflectors are fixed on the motors
respectively, and then some different parameters can be input to the motors to control the displacements of the reflectors. Experiment plans are listed in Table 2.

3.3. Test 3 – Two corner reflectors in the same range indexes

Two corner reflectors with different sizes are selected to test whether the results can show the displacements of the reflector with a larger size. Two stepped motors are placed in the direction of IBIS-S (Figure 4), and they are in the same range index. The two corner reflectors are fixed on the motors respectively, and then some different parameters can be input to the motors to control the displacements of the reflectors. Experiment plans are listed in Table 2.

Table 1. Test 1 for IBIS-S

| No. | CR (mm) | Direction | Interval (s) | CR (mm) | Direction | Cnt | Interval (s) |
|-----|---------|-----------|-------------|---------|-----------|-----|-------------|
| 1   | 1.00    | +         | 10          | 30 s    | 1.00      | -   | 10          | 30 |
| 2   | 0.50    | +         | 10          | 30 s    | 0.50      | -   | 10          | 30 |
| 3   | 0.10    | +         | 10          | 30 s    | 0.10      | -   | 10          | 30 |
| 4   | 0.05    | +         | 10          | 30 s    | 0.05      | -   | 10          | 30 |
| 5   | 0.01    | +         | 10          | 30 s    | 0.01      | -   | 10          | 30 |

Table 2. Test 2 and Test 3 for IBIS-S

| No. | CR_A (mm) | Direction | CR_B (mm) | Direction | Cnt | Interval (s) |
|-----|-----------|-----------|-----------|-----------|-----|-------------|
| Test 2 | 0.50 | +         | 0.20 | +         | 10 | 15          |
| Test 2 | 0.50 | +         | 0.20 | -         | 10 | 15          |
| Test 2 | 0.50 | -         | 0.00 | static   | 10 | 15          |
| Test 3 | 0.50 | +         | 0.30 | -         | 10 | 15          |

4. Results and Analysis

The echo intensity of the corner reflector is very high, and thus the corner reflector can be recognized easily on the SNR map. Then the cell of the corner reflector can be selected to analyze the performance of IBIS-S. The SNR map is shown in Figure 5.

4.1. Results of Test 1

The distance between the target and IBIS-S is about 16 m, the range resolution is 0.75 m, and sampling frequency is 200 Hz. The total station measures 3 times at each step. The results of IBIS-S are shown in Figure 6 and Figure 7, and the comparison between the monitored values and designed values are listed in Table 3.

Figure 5. The SNR map. (The peak represents the CR)

Figure 6. Results of IBIS-S (step values are 1mm and 0.5mm)
Figure 7. Results of IBIS-S (step values are 0.1 mm, 0.05 mm and 0.01 mm).

Table 3. Comparison between monitored values and designed values (IBIS-S)

| Step value (mm) | $D_{min}$ (mm) | $D_{max}$ (mm) | $D_{ave}$ (mm) | STDEV ($\sigma$) (mm) |
|----------------|----------------|----------------|----------------|-----------------------|
| 1.00           | 0.001          | 0.113          | 0.054          | 0.038                 |
| 0.50           | 0.001          | 0.018          | 0.008          | 0.006                 |
| 0.10           | 0.002          | 0.022          | 0.012          | 0.006                 |
| 0.05           | 0.001          | 0.025          | 0.004          | 0.006                 |

From Figure 6 and Figure 7, we can see that the results of IBIS-S are very accurate when the step values are 1 mm, 0.5 mm, and 0.1 mm. When the step value is 0.05 mm, the whole trend is right, but the results at some steps are not very accurate with a deviation about 0.004 mm, such as step 1 and step 11. The results are continuously recorded, and thus the final position of the CR shown in Figure 7 (d) is not as same as initial. When the step value is 0.01 mm, the results of IBIS-S cannot accurately monitor the displacements of the CR, but can only show the approximate trend, and thus the monitoring results are not reliable.

Some comparisons are made with TCRP 1201 at the same time when IBIS-S works. Because the accuracy of the total station cannot reach as high as IBIS-S, we compare only two cases (1 mm and 0.5 mm). The results of TCRP 1201 are shown in Figure 10 and the comparison between the monitored values and designed values are listed in Table 4.

Table 4. Comparison between monitored values and designed values (TCRP 1201)

| Step value (mm) | $D_{min}$ (mm) | $D_{max}$ (mm) | $D_{ave}$ (mm) | STDEV ($\sigma$) (mm) |
|----------------|----------------|----------------|----------------|-----------------------|
| 1.00           | 0.167          | 0.113          | 0.078          | 0.052                 |
| 0.50           | 0.250          | 0.018          | 0.115          | 0.082                 |

Figure 10. Results of TCRP 1201 (a: step value = 1 mm; b: step value = 0.5 mm).
4.2. Results of Test 2

We can select two cells with different peak values on the SNR map (Figure 11), and these two positions represent the two corner reflectors. The results are shown in Figure 12:

![Figure 11. The SNR map of Test 2.](image)

![Figure 12. Results of Test 2.](image)

We can see that the step values 0.5 mm of CRA and 0.2 mm of CRB are recorded respectively without interaction, and the results accurately reflect the displacements of CRA and CRB. By comparing of the results with the designed values, we find that there are only some small errors no more than 0.01mm.

4.3. Results of Test 3

The two corner reflectors used in Test 3 are in different sizes, and CR_A is larger. We can find the CRs in the SNR map (Figure 13). Because the two CRs are in the same range index, only the one with higher echo intensity can be detected by the radar. Thus, the peak value represents CR_A. The results are shown in Figure 14:

![Figure 13. The SNR map of Test 3.](image)

![Figure 14. Results of Test 3.](image)

We can see that the displacements of 0.5 mm with CRA are accurately captured by IBIS-S without the influence of CRB. By comparing of the results with the designed values, we find that there are only some small errors (e.g. the step between 350 s ~ 400 s) no more than 0.01mm.

4.4. Conclusions

Because of the high echo intensity, the corner reflectors can be selected easily on the SNR map. The differences of echo intensities of corner reflectors with different sizes are very obvious, and the performance of IBIS-S can be evaluated by the information of corner reflectors.

From the figures of Test 1 and Table 2, we can see that the trends and displacements with step values of 1 mm, 0.5 mm, and 0.1 mm are obtained accurately. When the step value is set as 0.05 mm, the trend is monitored accurately, but not all the step values are monitored right. Some step values are
not very accurate, but others are right. When the step value is 0.01 mm, only the approximate moving trends of the CR can be detected, but the displacements cannot be obtained accurately, and the differences between monitored values and designed values are very large. With a comparison between IBIS-S and TCRP 1201 (Table 3 and Table 4), we can see that the performance of IBIS-S is much better than the total station, and the accuracy of IBIS-S is higher.

From the results of Test 2, we can see that the corner reflectors in different range indexes can be selected by the different echo intensities. The monitored results of the two CRs shows that the displacements of the CRs in the neighboring range indexes can be recorded respectively without interference. The measured values and trends accord with the designed plans.

From the results of Test 3, we can see that when there are two CRs in the same range index the one with higher echo intensity can be recognized. The measured displacements and monitored trends accord with the designed plans, and the results are not affected by the smaller CR with lower intensity.

We can see from the three tests that the targets with high echo intensity can be detected by IBIS-S, and the displacements can be monitored very accurately. The sampling frequency is very high, and other traditional methods cannot reach its level. Thus, IBIS-S can be used to monitor the moving targets with very high accuracy, and even some micro-deformation can be detected precisely.

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