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Accuracy evaluation of PSI method using Sentinel-1A data to monitor open-pit mines instability, case study, Anguran open-pit mine

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Abstract

Landslides are one of the disasters and geohazards which cause economical losses and casualties annually worldwide. By the growth of population and urban development toward foothills, slope monitoring and landslide detection become essential. These actions could be done by advanced technologies such as satellites and processing of their products by related applications and packages. Also excavating large open-pit mines to extract metal and minerals, leads to instability of the terrains which makes risk of landslide an inevitable part of mining.
Studying the features of slope is one of the best techniques to avoid landslides and slope instability. First step of landslide is detection which remote sensing is one of the best ways to detect and monitor slops. Low cost and large area coverage makes this most efficient technique for monitoring and landslide detection. Synthetic Aperture Radar (SAR) is one of the sensors that is utilized to detect land movement by sending and receiving electromagnetic signals.
In this research to detect slope movements on Anguran lead open-pit mine walls, free Sentinel-1A SAR images which provided by European Space Agency (ESA) were processed by open source source softwares, SNAP and StaMPS. Displacements obtained from satellite data, were compared with displacements measured by survey, precipitation data and geological properties and features to figure out the major factors affecting the stability of slope. Generally, results demonstrate using of Sentinel-1A SAR data are acceptable for overall detections and displacements measuring, however for better results in active open-pit mines, sensitive radar sensors and commercial softwares are recommended

***Key words**: Open-pit mine slop instability, Landslide detection, ynthetic Aperture Radar, Persistent Scatterer Interferometry, Sentinel-1A.*

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Extended Abstract:

1. Introduction

Landslides cause financial and human losses in the world, annually (Koehorst et al., 2005). One of the areas prone to landslides is open pit mines. Due to the geological settings, Iran is one of the richest countries in mineral resources. The processing of such minerals and thus mining practices, introduces some geological hazards, e.g. slope instability in open pit mines. The open pit mines and the incidents lately amplifies the significance of monitoring and identifying the slopes prone to instabilities in order to reduce the costs and keep the flow of mining practice. Numerous studies have been conducted to investigate the surface displacements, such as landslides and slope instabilities (e.g. Colesanti & Wasowski, 2006) and landslides of open pit mines by radar satellite data such as ERS, Sentinel-1, (e.g. Mora et al., 2013) and TerraSAR-X (Hartwig, 2016) satellites. Remote sensing approaches contribute immensely to the detection and monitoring regularly at the target regions and slopes. Since the velocity of the movement at the earl stages is significance in the occurrence of the instability on the open pit slopes, the movements must be monitored from beginning continuously. By this practice, it will be easily practical to identify the spots prone to movement to implement the remedial engineering measures. In this research, we attempt to evaluate the reliability and practicality of applying an InSAR method through Sentinel-1 band C radar satellite imagery. We processed the satellite data by Persistent Scatterers Interferometry (PSI) in landslide detection and monitoring practice. Anguran open pit lead and zinc mine is located in Zanjan province, west of Tehran. The mine suffered from slope movements and occasional landslides for many years. For instance, the western wall of Angoran mine in 2006 witnessed a large landslide that continued for many years. To assess the monitoring probability of such movements in the future, the results of imagery data processing are compared with the ground data of Total Station surveys. The walls of the mine are composed mostly of lime and schist. The limestone presents fair stability, both fresh and weathered; however, as the weathering advances, the stability decreases. Their stability is strongly affected by the degree of schistosity, foliations and the stratigraphy (Borhani Takhteh et al., 2015). Schists are highly prone to weathering due to the ease of water infiltration and percolation along their surfaces. Because of the composition of primary minerals, forming clay minerals in the schists is quite common.

2. Materials and methods

The data obtained from the Total Station readings are prepared in the form of x, y, z coordinates (length, width and height) from a reference station in the local coordinate system. These readings are repeated periodically and at regular intervals (for example, monthly). Calculation of displacement is in some different forms of horizontal, slope, and vertical displacements. The PSI method is one of the multi-time interferometry methods. Given that the relatively older methods of radar differential interferometry (*DInSAR*) have failed to produce well-correlated results in most previous research, this method could greatly eliminate the correlation problem of the older methods. For instance, due to the vegetation, in the earlier methods of radar differential interferometry, a temporal non-correlation occurs in most of pixels in the image. a radar image shows the values of the sum of its reflections from a number of Persistent Scatterers points from the Earth's surface. When these scattering points move or shift between satellite passes, due to surface movements or vegetation growth, the phase of the return wave from the scattering structures is random leading to a lack of correlation (Hooper et al., 2007). However, if a scattering point that is relatively stable and has less motion than others, it looks brighter from the surrounding, because the waves reflect more strongly. Thus, the difference in the phase of the reflected waves due to the displacement, between the satellite transmissions, will be reduced and the lack of correlation will be small (Hanssen, 2001). The images used in this research are all from the *Sentinel-1A* satellite, which was received free of charge from the European Space Agency database website. The images are of Sentinel-1A satellite artificial radar sensor (SAR) and the required images have been taken in the Ascending Path. The above images have been taken and downloaded from passage 101 and frames 114, 115 and 116 from 12/10/2014 to 10/25/2016 in 31 images.

3. Tests results

The data obtained from the readings were collected by the Total Stations from July, 2014 to March, 2015, monthly. The format of this data was in the form of length, width, and heights for a number of stations on the western wall of the mine and at the upper steps of the wall. The resulting data are related to vertical displacement and slope direction of 5 stations named S1, S2, S3, S4 and S7. Three stations, S2, S3 and S4, have the highest displacement values. The main displacement occur in these stations through two stages; in the first stage from March, 2015 to May, 2015, and in the second stage from October, 2015 to March, 2015. Sentinel-1A satellite SLC images were processed in SNAP software, and required interferometers and further processing in StaMPS package were conducted. The stable scattering (PS) structures have been selected by StaMPS and the displacement rates were calculated. The calculated displacements indicate that the displacements are in the direction of satellite view (LOS). The view of the satellite is almost northeast and its angle is close to vertical. Thus, these displacement values of PSs can be considered as their vertical displacement. Through the first phase of displacements, the motion of PSs started from January, 2015, and continued until May, 2015. There are some discrepancies with the cumulative vertical displacement observed from Total Station readings. Nevertheless, the trend is almost the same. In the second phase of the motions, there is a better matching between the results of the two sets of data compared to phase one. The displacements started in October 2015 and continued until February 2015. There has also been a sharp increase in displacements since December 2014 in both phases. This time difference is created in the first phase of the transfer between the two types of data and also the difference in the transfer process at the end of the transfer phase of the second phase. Such variatioin in the accuracy of the resultsmight be due to the lack of similar PS numbers, very high displacement of the wall, satellite separation accuracy, type and justified sensor capability, the type of satellite imagery, and the performance of the algorithm used, and the small area of the movement. Nevertheless, the correlation between these two sets of observations (Ps and Total Station) is significant.

4. Conclusion

Comparing the results of the average displacement of PSs selected by the StaMPS package the cumulative vertical displacement collected from Total Station readings shows a relatively good agreement. Despite such agreement at the beginning of the displacement and then instability pattern in the western wall, the displacement values in the diagrams have shown a relatively large difference and have caused the unreliability of the results of image processing under the PSI method. The difference in displacement values can be attributed to the insufficient number of PSs selected in the image processing by the StaMPS package. This might be due to some factors such as small slip range, high displacement due to a large slip, large extraction in the mine wall, excess atmospheric effects due to extreme elevations and topography of the region, radar sensitivity, and the quality of the images. During the period of this research, a displacement of about 20 to 35 meters in the western wall has been observed, which high values are. The large displacement that occurred in the mine, especially the western wall, has caused the PSI method to select less Ps. In addition, some other factors such as low area of the landslide, lower sensitivity of C-band sensors as in Sentinel-1 (compared to X-band sensors), and possibly the open source nature of StaMPS package (compared to other commercial softwares) might have affected the number of selected PSs and the reliability of the results.

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