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Deformation Monitoring of Offshore Platform Using the Persistent Scatterer Interferometry Technique

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Abstract. One of the problems that occur during the exploitation of oil and gas is offshore platform deformation. It could occur due to the environments load as well as the extraction of oil and gas itself under the seabed that caused reservoir compaction. Offshore platform deformation may affect the platform structural integrity and cause loss of production, thus it is very important to monitor its occurrences. Offshore platform deformation monitoring has been carried out using the satellite-based Global Positioning System (GPS) technique until recently. Even though the technique has proven its worth for the job, it has however some limitations, the most prominent is it could only monitor selected portion of the offshore platform. Thus, this study presents an attempt of detecting and monitoring the deformation phenomenon of an offshore platform using the Persistent Scatterer Interferometry (PSI) technique. This technique would overcome some of the limitations of the previous (GPS) deformation monitoring technique. A total of 11 high resolution TerraSAR-X images (i.e., 3 m in StripMap mode) were acquired from Aug, 2012 to Apr, 2013 for this purpose, while one of the offshore platforms in South China Sea is being used as monitored platform. Preliminary results showed that detail and sensitive deformations could be detected by this technique. In addition, analysis results in the form of mean deformation velocity map and displacement time series would allow us to further understand the behaviour of offshore platform deformation.

Introduction

Offshore drilling platforms have become important assets due to the increasing demand for energy in our world (i.e., oil and gas production). One of the major problems that occur during the exploitation of oil and gas from an offshore platform is deformation. The deformation problem occurs due to the environments load as offshore platform is continuously exposed of extreme wind, wave, current, storm and seismic actions. Besides, the extraction of a large scale of oil and gas under the seabed caused instability of the structures. This instability phenomenon caused the offshore platform to undergo slow subsidence. Moreover, a shallow gas phenomenon in the vicinity of the platform can lead to the deformation of offshore platforms. Thus, monitoring the deformation of offshore platforms is significant to ensure that structural integrity is being maintained. Also, it can provide early detection of the possibility of platform damages and collapse. Any damage or collapse of offshore platforms can lead to loss of life, loss of oil and gas production, environmental pollution and severely affect industry reputation.

Interferometric Synthetic Aperture Radar (InSAR) is a radar imaging system that transmits signals of microwave through a SAR antenna on board of a satellite to illuminate targets in the surface. The InSAR is an effective way to measure vertical changes of the offshore platform by comparing the distance from a satellite to a ground point on the offshore platform taken at different times. When the ground point of the offshore platform moves away from (subsidence) or towards (uplift) the satellite, the distance between the satellite and the point has also changed. Moreover, the

InSAR can measure the surface deformation of offshore platform with higher densification of pixel-by-pixel basis and it provides a cost effective technique where it offers wide area coverage to comprehensively monitor multiple offshore platforms deformation on any single campaign. Recently, a new technique of InSAR which is called Persistent Scatterer Interferometry (PSI) was developed. This is an advanced technique to improve the ability of InSAR to detect deformation using a large number of Synthetic Aperture Radar (SAR) images over the same area [1]. The PSI technique selects the pixels that have stable amplitudes (i.e., those with the same backscattering amplitudes) from a large stack of interferograms to reduce the phase decorrelation and remove the atmospheric delay. This technique has the capabilities to achieve millimetre accuracy of the surface deformation estimations. A number of studies have demonstrated that the PSI technique have been successfully used for land deformation application such as landslide monitoring [2], volcano deformation [3] and urban deformation [4].

This study assessed the feasibility of the application of the PSI technique for monitoring the deformation of offshore platform using TerraSAR-X satellite images. The outcome of the study is presented in the form of mean deformation velocity maps and displacement time series of each measured Persistent Scatterer (PS) of the monitored platform.

Study Area and Data Availability

In this study, one of the PETRONAS offshore platforms (referred to P platform) in South China Sea is being used as monitored platform (refer with Fig. 1). The platform is located approximately 250 km off the east coast of Peninsular Malaysia. The platform is chosen as the first test site to apply the PSI processing technique due to previous study based on GPS has revealed the said platform has deformation history rate of 0.0094 m for the period of two months [5].

Figures 1: P platform

After deciding on the test site, the InSAR satellite data will be acquired. It was decided that the satellite data sets to be used is the TerraSAR-X. The TerraSAR-X satellite is a German Earth observation satellite launched in June 2007 at an altitude of 514 km. The TerraSAR-X satellite is chosen because this satellite has a better pixel resolution, short repeat orbit interval of 11 days with a shorter wavelength of X-band (3.1 cm). There are a total of 11 TerraSAR-X satellite images over the P platform from the descending track (North to South) were acquired in this study (refer with: Table 1). The images were acquired in the standard StripMap mode with 3 m pixel resolution. Each image has covered an area of 30 km (width) x 50 km (length), at an incidence angle range from 24.86 to 27.86 in HH polarization. The images were acquired every 11, 22 or 33-day repeat cycle, with a time span of 8 months from 25th August 2012 to 24thApril 2013. The image acquired on 04 January 2013 was selected as the master image because it has relatively short perpendicular and temporal baseline corresponding to other images. The maximum perpendicular and temporal baselines with respect to master image are 344.5 m and 132 days, respectively, while the minimum ones are 2.715 m and 11 days (refer with: Table 1).

Table 1: Date of acquisition, perpendicular and temporal baseline with respect to the master acquisition of the TerraSAR-X data used.

Image number	Date (dd/mm/yyyy)	Perpendicular baseline (B_{perp}) [meters]	Temporal baseline (B_{temp}) [days]
1	25.08.2012	167.8	132
2	27.09.2012	180	99
3	30.10.2012	344.5	66
4	21.11.2012	75.07	44
5	13.12.2012	180.2	22
6	24.12.2012	39.32	11
7	04.01.2013	0	0
8	26.01.2013	4.939	22
9	17.02.2013	2.715	44
10	22.03.2013	270.3	77
11	24.04.2013	63.7	110

PSI Processing

The Sarproz software was used in this study to perform the PSI processing. The procedures of data processing are described below:

Persistent Scatterer Candidate (PSC) Selection. The PSC is identified in a series of interferogram based on the pixels which have the phase stability characteristics in time. In this study, the phase stability of each pixel is determined by the amplitude dispersion index, since there is a statistical relationship between amplitude stability and phase stability. Ferretti et al. showed pixels with amplitude dispersion index less than 0.25 are expected to have small phase variants [6]. In this way pixels with a constant signal and high signal to noise ratio (SNR) are selected. The amplitude dispersion index is defined by Ferretti et al. as [6]:

$$D_A = \frac{\sigma_a}{\mu_a} \tag{1}$$

where D_A is the dispersion index, σ_a is the standard deviation of the amplitude return relative to each individual pixel and μ_a is the its average.

Network Construction and Estimation of the Model Parameters of Interest. After selection of all the PSC with D_A<0.25, they were connected to construct a network. The length of the arcs (i.e., the path of neighbouring PSC pairs) in the network is limited to a certain maximum length in order to minimize the effect of atmospheric and orbital errors. If there are N PSC phase observations, only N-1 couples of independent phase differences could be formed. The phase differences for a couple of PSC are influenced by several factors such as differential linear deformation, differential existing DEM inaccuracy, differential atmospheric phase screen (APS) and unmodelled deformation (nonlinear deformation and noise). After the calculation of the phase differences of the each couple of the PSC, the modelled parameters of interest (i.e., linear deformation difference and DEM error difference) can be estimated from them. Here, the deformation rate is in millimetres/year while the DEM error is in meters. Noted that the modelled parameters of interest are estimated from wrapped phase difference.

Spatial Integration and Integration Test. The ensemble phase coherence $\hat{\gamma}$ introduced by Ferretti et al. is used to evaluate how good the observed phase difference of each arc on fitting the modelled parameters of interest [6]. The arcs with ensemble phase coherence $\hat{\gamma}$ lower than the threshold of 0.75 (i.e., with large residuals) are assumed to be unreliable and hence those arcs are removed [4]. The measure of the variation of the residual phase for a pixel (*x,y*) is defined as:

$$\hat{\gamma}_{x,y} = \frac{1}{N}\sum_{k=1}^{N} e^{(j.\phi\ error_{x,y})} \tag{2}$$

where N is the total amount of interferograms and j is the imaginary number. The residual phase $\phi_{error_{x,y}}$ is the difference between the modelled parameters and observed phase difference at location (*x, y*) in the interferogram. The parameters (linear deformation rate and DEM error) at each PCS pixel can then be obtained by spatial integration the modelled parameters of interest of each couple of PCS with respect to a stable reference point.

Atmospheric Error Estimation and Nonlinear Deformation Estimation. The residual phases at the PSC in each interferogram are calculated by removing the phase contribution by linear deformation difference and DEM error difference on arcs. Then, the residual phases can be unwrapped using the Integer Least Squares (ILS) approach [7]. The residual phases contain the phase contribution due to atmospheric effects and unmodelled deformation (nonlinear deformation and noise). Under the assumption that the atmospheric signal is strongly correlated in space and randomly in time, it can be subtracted from the other components of the residual phase (unmodelled deformation) using the low-pass filtering in the spatial domain and high-pass filtering in the temporal domain [4,6]. The atmospheric phase contribution for the pixels of each interferogram those are not included as the PSC in the network can be estimated by using a Kriging interpolation method. The result is known as APS. Finally, the nonlinear deformation component is estimated by using low pass filtering process in both time and space to the residual phase (i.e., after removal of the phase contribution due to the modelled parameters and atmospheric errors). It should be noted that this nonlinear deformation component will be added to the linear deformation estimates at the end of the processing.

Final Estimation of PS Points. From the differential interferograms without APS, the modelled parameters of interest (i.e., linear deformation difference and DEM error difference) can be estimated by the iteration process for all pixels or other PSC that have a lower amplitude dispersion index (i.e., D_A<0.40). In this way the number of detected PS points will be increased and significantly improved the PSI results. After estimation of the modelled parameters, the corresponding PSC is tested based on the ensemble phase coherence $\hat{\gamma}$ quality assessment (refer section 3.3) and the final set of PS points is selected. The estimated linear deformation is combined with the nonlinear deformation rate to derive the deformation time series.

Results and Analysis

Figure 2 shows a mean amplitude image corresponding to the study area. The mean amplitude image is generated from all the 11 SAR images. The high backscattering capability can be observed in the offshore platform while less backscattering in the ocean area. Hence bright region represents the offshore platform and offshore support vessel (OSV) while that dark region is the ocean. A total of 27 PS points is spread over the P platform (refer with: Fig. 2). However, there are no PS points are detected in the middle of P platform and on the OSV. This is due to displacements or movements of objects from their positions in the middle of P platform and the movement of the OSV. In other words, the middle portion of P platform and OSV are significantly influenced by temporal deccorelation effects, which lead to a loss of coherence.

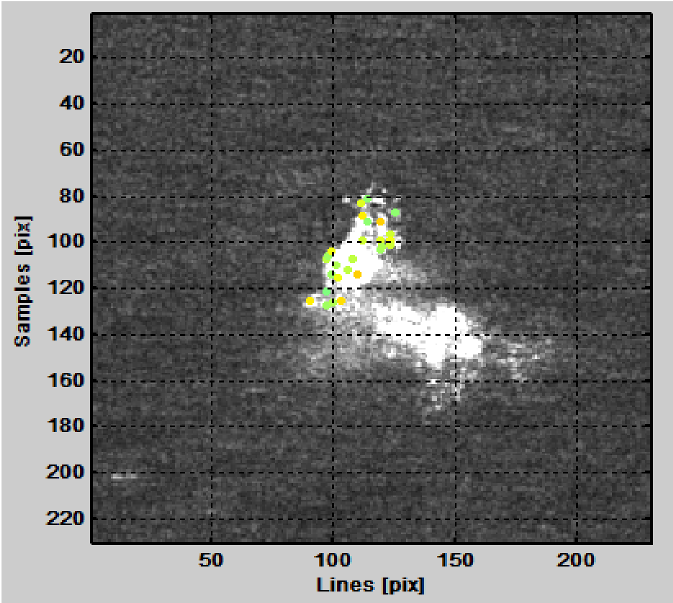
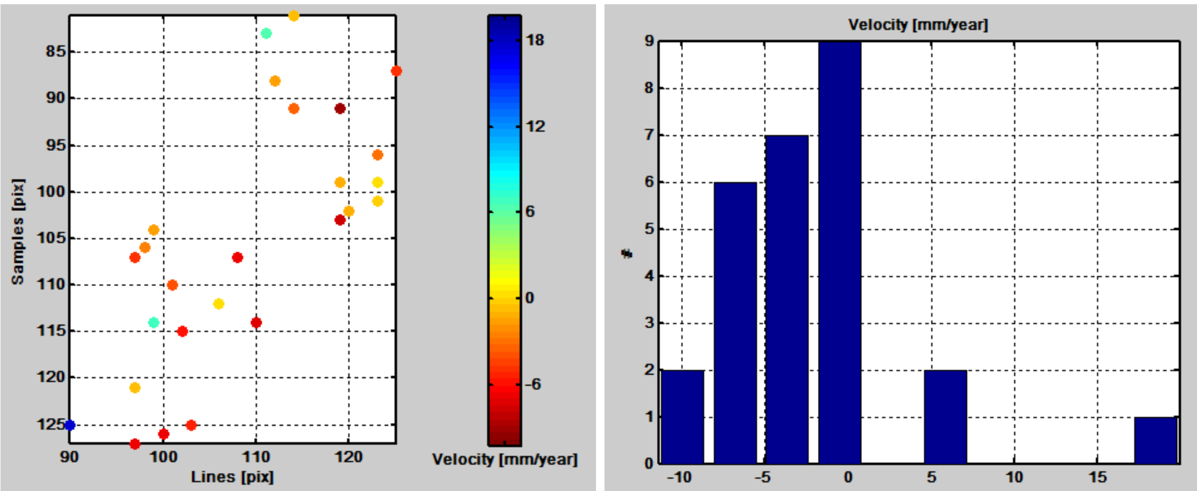


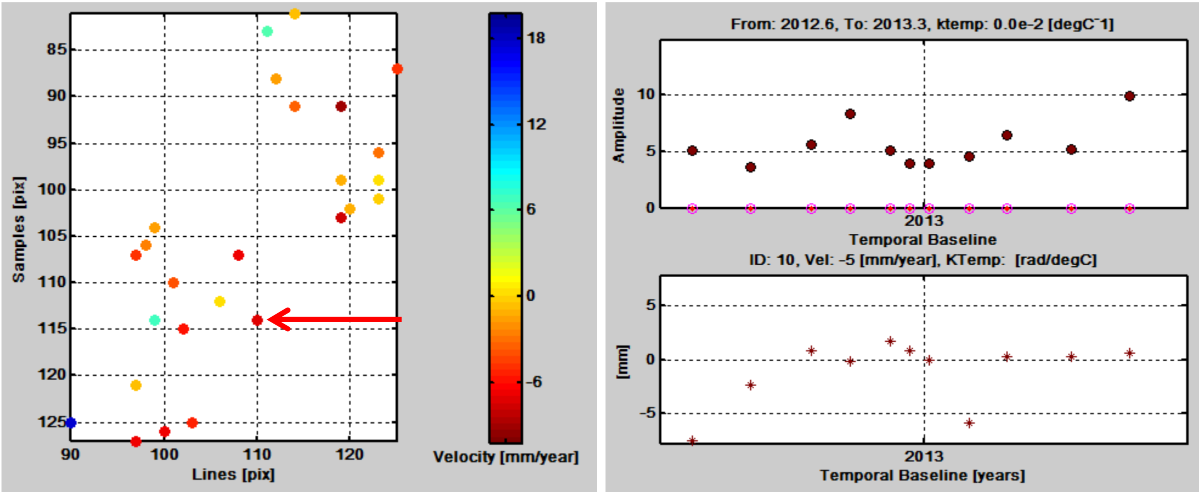
Figure 2: The distribution of 27 PS points, superimposed to the mean amplitude SAR image.

Figure 3 shows the colour variation of PS points corresponds to the variation in linear deformation rates, which is from -10 mm/year (red) to 20 mm/year (blue). The histogram shows that nine of the PS points were detected in the P platform have zero deformation rates which indicate the P platform is in a stable condition. On the contrary, 15 PS points demonstrate that subsidence have occurred on the P platform. The PS points have subsidence rates range of -1 mm/year to -10 mm/year. Also, three PS points show the P platform have uplift, two of them have uplift 5 mm/year, while one has uplift of 20 mm/year. Thus, the subsidence and uplift rate of the P platform indicates that the P platform has moderate movement.



Figures 3: Deformation rate estimation over the P platform. Deformation rates range from -10 mm/year to +20 mm/year.

Meanwhile, Figure 4 shows the deformation time series and amplitude variation of selected PS point which the PS point is located in the subsidence area. The position of the PS point is indicated by the red arrow. The results show that the deformation rates do not vary significantly over time.



Figures 4: Deformation time series and amplitude variation of PS point that identified in the subsidence area.

Concluding Remarks

The PSI technique has been utilized and tested to monitor the deformation of P platform. The moderate movement and minimum signal decorrelation make P platform very suitable for the application of PSI technique. This study has revealed that the P platform has experienced with some subsidence and uplift. In the next phase of this study, the accuracy of PSI results will be validated by comparing the observed deformation rates with GPS and levelling survey data. Once the PSI and GPS results are validated, it is proposed that PSI technique to be adopted for future offshore platform deformation measurements and monitoring.

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