APPLICATION OF GROUND BASED RADAR SYSTEM IN STRUCTURAL MONITORING

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ABSTRACT

Air or satellite borne radar systems has shown millimeter accuracy in change detection by realizing the phase of the returned signal, which has put the radar system a useful piece of tool in structural monitoring and disaster prevention [1]. However the temporal availability of data is very limited due to long revisiting time. This problem could be solved by using a ground based radar system, which provide continuous monitoring of the area of interest. When operated in synthetic aperture mode, the data frequency is in order of minutes, while when operated in real aperture mode, the data frequency is a fraction of second, allowing not only long term displacement but also vibration mode analysis. The ground based synthetic aperture radar system by LiSALAB was used in this study to demonstrate monitoring of a railway bridge in real aperture and synthetic aperture mode.

Index Terms— Ground based, Synthetic aperture radar, Structural monitoring

1. INTRODUCTION

Over the past decade ground based synthetic aperture radar (GBSAR) has gain more attention by its ability as a deformation monitoring tool. GBSAR is a radar equipment which actively, or passively in some designs, sending out signal and retrieving both the phase and amplitude in the complex return. The amplitude indicates the presence of radar reflector in a resolution cell, and the warped phase is an accurate measure of distance (d) from radar antenna to target as a multiple (n) plus fraction of wavelength (λ):

$$d = \lambda(n + \frac{\phi}{2\pi}) \tag{1}$$

The measurement at a single position is identical to conventional real aperture radar, which gives a one dimensional data with no information of target position in cross-range. By setting the radar in motion along a linear rail and repeating measurement at different positions, a technique similar to range pulse compression can be applied along cross-range, namely azimuth compression. While we will not discuss azimuth compression here, there are a number of algorithms available, omega-k and range-doppler [2], for example.

2. HARDWARE CONFIGURATION

In this study, a model of ground based synthetic aperture radar system by LiSALAB was used, which utilize a Vector Network Analyzer as a radar transceiver and passed the signal through an external amplifier. See figure 1 for a schematic sketch. The system make use of a stepper motor to position the radar along a 2.7 meters rail, at each position, the radar stops, send the signal and process the echo, then proceed to the next position. Ku-band was used in this study.

The equipment used are:

1. LiSALAB LEDA6 System
2. FARO Laser Scanner

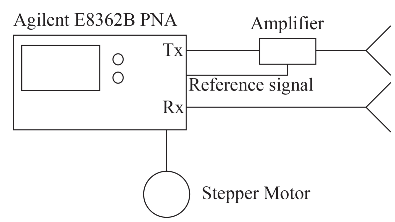


Fig. 1. Schematic of the radar system

3. LOCATION OF EXPERIMENT

Field experiment was conducted on 1 October and 8 October 2015 for acquiring data of a railway bridge across Wabash River near North 9 Street, West Lafayette of Indiana, United States. Latitude and longitude are 40.475665E, 86.867235W. (A photo of the bridge is shown in figure 2) The data for synthetic aperture radar interferometry was captured on 1 October when a train stopped on the bridge through out the measurement, and was compared to an empty bridge. The data for real aperture radar setting was capture on 8 October when a train passed the bridge at about 12:54pm. Point cloud of the bridge was also captured using a Laser Scanner.

Fig. 2. The bridge to be measured

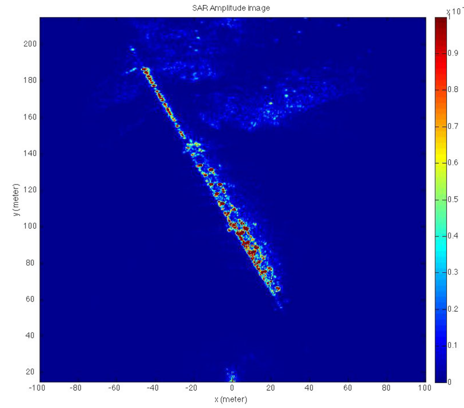
4. RESULTS

4.1. Synthetic aperture mode

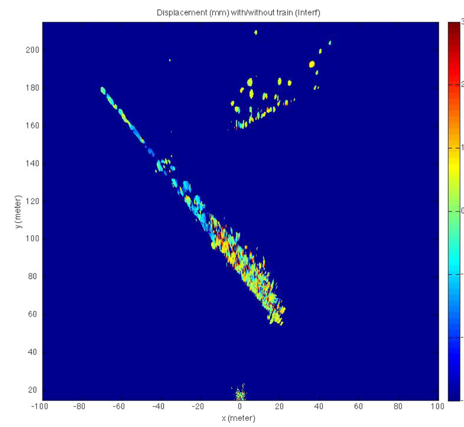
The amplitude of the returned signal in synthetic aperture mode was shown in figure 3, where a linear structure with periodic high reflectance due to corners on the structure can be seen. One complete synthetic aperture scan was done while the train was stopped on the bridge, and the data was interfered with another scan while there is no train on the bridge. The resultant range displacement was calculated from interferogram and shown in figure 4.
Although not very significant because of the large angle between vertical and radar range, it can be observed the bridge didn't show uniform subsidence, the range displacement at far range section of the bridge has shown displacement about 1-2 millimeter, while that of near range has displacement close to zero, which is possibly due to the difference of load of the train.

4.1.1. Real aperture mode

Operating the radar in real aperture mode allows higher data frequency by reducing one dimension along cross-range, therefore the choice of radar position and target profile becomes important that layover of targets in same range has to be prevented. In this sense, a bridge is an ideal structure to be monitored in real aperture mode.
The pulse repetition interval in this acquisition was 0.3 seconds, which is limited by the bandwidth, and other internal settings. Further improvements could reduce the interval by an order of 10 and allowing a better analysis of vibrational motion.
Since the radar captures the response of whole range while



a) Amplitude of the return signal of the bridge



b) Interferogram of the bridge with and without train

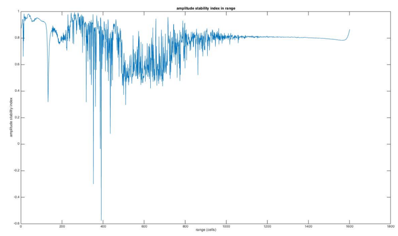
Fig. 3. Results of synthetic aperture mode

not all range cell contains meaningful data, an amplitude stability index (ASI) was used to judge whether the range cell is stable in amplitude, hence worth keeping.

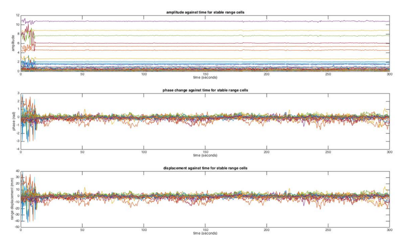
$$ASI = 1 - \frac{\sigma}{\eta} \quad (2)$$

where σ is the standard deviation, η is the mean of the range cell along time of acquisition.
The ASI for each range cell was shown in figure 4a, the periodic peaks corresponding to the corners on the bridge structure can be easily seen in the plot, which act as reliable radar reflectors to indicate displacement of the structure. The amplitude, phase, and range displacement against time in real aperture mode was shown in figure 4b, where a train was passing at the time acquisition started and the bridge was empty after about 20 seconds.
Point cloud of the bridge obtained from a laser scanner was used to identify the position of each stable cells in Cartesian coordinate, and a projection was done to transform the plot of range displacement against range to the plot of vertical displacement against position along bridge. The result shown

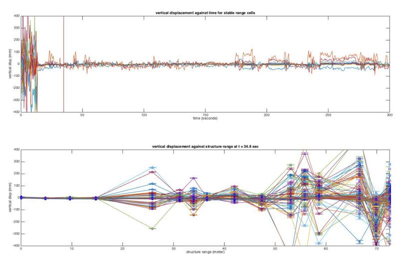
in figure 4c was presented by accumulating each frame of a GIF, while each frame represent the vertical position of the bridge at certain time. And the corresponding error at each range was shown in figure 4d.



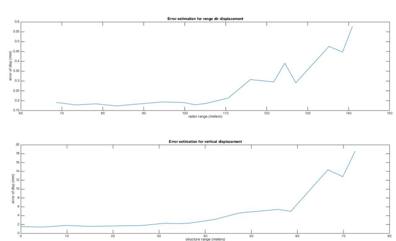
a) Amplitude stability index against range cells



b) Amplitude, Phase, and Displacement against time



c) Displacement against position along bridge at different time



d) Error of range (upper) and vertical (lower) displacement against range

Fig. 4. Results of real aperture mode

5. CONCLUSION

This study has demonstrated the capability of using ground based radar systems in real and synthetic aperture mode for structural monitoring by exploiting phase information. In synthetic aperture mode, the radar system could be used to monitor relatively slow displacement on structures or slopes. In real aperture mode, by incorporating with point cloud data, the radar system could be used for vibration mode analysis of bridges and towers under the influence of wind or traffic. Result of this study could be greatly improved by a better choice of position to place the radar, nevertheless, an impressive 0.3mm standard deviation of displacement measurement along range has been achieved.

6. REFERENCES

[1] Alessandro Ferretti, Giuliano Savio, Riccardo Barzaghi, Alessandra Borghi, Sergio Musazzi, Fabrizio Novali, Claudio Prati, and Fabio Rocca, "Submillimeter Accuracy of InSAR Time Series: Experimental Validation," *IEEE Transactions on Geoscience and Remote Sensing*, vol. 45, pp. 1142-1153, May. 2007.

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