A SHORT REVIEW ON PERSISTENT SCATTERER INTERFEROMETRY TECHNIQUES FOR SURFACE DEFORMATION MONITORING

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ABSTRACT

Technology advancement has urged the development of Interferometric Synthetic Aperture Radar (InSAR) to be upgraded and transformed. The main contribution of the InSAR technique is that the surface deformation changes measurements can achieve up to millimetre level precision. Environmental problems such as landslides, volcanoes, earthquakes, excessive underground water production, and other phenomena can cause the earth's surface deformation. Deformation monitoring of a surface is vital as unexpected movement, and future behaviour can be detected and predicted. InSAR time series analysis, known as Persistent Scatterer Interferometry (PSI), has become an essential tool for measuring surface deformation. Therefore, this study provides a review of the PSI techniques used to measure surface deformation changes. An overview of surface deformation and the basic principles of the four techniques that have been developed from the improvement of Persistent Scatterer Interferometric Synthetic Aperture Radar (PSInSAR), which is Small Baseline Subset (SBAS), Stanford Method for Persistent Scatterers (StaMPS), SqueeSAR and Quasi Persistent Scatterer (QPS) were summarised to perceive the ability of these techniques in monitoring surface deformation. This study also emphasises the effectiveness and restrictions of each developed technique and how they suit Malaysia conditions and environment. The future outlook for Malaysia in realising the PSI techniques for structural monitoring also discussed in this review. Finally, this review will lead to the implementation of appropriate techniques and better preparation for the country's structural development.

1. INTRODUCTION

Surface deformation is described as a gradual and irreversible shift resulting in landslides, unstable slopes, collapses, and other hazards on loess slopes. Few factors led to the features or structural deformation changes: earthquake, flood, excessive groundwater extraction, environmental load, poor soil condition, and soil erosion (National Academies of Sciences, Engineering, and Medicine, 2018)
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Conventional geodetic measurements and a real-time kinematic GNSS tracking system have been used to map current surface deformation shifts (Parwata et al., 2020). In order to measure and monitor changes in surface deformation, there are two general techniques used in surface deformation monitoring: (1) Geodetic and (2) geotechnical methods (Beshr, 2015; Scaioni. 2018). The geodetic approach uses tools like total station, precise levelling, GPS and InSAR. In contrast, the geotechnical technique uses the instruments such as accelerometer, seismometer, laser, inclinometer, tiltmeter, and micrometre (Din et al., 2015; Jesus et al., 2019). It is common knowledge that the classic and traditional approaches are often used for surface deformation and strain studies because it is exceptionally accurate global instruments (Dumka et al., 2020).

Many scientific articles on using the InSAR technique for deformation control indicate that the measurements are highly precise. Interferometric Synthetic Aperture Radar (InSAR) has shown considerable capabilities in mapping surface deformation and spatiotemporal evolution during various phases of the seismic cycle over the last decade (Zhao et al., 2021). Additionally, the approach offers dense spatial and temporal restrictions on fault geometry source parameters as well as various physical mechanisms of intraplate and crustal faults over the world (Massonnet et al., 1993; Elliott et al., 2016). This technique offers extensive ground coverage at low expense, with the precision of a few centimetres to a few millimetres (Tosi et al., 2016).

Furthermore, the "Persistent Scatterer Interferometric SAR (PSInSAR)" has been developed for precise surface deformation measurements using temporally stable persistent scatterers (Burgmann et al., 2000; Ferretti et al., 2001; Psimoulis et al., 2007). Persistent Scatterer Interferometry (PSI) is an advanced remote sensing tool that can monitor and quantify the Earth displacement over time. PSI is a remote sensing technique for detecting surface deformation, which is a sign of future geohazards. It is possible to acquire valuable knowledge about geohazards, such as landslides, by recording such deformations over time (Xue et al., 2018).

The progression of PSInSAR fundamentals and techniques allow researchers to broaden their knowledge to monitor surface deformation changes. Currently, there are several techniques developed from the improvement of PSInSAR, which are Small Baseline Subset (SBAS) (Berardino et al., 2002), Stanford Method for Persistent Scatterer (StaMPS) (Hooper, 2008; Hooper et al., 2004), SqueeSAR (Ferreti et al., 2011) and Quasi Persistent Scatterer (QPS) (Perissin and Wang, 2012).
Thus, this paper will review the PSInSAR techniques that have been developed in order to monitor surface deformation changes.

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2. GEODETIC METHOD IN MONITORING SURFACE DEFORMATION

2.1 Overview of the Persistent Scatterer Interferometry (PSI) and Its Limitations

Ferreti et al. (2001) developed the Permanent Scatterers (PS) technique, a sophisticated algorithm for processing data collected by SAR sensors. It is a method that draws on the standard Interferometric Synthetic Aperture Radar (InSAR). In InSAR, a pulse of electromagnetic waves travelling through the atmosphere will collide with the earth's surface, causing part of the signal lost before reaching the transmitting antenna. As a result, InSAR hires Radio Detection and Ranging (RADAR) to evaluate the target's reverted wave pulse as well as the distance between it and the antenna (Zhou et al., 2009). In general, the concept of InSAR involves the phase difference of two SAR measurements found on the ground surface in the same region (Ø2-Ø1) (Ramirez et al., 2020). As shown in Figure 1, the acquisition is carried out at different times to calculate and quantify the variations in surface displacement between phase measurements of the same pixel (Zhou et al., 2009).

The PSInSAR method was developed and patented to measure a surface deformation at high accuracy, up to a millimetre level (Din et al., 2019). The primary motivation behind the development of this technique is to address the shortcomings of conventional InSAR, which are caused by de-correlation, atmospheric errors, lack of deformation data, and temporal resolution data (Latip et al., 2019). PSInSAR exploits large stacks of SAR images, enabling the detection of the most stable scattering targets over year(s) (Crosetto et al., 2016; Liu et al., 2020). It employs several interferograms made from a big pile of SAR images, with only specific phase-stable pixels selected during the image span (Din et al., 2014). The most stable scattering targets will be estimated, thermal noise is removed from it, and finally, permanent scatterers' movement is measured (Ismail et al., 2016). The PSI principle is shown in Figure 2; the scattered points contribute to the phase of a single-pixel image, while the plots represent the simulation of phases for 100 iterations. Figure 2 (b) shows that the persistent scatterer is three times brighter than the number of the smaller scatters; hence only the bright scatters will be processed. Then, the image de-correlation will also be decreased (Hooper et al., 2001; Din et al., 2015). This method is ideal for slow-moving mapping surfaces, such as landslides, tectonic movement, and surface deformations over time.

Regardless of PSInSAR's ability to detect ground deformation with millimetre accuracy (Morgan et al., 2011; Latip et al., 2015), for this technique, surface deformation is only measured in terms of vertical displacement, which is subsidence and uplift relative to the first SAR acquisition and local spatial relation within the image region (Parker et al., 2017). In vegetation and water area, the PSInSAR technique is also challenging to detect stable pixels within low coherence areas, particularly in extra-urban areas (Cigna et al., 2019; Liang et al., 2020).

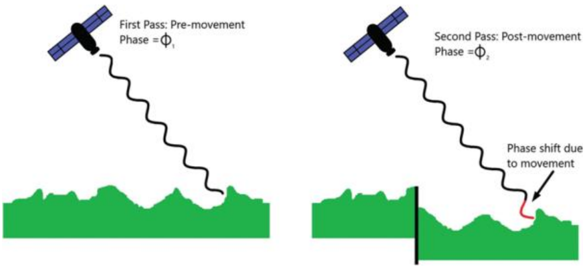

Figure 1. Principle of InSAR (Leighton et al., 2016)

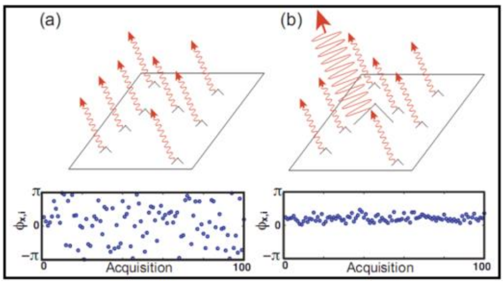

Figure 2. The phase simulation of (a) a dispersed scatterer pixel and (b) a permanent scatterer pixel (Hooper, 2006)

3. DEVELOPMENT OF PSI TECHNIQUES

The surface deformation changes monitoring techniques have been developed and explored by a good number of researchers. This advancement is focused on the use of Persistent Scatterer Interferometry (PSI) to strengthen and refine Ferreti et al. (2001) PSI's technique. Four methods will be extensively explored in this study to address the shortcomings of the original PSI.

3.1 Overview of Small Baseline Subset (SBAS)

Berardino et al. (2002) has invented the SBAS method. The SBAS method is intended to minimise phase de-correlation and topographic errors, as the PSI method decreases the influence of phase de-correlation and atmospheric errors. It can be achieved without obtaining a master image from image pairs separated by short temporal and spatial baseline by picking more coherent interferograms. Further, the de-correlation noise is reduced by applying the filtering phase to all the selected interferograms.

This SBAS method uses the Distributed Scatterers (DS) to retrieve the information from the SAR images. DS can be regarded as a summation of coherent of many random small scatterers within a resolution cell. It solves PSI's problem of not utilising Permanent Scatterers (PS) in non-urban areas, such as areas surrounded by fields, forests, soil, and rocks. Firstly, to minimise spatial and temporal de-correlation, interferograms is produced from SAR image paired with perpendicular and temporal baselines less than a certain threshold. The interferograms that have been selected undergoes complex multi look processing, which improves the scattering characteristics of DS points. Then, phase unwrapping is conducted for each interferogram. Each unwrapped interferograms contain information of the phase difference called the surface changes of detected DS points from all the images. The phase model will be established to estimate the deformation and elevation correction using the singular value decomposition (SVD) method to combine all the information needed, such as time and surface changes deformation. Instead of using PS points, this technique utilises the DS points because numerous points can be monitored and measured compared to the PSI technique.

However, as discussed earlier, the image resolution will be reduced, which causes the user to lose some details of the images when using this Small Baseline Subset technique. The interferograms are often divided into multiple independent subsets during Small Baseline Subsets (SBAS) InSAR processing, which invariably leads to a rank deficiency problem. The most common method is singular value decomposition (SVD), which results in consistently skewed deformation estimation.

3.2 Overview of Standard Method for Persistent Scatterer (StaMPS)

The Stanford Method for Persistent Scatterers (StaMPS) is a multi-temporal processing technique improved from PSI and was designed by Hooper et al. (2007). It uses the Delft Object-oriented Radar Interferometric Software (Din et al., 2019) provided by Delft University of Technology to form differential interferograms (Kampes et al., 2003). In all interferograms, phase analysis is used to distinguish low amplitude pixels with phase stability. In Differential Synthetic Aperture Radar (DInSAR), the phase stability cannot be defined or determined using the amplitude-based analysis since it is the limitation of the technique. This technique relies on the stable natural and man-made targets, called Persistent Scatterers (PS), which show a reliable and dominant scattering characteristic over the period (Hooper et al., 2004; Latip et al., 2015).

StaMPS uses Amplitude Dispersion Index (ADI) as a PSI tool for initial PSC selection. However, the StaMPS threshold is higher (lower than 0.4) (Vadivel et al., 2020). The spatial coherence of deformation and ambient signals are used to establish the interferometric process model. Point by point, step coherence and elevation adjustment are calculated iteratively, and low coherence points are removed using this method.

Compared to Persistent Scatterer Interferometry, the advantage of this method is that more stable points can be determined predominantly in non-urban areas since it uses amplitude and phase analysis rather than PSI, which only use amplitude. StaMPS isolates the signal due to deformation from several annoying phase components, such as DEM, atmospheric, and orbital errors, after determining the most stable pixel or PS pixels. The deformation time series can be acquired without previous knowledge of the deformation frequencies, as opposed to the PSI technique. Rather than having a prior deformation model presume its temporal structure, this can be accomplished by considering the spatially correlated presence of deformation. The StaMPS method employs a 3D phase unwrapping algorithm to achieve the absolute phase of PS points (Hooper and Zebker, 2007). Then, deformation time series can be seen and estimated after all the errors in the signal are reduced.

However, most of the study areas using this technique are terrain areas such as mountainous and volcanoes since the deformation analysis and estimation are correlated at a certain distance. This technique is not suitable for monitor the structural building due to the limitation of estimating the deformation at a particular area of a building.

3.3 Overview of SqueeSAR

SqueeSAR is a patented multi-interferogram technique that provides high precision measurements of ground surface deformation over the same field and acquisition geometry. It is an advance on PSI techniques (Ferreti et al., 2011; Ferreti et al., 2014; Bischoff et al., 2020). Ferreti et al. (2011) are the researchers who design and proposed this method called the SqueeSAR technique. It is allowed to determine a more significant number of Measurement Points (MPs) in the extra-urban areas than PSI based on the Persistent Scatterers (PS) approach.

This technique is proposed to increase the density of measuring points in space, particularly in extra-urban areas, by using the signal from PS and DS, which entails the statistical study of various types of natural radar targets at various times. Based on statistical methods, it raises the density of chosen targets for interferometric processing and increases interferometric coherence (Ferretti et al., 2011). Debris fields, uncultivated land, scattered outcrops, and abandoned areas are examples of DS, which can be defined as a significantly homogeneous group of pixels in radar images where adjacent pixels have the same reflectivity values. Meanwhile, PS refers to high reflectivity and radar targets, such as building linear structures and rocky outcrops (Alberti et al., 2017). Based on the mathematical analysis of amplitude and phase results, this technique will select a sparse grid of image pixels that can be used to analyse and map slow surface displacement processes with a few millimetres of precision (Ferretti, 2014). Furthermore, the higher the PS and DS density, the greater the influence of the erroneous atmospheric phase elements filtering (Ferreti, 2014).

The average rate of displacement along the satellite line of sight and its time history can be estimated for all MPs. The measurements of SqueeSAR's displacement vary in space and time, as with all InSAR data: they are connected to a reference point established within the area of interest (AOI) and the date of the first satellite acquisition (Alberti et al., 2017). In this technique, DS's signals are first processed to reduce the phase noise and estimate the coherence matrix for each DS by applying adaptive filtering. Then, the optimal phase values of each DS are estimated by implementing the phase triangulation algorithm. The DS and PS are processed together using the conventional PS processing chain to produce the deformation time-series (Latip, 2019).

However, because of the lack of coherence, this technique is unable to detect any accurate pixels for assessing the movement of the younger part, especially the most active area in the terrace zone (Mirzaee et al., 2017)

3.4 Overview of Quasi-Persistent Scatterer (QPS)

Perissin and Wang (2012) suggested the Quasi-Persistent Scatterer (QPS) boost the Persistent Scatterer Interferometry (PSI) capability, which has a drawback of achieving adequate efficiency in non-urban areas due to low PS density. The core principle of the QPS methodology is to loosen the tight constraints set by the PS analysis developed by Ferreti et al. (2001) so that information can be obtained from partly coherent targets (Perissin et al., 2012). Therefore, the QPS methodology integrates the phase of spatial and temporal correlation analysis to derive the extracted information from partly consistent targets and improve the spatial distribution of measurable points. It can manage the detection of decorative targets and the distributed targets in the processing and analysis.

In general, QPS assigns a weight to each interferometric phase based on its interferometric coherence and processes the most coherent interferograms given the available dataset. It means that each pixel of the radar image is processed using the best interferogram available, and the subset will vary from one pixel to the next. The main advantage of this technique is that it has a tremendous advantage for extra-urban areas. According to Luo et al. (2012), this technique has three main differences from the original PSI techniques. First, more than one reference image can be selected. Second, it is vital to keep track of partly consistent targets that are only coherent for a subset of interferograms. Lastly, spatial filtering can be applied to the processing.

However, there are disadvantages to this approach, such as lack of precision, accuracy, and resolution. Pixel by pixel, the measured motion would have a varying degree of fidelity since the subset of interferograms is pixel-based.

4. PRO AND CONS BETWEEN TECHNIQUES

Since the developed techniques objectives are to overcome the Persistent Scatterer Interferometry (PSI) limitations by Ferreti et al. (2001), Table 1 describes the strength and weaknesses of each developed technique.

Techniques	Pro	Cons
Persistent Scatterer Interferometry (original implementation) (Ferreti et al., 2001)	- Overcome limitations of the DinSAR technique caused by de-correlation and atmospheric errors - Can achieve millimetre accuracy of surface deformation in urban areas	Not suitable for sub-urban areas as the low spatial density of extracted PS points.
Small Baseline Subset (SBAS) (Berardino et al., 2002)	A number of measurement points improved as the information extracted from distributed scatterer (DS) rather than persistent scatterer (PS).	The DS is affected by spatial and temporal de-correlation but still contain coherent information.
Stanford Method for Persistent Scatterers (StaMPS) (Hooper et al., 2007)	- Use phase analysis to identify low amplitude pixels with phase stability - Deformation time series can be obtained without prior knowledge of deformation rates - Combines both PSI and SB techniques to improve the spatial density of measurement points - Suitable for urban and non-urban areas, especially terrain areas	Not suitable for monitoring deformation of the structural building since its limitation to detect movement on specific points.
Quasi Persistent Scatterer (QPS) (Perissin and Wang, 2012)	- Obtained information from partly coherent targets for a subset of interferograms. - More than one reference image can be selected - Great advantages for extra-urban areas	Lack of precision, accuracy and resolution

Table 1. The strength and weaknesses of each developed technique

According to Table 1, initially, PSI techniques introduced to overcome the limitation of the DInSAR techniques affected by temporal and spatial de-correlation led to inaccurate deformation information and atmospheric disturbances. Significantly, the deformation rates can achieve millimetre accuracy, especially in urban areas. The main problem with this original implementation of Persistent Scatterer Interferometry (PSI) is that this technique is unsuitable for measuring deformation or movement of surface in non-urban areas as the PS points extracted from the images contain low spatial density. It has caused the processing analysis cannot detect the most stable target.

The developed techniques, SBAS, StaMPS, SqueeSAR and QPS techniques, are suited for non-urban areas. However, each method has its limitations and strengths. Small Baseline Subset (SBAS) techniques used a more significant number of measurement points as the information extracted from the images, including distributed and persistent scatterers. The difference with the PSI technique is that it only exploits the persistent scatterers pixel used in the processing to measure the deformation rates of the surface. The SBAS technique using DS and PS measurement points can determine the suitable pixel that will be used in low coherent areas such as vegetated and non-urban areas. However, since the technique used the DS points, it will be affected by the temporal dan spatial de-correlation, but it still coherent information that can be used in the processing.

Another technique is Stanford Method for Persistent Scatterers (StaMPS). The good idea about this technique is its used phase analysis to detect the low amplitude pixels with phase stability which means this process allowed the detection of stable pixels even with low amplitude. A time series of deformation can be created without prior knowledge of the temporal nature, unlike the PSInSAR (original implementation) approach. In order to increase the spatial density of measurement points, especially in rural areas, the PSI and SBAS techniques are integrated as both techniques have been described earlier. However, this technique also has its limitation: the deformation rates are within a large area. So, this technique cannot be used for a small structure such as a building. Because deformation analysis and estimation are associated at a given distance, most of the study areas that use this technique are terrain areas such as hills and volcanoes.

Ferreti et al. (2012) have developed their techniques to overcome the problem faced by the original PSI techniques, SqueeSAR. The strength of this technique is the exploitation of signals from DS and PS points to increase the spatial density of measurement points in space, especially in rural areas, at various times. This technique is the same with few developed approaches that use PS and DS pixels to determine stable pixels in non-urban areas such as vegetated and abandoned areas. The difference between this technique and other techniques is its settling down with the DS signal, reducing the phase noise. After that, both DS and PS will be processed together to estimate the deformation time series. This technique's weakness is its inability to identify any accurate pixels to determine the active region of movement, such as the terrace area.

The Quasi-PS (QPS) approach combined phase spatial and temporal correlation analysis to extract information from partly coherent targets and improve the spatial dispersion of measured points is the strength of this technique. This approach handles the detection of both distributed and decorrelating targets. There are three main difference modifications applied to this technique as described in section 4.0. Even though through this technique, accuracy and resolution will be lost, but distributed, and decorrelating targets can be detected and determined.

5. PREVIOUS STUDIES AND DISCUSSION

Deformation is commonly caused by erosion and sedimentation, chemistry and temperature, and flora and fauna phenomenon (Gao et al., 2019; Navarro-Hernández et al., 2020). According to Borghero (2017), the main driver to the deformation that occurs is environmental causes. Whether subsidence or uplift, the deformation can affect a particular place in public safety and the economy. Surface deformation changes monitoring an area or structural development is crucial to ensure public safety and interest. Currently, surface deformation monitoring is carried out through conventional methods using ground-based tools, such as GPS, total station, and precise levelling (Martins et al., 2020), which is inconvenient for cost and time (Aslan et al., 2020). These conventional methods measure surface deformation only on a point-by-point basis, rather than PSI techniques, which measure on a pixel-by-pixel basis and cover large areas (Lagios et al., 2013; Xu et al., 2018).

Furthermore, Malaysia is well known as a tropical rainforest country, which means urban and extra-urban areas are significantly well balanced. A proper technique is required so that PSI methods can be used to measure both areas. For instance, due to land subsidence, Sultan Abu Bakar Dam in Pahang, Malaysia, is experiencing enormous flooding that cost properties, assets and claimed four people's lives in 2013 (Faudzi et al., 2019). Therefore, this study presents an endeavour to monitor surface deformation changes using Persistent Scatterer Interferometry (PSI) techniques.

Through literature reviews, several techniques to further improve the monitoring of surface deformation changes are Small Baseline Subset (SBAS), Stanford Method for Persistent Scatterers (StaMPS), SqueeSAR and Quasi Persistent Scatterer (QPS) techniques. The four techniques described in section 3 are used to track surface deformation changes. The first approach uses the Small Baseline Subset (SBAS) method, which uses 36 Sentinel-1A images collected from the European Space Agency from 2015 until 2018 in Tianjin, China. The images have been processed and analysed. Levelling work has been carried out in the study area to verify the deformation estimation using the SBAS method. According to Zhu et al. (2020), as shown in Figure 3, the SBAS system has proven effective for calculating and tracking land deformation up to the millimetre (mm) level. Most deformation rates are in the range of -18mm/yr to 9mm/yr throughout the research period, in which negative values indicate subsidence and positive values indicate uplifting. The maximum subsidence experienced in Youzhangbao.

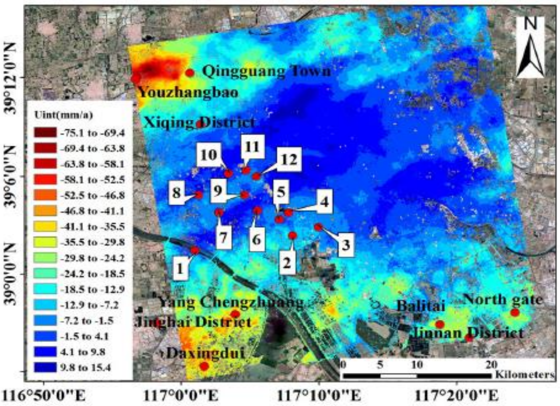

Figure 1. Ground deformation rate in Tianjin from 2015 to 2018 (Zhu et al., 2020)

Stanford Method for Persistent Scatterers (StaMPS) is the second PSI method development reviewed in this study. Seventeen (17) SAR images from the ERS-2 satellite mission are requested from the European Space Agency (ESA) to cover the Kelantan catchment. This images data have been downloaded and processed using the StaMPS method. StaMPS is a multi-temporal and advanced tool to monitor deformation changes in urban areas while offering open-source software. According to the study conducted by Din et al. (2016), land subsidence monitoring was carried out in Kelantan, Malaysia, since 70% of the state's total domestic water are from groundwater extraction.

Figures 4 and 5 show the deformation map of two study areas in Kelantan. The results of using the StaMPS approach at Tumpat and surrounding areas, with deformation rates ranging from -1.8mm/yr to 0.6mm/yr, are shown in Figure 4 (left). Figure 4 (right) illustrates the time series of deformation levels over time. Similarly, Figure 3 shows the result in the Tg Mas cropping area. The StaMPS method used shows the deformation rates with its surrounding area range from -2.3mm/yr to 1.4mm/yr in Figure 5 (left). Figure 5 (right) indicates the deformation rates throughout the years is estimated at -2.39mm/yr. It shows that StaMPS can detect and give a better result of land deformation changes in low coherence areas.

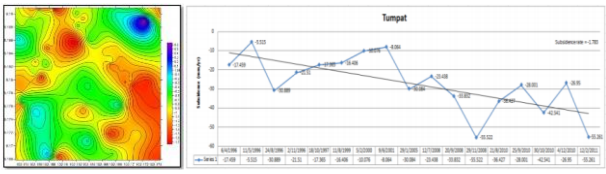

Figure 4. Deformation rate at Tumpat, Kelantan (Din et al., 2015)

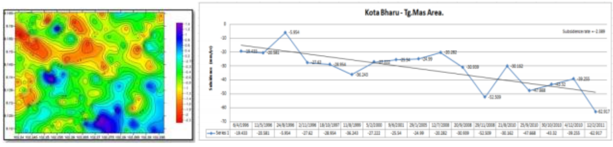

Figure 5. Deformation rate at Tg Mas Area, Kelantan (Din et al., 2015)

Another method realised is SqueeSAR, developed by Ferreti et al. (2011). This method utilises the PS and DS points known as Measurement Points (MPs). In the study carried out by Alberti et al. (2017) at an archaeological site, 38 ENVISAT images acquired from 2003 until 2010. There are 62 000 MPs identified, which can estimate the deformation time series analysis along the Line of Sight (LOS). Figure 6 shows that all MPs with the range of average displacement rate are from 02.mm/yr to 0.6 mm/yr. Furthermore, the precision of the SqueeSAR result is determined by the distance between the MP and the reference point; the shorter the distance, the better the precision (Alberti et al., 2017). As discussed further on the specific area, Figure 7 shows that the deformation results using the SqueeSAR method is identified and estimated about +-1.5mm/yr and reveal a large number of MPs are almost stable. The exploitation of a large number of points gives an accurate and precise measurement.

The last method implemented is Quasi Persistent Scatterer (QPS) technique, developed by Perrisin and Wang (2011). A total of 90 scenes were acquired using this approach from Sentinel-1A between October 2014 and November 2017 in both ascending and descending orbit directions. This method helps monitor land deformation in non-urban areas since it improves the number of PS points. Figure 8 shows the surface deformation changes using the Quasi-PS (QPS) method in non-urban areas plus vegetation areas. The figure (left and middle) shows maximum displacement experienced by the ascending direction (left) and descending orbit direction (right) of the study area is -512mm/yr and -619mm/yr, respectively.

The colour of the PS point shows the cumulative land deformation of the area. This result has been geocoded and loaded onto Google Earth optical layer. From this point of view, two zones of several land displacements are significantly correlated to each other. Figure 8 (right) shows the integration of deformation results using the Quasi-PS (QPS) method between two zones, and it proves that this method can measure deformation in non-urban areas.

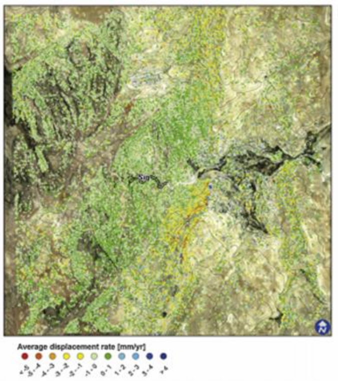

Figure 6. Distribution of MPS with their deformation rate estimation (Alberti et al., 2007)

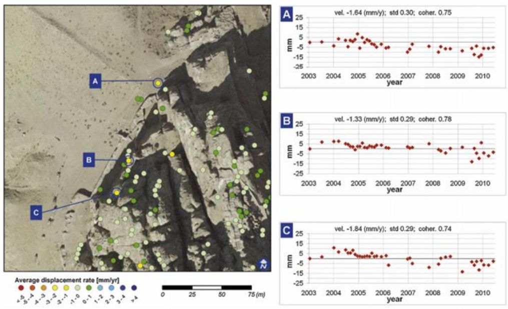

Figure 7. The land deformation over a specific area in archaeological site (Alberti et al., 2007)

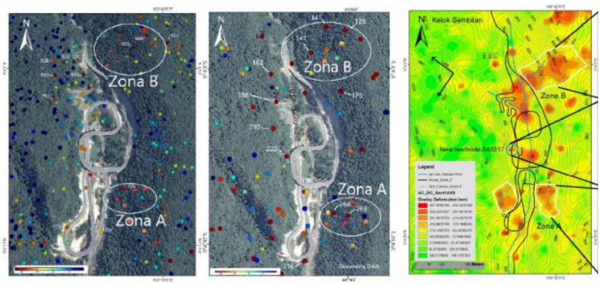

Figure 8. Land deformation area observed in orbit direction of satellite images and overlay between two directions (Razi et al., 2018)

6. CONCLUSION

In conclusion, the breadth and depth of these four developed methods in monitoring surface deformation changes have become apparent to users. With the rapid development of PSI techniques, it is very significant in Malaysia to have the surface deformation changes monitoring for structural building or man-made features such as dams, buildings, roads, etc. So that the authorities can take initial steps if the movement is quite significant as a result of monitoring using the PSInSAR technique. Since Malaysia is also located in low latitude region, the selection of proper techniques is crucial so that the analysis results are improved. This development provides better accuracy and complements each other to improve the PSI techniques for monitoring surface deformation changes. Finally, is it expected that through this review study, the use of PSI techniques will improve the estimation of surface deformation changes to help authorities implement better plans, particularly in the construction of man-made features and designing preventative measures to elude natural disasters in the future.

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