Integrative Landslide Emergency Monitoring Scheme Based on GB-INSAR Interferometry, Terrestrial Laser Scanning and UAV Photography

Xiangtian Zheng 1,2, Xiaolin Yang 2,a, Haitao Ma 2, Guiwen Ren 2, Zhengxing Yu 2, Feng Yang 2, Hao Zhang 1 and WenYuan Gao 3

1School of Mechanical Electronic & Information Engineering, China University of Mining and Technology (Beijing), No, Ding-11, College Road, Haidian District, Beijing, 100083, China
2China Academy of Safety Science and Technology, No. 32, Beiyuan Road, Chaoyang District, Beijing, 100012, China
3Panzhihua steel group co. LTD, SiChuan, PanZhihua, 617000, China

a Corresponding author: Xiaolin Yang; email: yangxl@chinasafety.ac.cn

Abstract. In this study, an integrated remote sensing scheme comprised of a Ground-based Interferometric Synthetic Aperture Radar (GB-INSAR), Terrestrial Laser Scanning (TLS) and an Unmanned Aerial Vehicle (UAV) is utilized for rockslide emergency monitoring. GB-INSAR, here proposed as surface deformation monitoring of residual dangerous rock mass, provides data support and decision basis for the study of secondary slope instability. TLS grasps the landslide body as point cloud, and the 3D modelling of the main hidden danger area of secondary sliding at the site. UAV obtained timely geographic information about disasters, investigated potential hazards and shared them in real time. A case study, based on the entrustment of China Ministry of Emergency Management (CMEM) and China Institute of Geological Environment Monitoring (CIGEM), deals with a rockslide locates at K18+350 Junhong Road (Beijing, China). First, acquired data are processed for early warning of hazard to ensure the safe transfer of personnel and property within 72 hours in villages and towns affected by dangerous rock masses. Second, the monitoring services ongoing on accurately measurement of each hidden risk spot in the spatial coordinates, elevation and dynamic change and influence range. The methodology has been proved effective in emergency management.

1. Introduction
Landslides or rockslides are major worldwide natural hazards causing grave losses of life and property. If such slide occurs near the town and with high risk of secondary disasters, reliable real-time deformation monitoring system should be set up for dangerous slope emergency management. In combination with the analysis of the disaster triggering factors, temporal and spatial kinematics of rockslide can be mastered. Unlike previous long time series monitoring activities, the emergency monitoring and warning system should meet the requirement of continuous comprehensive and reliable data within extremely short time period. To ensure the safe transfer of residents and property, and to provide messages to rescuers, geological prospecting personnel for early warning of slope instability.

Generally, deformation monitoring of unstable slopes is crucial for disaster prevention, current technology falls into contact or non-contact mode categories. The former includes the inclinometer,
strain gauges, in-situ sensors network, GNSS and other monitoring systems need to be placed on the surface or embedded in the target body [1-3]. Contact measurement technologies generally have small coverage and risky installation. They often require excavation or borehole construction, hardly meet the large-scale and efficient requirement of emergency monitoring. Non-contact measurement systems mainly include prismatic-free total station, TLS with reflective targets, UAV photography, real-aperture radar (RAR) and interferometric synthetic aperture radar (IN-SAR) [4-8]. The optical remote sensing methods are greatly affected by the adverse weather conditions, while the emergency monitoring site is often exposed to heavy rain, fog and smoke.

Unlike other remote sensing methods, IN-SAR provides continuous spatial coverage, relatively insensitive to the surrounding environment and can work in almost any weather condition facilitating long-term overall analysis and prediction and played important role in landslide susceptibility analysis and large-scale macroscopic monitoring coupled with corner reflectors (CR) [9,10]. However, in regional emergency monitoring cases, space-borne and air-borne IN-SAR systems have limited regional spatial resolution, require longer sampling time intervals than ground-based ones, and monitoring is inflexible. GB-InSAR deformation measurement is a newer technology, which has been proved as operational tool in emergency management situations, shorter time intervals (every 10 minutes) [11]. Although there is a gap with real-time monitoring requirements, which means data gather interval < 30s, it enjoys the advantage of continuous space coverage of landslide and relative high dis-placement measurement precision up to sub-millimetre level [12]. These characteristics show that application of GB-InSAR is competent for landslide emergency monitoring and early warning.

There were several landslide deformation monitoring cases using GB-InSAR for disaster prevention and post-emergency management, essential publications are summarized as follow. LISALab applied differential SAR interferometry (DInSAR) monitored several landslides in Italy analysed the coherence features, mapped interferograms with digital elevation model (DEM) of 5×5 resolution. Later they reported early-warning method combining temporal sequenced interferograms, LOS velocity and inverse velocity analysis [13-16]. Pieraccini et al. mapped the cumulative displacements with topographic maps in order to identify the deformation location more accurately, TLS was used as a comparison [17,18]. Lingua et al. integrated TLS fast topography surveying with GB-InSAR for geometric mapping of coherence map and cumulative displacement [19]. Casagli et al. presented relationship between GB-InSAR feature points’ data curve vibration with rainfall events [11]. Takahashi et al. considered the LOS displacement difference between gentle slope and steep slope, which corresponds to regional difference [20]. Updated emergency monitoring cases widely used multivariate remote sensing information fusion. For example, improved terrain mapping accuracy TLS cooperated with GB-InSAR [21], space-borne and ground-based SAR joint analysis with Permanent Scatter Interferometry (PSI) [22-24], synthetic monitoring network comprised of space sensors, in-situ sensors and UAV scanning [25,26]. These integrate schemes complement the main weaknesses of GB-InSAR deformation monitoring: mainly including inconvenience of using 2D results, lacks comprehensive understanding of the landslide due to fixed monitoring, de-correlation and near real time but still exist time interval.

Remote sensing monitoring scheme is designed in the early stage of emergency response, so as to manage temporal-space state of targets, future development, prediction of secondary disasters, etc. It needs combination with landslide warning, disaster assessment, and risk aversion and risk evaluation theory for rapid emergency response. The relevant achievements applicable to remote sensing monitoring, early warning and emergency dis-aster prevention system summarized as below. Firstly, remote sensing has been proved effective in landslide hazard assessment and consequence analysis. For example, kinematical evaluation of large landslide failure or land-slide group, finding the landslide source and the possible sliding path or the backward and lateral extension area of the landslide using very high resolution satellite images (VHR) [27]. The destructive force of an existing or potential landslide and its extension at a given time in an area for damage assessment [28], landslide intensity scaling [29] and landslide susceptibility mapping [30]. Although the applications listed above are mostly based on satellites, they also illustrate the potential of emerging remote sensing methods such as GB-
InSAR, TLS and UAV photography for rapid analysis and evaluation of spatial distribution, volume, stability, possible expansion, impact range and intensity of smaller landslides. Secondly, remote sensing is conducive to the rapid investigation of the elements at risk in the region. The population, buildings, engineering facilities, economic activities, public utilities equipment, infrastructure and environment, which are important parts in landslide risk evaluation. Thirdly, in view of the remote sensing monitoring methods in the related results on the landslide kinematics, in order to grasp the relationship between the inducing factors and landslides for mechanism study within short period.

Figure 1. Integrative sensors emergency monitoring work flow.

This paper reports the emergency rescue experience of China Safety Emergency Surveying Team (CSEST) using GB-InSAR device known as S-SAR updated upon previous works [31]. Specifically, three innovative technology GB-InSAR, TLS and UAV were integrated not only for monitoring but as a scheme for rapid assessment of rockslide, early warning of secondary disaster and slope control scheme design. The work aims to illustrate the advantage of the technique to operate during rockslide emergency for civil prevention by a case concerns Junhong road K18+350m-K18+430m (Fangshan, Beijing). Concerning the rockslide and the residual hazardous rock mass, GB-InSAR provided cumulative displacement maps, velocity diagrams to forecast the evolution of the rockslide kinematic. TLS was contributed to rapid modelling of rock mass structure of slope, and extraction of geometrical features of landslide mass and profile line features. The features were accurately matched with GB-InSAR data constituted 3-dimensional deformation field for correct and sound risk and hazard zonation. UAV photography was used for investigation of hidden hazardous points and rockslide influence area. The fusion method proposed in this paper can be used to judge the square quantity of landslide within 12 hours, including stacking volume and residual volume. The risk area of landslide and the influence of inducing factors on landslide were found within 24 hours. The landslide extension area was demarcated within 48 hours and the risk assessment of disaster bearing body was completed. The proposed technique provides feasible program for landslide emergency response in fast survey, quasi-real time monitoring and risk evaluation.

The rest of this paper is arranged as follows. Section 2 briefly presents our integration scheme work flow and study area. Section 3 detailed the GB-InSAR, TLS and UAV photography rockslide monitoring methodology. Section 4 demonstrates and explains the main results of the risk assessment and slope treatment design. Discussion is provided in section 5. Section 6 concludes the paper.
2. Scheme Methodology and Principles

2.1. Research material
At Greenwich Mean Time (GMT)+8 8:30 a.m. on August 11, 2018, a mountain collapse occurred at K18+350m of Junghong road, x209, Daanshan township, Fangshan district, Beijing, China, causing two-way obstruction of the road and smashed road surface, subgrade and guardrail. The collapse of the mountain blocked the main access to the upper coal mine and many scenic spots, threatening the lives and property of the surrounding people. Previously, the area has been included in the danger point of landslide compilation (1:10,000) and included in the group survey and prevention plan. The collapse of this area occurs from time to time. The most recent one occurred at 11:25 a.m. GMT+8, July 19, when the mountain at K10+50m of Junhong road collapsed, with a volume of about 120 cubic meters. Local civil protective departments appointed inspectors to regularly inspect the surrounding mountains every day to check whether rock mass looseness, cracks, rockfall, dangerous rocks and pumice and whether there is collapse accumulation in the protective network. 10 minutes before the collapse of the mountain, inspectors found that the top of the mountain has continued to roll down gravel and a small amount of road collapse, decisive measures to stop the road break to prevent the passage of personnel and vehicles, timely report to the civil protection department, to start the collapse emergency response. As instructed by the head of the ministry of emergency management, our team in China forms a joint investigation team with experts from China geological disaster prevention and control technical guidance centre to provide support and technical services for local governments and civil protection departments.

The area has been the focus of previous geological hazard surveys. Under the influence of heavy rainfall, the rock and soil mass collapsed on the slope, burying the mining road and the only village-level road outside the village, completely blocking the travel of more than 800 people in Daanshan coal mine. A preliminary investigation found that the special geological condition, slope collapse has occurred in addition to the part of the residue in vitro, there are significant security hidden danger, the whole slope after comprehensive analysis decided to organizations and villagers' safe transfer in mines, and set up the emergency monitoring, for emergency monitoring of the slope, to early warning of secondary instability of slope, which guarantees personnel transfer process. The previous emergency monitoring experience was summarized, as shown in Fig. 1. The multi-data fusion scheme was designed for this paper, and the monitoring scene layout was shown in Fig. 2.

2.2. Methodology
The GB-INSAR system transmits and receives step-frequency continuous waves (SFCW) in the range direction and forms a synthetic aperture in the cross-range via beam-forming algorithm. A Back projection (BP) algorithm is applied in the imaging process. A dual-antenna interferometer was installed on a linear rail: one antenna transmitted electromagnetic waves and the other received reflected waves. The antennas were driven by a motor on the rail, moving in a “go-stop-go” mode. The interferometer moved from the rail initial position to a set position to form a synthetic aperture with length denoted by \( L_s \); \( L \) is the effective length of the rail, so \( L_s \leq L \). The antennas moved at a fixed time interval. Every stop represents one azimuth sampling point in a series of \( N \) points. The SFCW frequency hopping point number is \( K \). Original echo data are represented by a \( k \times N \) complex array. In one scan, no relative displacement occurred between targets and the GB-INSAR. The main characteristics of the GB-INSAR are shown in Table 1.

TLS 3D laser scanning is a cooperative target laser rangefinder and Angle measurement system integrated automation rapid measurement system, the object to be measured at the scene of the complex space and rapid scanning measurement, direct access to laser spot the horizontal surfaces in contact with, zenith distance, slant distance and reflection intensity, automatic storage and computing, point cloud data obtained. After computer processing, point cloud data, combined with surface reconstruction software, can quickly reconstruct the three-dimensional model of the object under test and various mapping data such as line, surface, volume and space. It consists of three parts: scanner, controller and power supply system. The laser scanner itself includes laser ranging system and laser scanning system, and integrates CCD and instrument internal control and correction system. Instrument through two synchronous mirror rotate quickly and orderly, will send a narrow beam of a laser pulse emitter laser pulse sweep area to be tested in turn, each pulse measurement analyte from a surface and back by the
time (or phase) to calculate the distance, at the same time, the built-in precision clock control encoder, each laser pulse synchronous measurement transverse scan Angle observation \( \alpha_{TLS} \) and longitudinal scanning Angle observation \( \theta_{TLS} \). In addition to two Angle values and a distance value \( S \), the original observation data of the laser scanning system also have the reflection intensity \( I \) of the scanning point mapped to grey scale to form the three-dimensional surface coating. When splicing scanning data of different sites, it is necessary to use common points for transformation to unify them into the same coordinate system. Spherical targets or black-and-white targets are used for common points. However, this type of target is not easy to find in the emergency site. Generally, the coarse target with strong reflectivity can be selected for scene Mosaic at the end of the natural targets.

UAV photography can comprehensively perceive complex scenes in a wide range, high precision and high definition, and intuitively reflect the appearance, position, height and other attributes of ground objects through the data acquisition equipment and data processing process with high efficiency. It is equipped with multiple sensors on the flight platform, and is currently commonly used as a five-lens camera. At the same time, influences are collected from different angles, such as vertical and tilt, so as to obtain more complete and accurate information of ground objects. Vertical ground Angle shooting is to obtain a group of images vertically downward, known as positive, lens orientation and the ground into a certain Angle shooting of the four groups of images pointed to the southeast and northwest, known as oblique. Tilt image can provide a better perspective to observe the side of the building and output a high-resolution triangular mesh model with real texture. This triangular mesh model can accurately and finely recover the real colour, geometry and detail composition of the modelling subject.

Data fusion technology is a combination of three kinds of technology results data, namely GB-INSAR surface deformation measurement, the TLS point cloud of the three-dimensional space position information and UAV tilt photography features of image data fusion, the ultimate visual results for TLS elevation, unmanned aerial vehicles as surface texture information, which results in rapid accurate risk and hazard zonation, and analyse the landslide extension and sliding path.

Figure 3. Geometric relationship between GB-INSAR and 3D space.

Specific operation process:
- First, the TLS set up a scanning station in front of the GB-INSAR, and the line of sight (LOS) of the radar should not be obstructed. Meanwhile, the Real Time Kinematic (RTK) should be used to
measure the geographic coordinates of WGS84 (World Geodetic System) in meters of the scanning station.

Then, GB-INSAR began to operate, automatically scanning and processing data to obtain the slope imaging map, coherent map, deformation map;

At the same time, the UAV for automatic route planning, take-off point for GB - the position of the SAR and the TLS, UAV with Global Positioning System (GPS) emergency monitoring using an automated medium-sized UAV INSPIRE2 mounted a camera holder, guarantee the stability of the image through an automated process for regional Mosaic image, and in the original aerial photographic images (such as Google Earth), can get behind landslide profile.

Slope deformation data can be obtained using the following process

\[ I(a, r) = \sum_{n} e^{-j\lambda c r_n} \cdot \text{psf}(a - a_n, r - r_n) \]  

(1)

where \( r_n \) represents the range of the nth target, \( a_n \) denotes the nth target azimuth length to \((0,0)\), and \( \lambda \) is the intermediate frequency wavelength, \( \text{psf}(\cdot) \) on behalf of the point spread function (PSF), is the impulse response of the imaging system for a low-pass filter point target. The results of Eq. (1) not only contain amplitude and phase information, but also represent the physical properties and geometric parameters of the imaging scene.

\[ r = \sqrt{E[I_1 \cdot I_2^*]} \]  

(2)

where \( E[\cdot] \) represents the mathematical expectation. We used a similar IN-SAR image processing method for these calculations and a movable search window. The coherence of each pixel is the calculation of Eq. (3) for its adjacent k pixels. The search window is utilized to find the same targets in two images which are sufficiently consistent.

\[ \Delta d_n = R_1 - R_2 = -\frac{\lambda_c \cdot \angle(I_1, I_2^*)}{4\pi} \]  

(3)

where \( \angle(\cdot) \) denotes the phase information of the extracted complex image; \( I_1, I_2 \) represents complex matrixes collected before and after displacement, calculated from Eq. (5); “*” is the complex conjugate operator.

The slope deformation data can be obtained using the following process. Fig. 2b illustrates the monitoring geometry of GB-INSAR from the distance upward viewing Angle. In emergency monitoring activities, the upward viewing angle is adopted because the deformation monitored by radar is the apparent deformation and the component along the line of sight in the real glide direction. \( R_{\max} \) and \( R_{\min} \) are the preset parameters, which are used to intercept the range scope of the GB-INSAR image, represent the direction of the central LOS of the radar phase, and read from the mechanical reading panel on the radar side. Slope angle \( \theta_{\text{slope}} \) can be obtained by 3D surface modeling with a 3D laser scanner. In addition, the maximum monitoring range of the radar is related to the non-fuzzy distance \( R_u = c/2 f B / (K - 1) \) of the radar, which is not described here. As shown in Fig.2c, the intersection between the radar electromagnetic beam and the slope surface is approximately an ellipse, then the calculation method of azimuth extension range and distance extension range is as follows:

\[ L_u = 2R_0 \cdot \tan\left(\beta \cdot \frac{3}{2}\right) \]  

(4)

\[ L_u = 2R_0 \cdot \tan\left(\alpha \cdot \frac{3}{2}\right) \]  

(5)

where \( L_u \) stands for the cross range scope, \( L_u \) represents the range scope. As shown in fig.3, the mapping relationship [32] between GB-INSAR and terrain is illustrated. \( s \) is the phase center of the GB-INSAR
array and $s-ar$ is the cross section by range and azimuth direction. The plane rotates around the $s-a$ axis as the target range changes. $H$ is the rail axis distance to $o-xy$.

Table 1. GB-INSAR Interferometer, TLS and UAV Characteristics

| GB-SAR Characters          | Value   | TLS Characters             | Value   | UAV Characters     | Value   |
|----------------------------|---------|----------------------------|---------|-------------------|---------|
| Radar center frequency $f_c$ | 17.25 GHz | Best scan resolution       | 15mdeg  | Flight time       | 27min   |
| Synthetic aperture length $L_s$ | 1m      | Scan time for view of 100°×120° | 41min   | Video resolution  | 6K      |
| Radar bandwidth $B$         | 500 MHz | Best Resolution @ 2000m range | 524mm   | Control range     | 7km     |
| Linear scanion point number | 126     | Best Resolution @ 100m range | 26mm    | Speed             | 94Km/h  |
| Antenna gain               | 0 dB    | Footprint @2000m range     | 544mm   | Vertical GPS Accuracy | 0.1m   |
| Transmitted power          | 33 dBm  | Footprint @100m range      | 28.4mm  | Horizontal GPS Accuracy | 0.3m  |
| Polarization               | VV      | Laser pulse repetition rate PRR (peak) | 50kHz  | Max Pixels        | 16.0M   |
| Target distance            | 500-800m| Max. measurement range     | 2500m   | Optics            | 15mm F/1.7 ASPH |
| Measuring time per image   | 10 min  | Range with natural targets $\rho \geq 20\%$ | 1300m   | Diagonal FOV      | 72°     |
| Number of transmitted frequencies $K$ | 10001   |                             |         |                   |         |

Two-dimensional topographic map is obtained two-dimensional SAR images by 2 d image space with real 3 d space and real three-dimensional space and TLS point cloud, the relationship between the two-dimensional SAR image mapping results are each pixel coordinate values assigned to the corresponding 3 d point cloud, and then realize the three-dimensional point cloud map point cloud surface color reflect the shape variable data map visualization system. Next, UAV photography acquires the surface texture of the scene. The UAV itself is equipped with a cloud platform and a high-precision GPS. The characters of the UAV are shown in Table 1. The texture can roughly identify the track position coordinates and the texture of the giant rock on the slope. The texture is encoded with the coordinates of WGS84, and the corresponding points can be found in the TLS point cloud, so as to achieve texture mapping and the correspondence between the fused point cloud deformation and the ground object target. TLS point cloud coordinate measurement, the three-dimensional coordinates of the measured point cloud accurately select the three-dimensional coordinates of the two endpoints of the select orbit on the TLS point cloud; The coordinates of any cloud point $A(X_A,Y_A,Z_A)$ under test are:

$$
\begin{align*}
X_A &= S \cdot \cos \theta \cdot \cos \alpha \\
Y_A &= S \cdot \cos \theta \cdot \sin \alpha \\
Z_A &= S \cdot \sin \theta
\end{align*}
$$

where $S$ represent the distance from GB-INSAR phase center to the target, and $\theta$, $\alpha$ has been explicated in Fig. 2. In order to form a complete 3D surface, interpolation and surface modelling are necessary.
3. Results
The acquisition scheme of emergency rescue monitoring data has a time hierarchical progressive relationship. Optical image acquisition is the fastest, and acquired by mobile phone or digital camera. Deformation matching to this type of optical image has the lowest accuracy. The scheme with the highest accuracy is based on scatter drawing, but the drawing efficiency is very slow. TLS point cloud reconstruction method in field application effect is very good, processing speed, moderate accuracy is associated with modelling algorithm, the density of points, the degree of the slowest, scheme, optical image acquisition time can be near real time. GB - because of the need to preheat the SAR system, precision correction, permanent scatterers screening operation, more time consuming, so for about 1 hour 5 images can complete deformation image acquisition; high precision mode, the scene view 120° scan time is about 40 min. The update interval of UAV surface texture at the rescue site is about 12h. Figures and tables, as originals of good quality and well contrasted, are to be in their final form, ready for reproduction, pasted in the appropriate place in the text. Try to ensure that the size of the text in your figures is approximately the same size as the main text (10 point). Try to ensure that lines are no thinner than 0.25 point.

3.1. GB-INSAR Results
Fig. 4a with gold sector roughly identified radar radiation scope, the emergency monitoring station can be used in radar high accuracy measuring range >1.5 km long distance measuring instrument measuring the scenario requires observation target distance radar interferometer, which estimates radar electromagnetic beam cover key monitoring target, whether these goals by geological and geotechnical experts usually given comprehensive on-site investigation and historical data. After a scan, the data is processed. As shown in fig.4b, is the imaging image of radar echo data.
Figure 4. The 2D SAR images titled by gathered time a. Emergency monitoring system, b. Amplitude image, c. Coherence map, d. Displacement map.

The size of a pixel in the image can be expressed as follows:

\[ da = \frac{\lambda_c}{2L_s} R_{ref} \]  

(7)
\[ d_s = \frac{c}{2B} = \frac{c}{2(K - 1)\Delta f} \quad (8) \]

The first step of conventional BP imaging method is to establish imaging grid, the grid after imaging point linear interpolation, according to the type (1) to obtain the grid point data, take the energy complex data is the amplitude image the coordinate value. The coordinate values of all grid points are mapped to grey scale colour map to display a two-dimensional image. The bright points in the image correspond to the targets with strong reflectivity on the slope body, which are usually giant rocks on the slope. As shown in fig.4c, the coherence coefficient diagram between this moment of GB-INSAR and the data scanned last time is shown. The pixel point of the coherence >0.9 corresponds to the point with high signal noise of radar echo. It can be seen that most targets on the slope have good coherence. As shown in figure 4d, GB-INSAR displacement map with yellow > displacement \( \lambda/4 \) is the background of single-scan displacement map to reveal deformed areas. The deformation value indicates that the target pixel moves towards the direction of radar line of sight, while the deformation value indicates that the target pixel moves in the direction of radar line of sight.

3.2. TLS Results

Figure 5. a. The point cloud with outliers deleted b. TLS 3D surface model in TLS device-self coordinate.

TLS locates in a fixed position to scan a station, to get the number of point cloud is limited, due to the shade or laser reflectivity low often has a large number of vacancies, in fact, a kind of based on scattered disorderly 3 d laser scanning point cloud’s own coordinate system of 3 d modeling, obtain the results of data body called the DSM (Digital Surface Model), based on the TLS itself in the cartesian coordinate system, the TLS fuselage laser position for the origin of coordinates.

3.3. Integrative Results

The deformation trend of slope was analysed as a whole. The slope shape variables affected by rainfall on August 12 and 13 continued to increase, during which there was an accelerated deformation stage.
4. Discussion

The development trend of slope deformation was analysed as a whole. The slope shape variables affected by rainfall on August 12 and 13 continued to increase, during which there was an accelerated deformation stage. The rainfall stopped on August 14, the overall shape variable was mainly negative displacement, and the deformation tended to be stable on August 15. According to the field investigation and the guidance of geological experts, the collapse body is divided into three parts. The second part is the area of collapse accumulation. The third part is the right side of the collapse body, which leads to the Junhong roadside slope area of the coal mine living area. During the 69 hours of continuous monitoring, monitoring activities, 262 groups of data processing image 786 frames, based on the results of fusion Fig6 and Fig7, analysis of each part of the daily collapse body changes, the upper parts of vertical slope steep hills, rock structure, strong weathering and unloading, the back of the development of multiple cracks, collapse, falling under the action of rainfall is still happen. The lower part of the collapse body is the accumulation body, which is formed by the debris of the collapsed rock body and is loose. The slope is steep and tends to be stable gradually. Under the action of rainfall, local sliding or sliding occurs. The mountain on the right side of the collapse body, lithology is sandstone and basalt, high strength of the rock body, submassive structure, part of the Mosaic structure, local crushing, the development of solitary stone. Overall stability, local rockfall is likely to occur.
5. Conclusion
This paper shows the results of applying the GB-INSAR system developed in CASSAT to slope collapse emergency monitoring in China. The echoes of the collapsed slope are successfully acquired by GB-INSAR and then exactly mapped with TLS DSM and UAV photography texture by the presented processing procedure and is consistent with the real deformation characteristics. Showing that GB-INSAR, TLS and UAV data fusion works well in landslide and collapse deformation disaster management, with a spatial resolution of a few meters and an accuracy in the displacement assessment within millimetres level.

ACKNOWLEDGEMENTS
This research was financially supported by the National Key Research and Development plan (Grant No. 2017YFC0804603); Science and Technology Program of Beijing (Z171100002317008); The Fundamental Research Funds for the Central Public Welfare Research Institutes (2017JBKY05) and Distinguished scholar Sun Yueqi, China University of Mining and Technology (Beijing).

References
[1] Qu, Shi Bo. Methods on Regional Deformation Extraction Using Ground Based Sar. Institute of Electronics of Chinese Academy of Sciences (2010).
[2] Scaioni, Marco, Fabio Roncoroni, Mario Ivan Alba, Alberto Giussani, and Mattia Manieri. "Ground-Based Real-Aperture Radar for Deformation Monitoring: Experimental Tests." Paper presented at the International Conference on Computational Science and Its Applications (2017).
[3] Di Pasquale, Andrea, Giovanni Nico, Alfredo Pitullo, and Giuseppina Preziosos. "Monitoring Strategies of Earth Dams by Ground-Based Radar Interferometry: How to Extract Useful Information for Seismic Risk Assessment." Sensors (Basel) 18, no. 1 (2018): 244.
[4] Yang, K., L. Yan, G. Huang, C. Chen, and Z. Wu. "Monitoring Building Deformation with Insar: Experiments and Validation." Sensors (Basel) 16, no. 12 (2016).
[5] Intrieri, Emanuele, Giovanni Gigli, Francesco Mugnai, Riccardo Fanti, and Nicola Casagli. "Design and Implementation of a Landslide Early Warning System." Engineering Geology 147-148, no. 5 (2012): 124-36.

[6] Qiu, Zhiwei, and Xueqin Wang. "Application of Subsidence Monitoring over Yangtze River Marshland with Ground-Based Sar System Ibis." Paper presented at the SPIE Optical Engineering + Applications (2014).

[7] Luzi, Guido, Massimiliano Pieraccini, Daniele Mecatti, Linhsia Noferini, Giovanni Macaluso, A. Tamburini, and Carlo Atzeni. "Monitoring of an Alpine Glacier by Means of Ground-Based Sar Interferometry." IEEE Geoscience &Remote Sensing Letters 4, no. 3 (2007): 495-99.

[8] Tapete, Deodato, Nicola Casagli, Guido Luzi, Riccardo Fanti, Giovanni Gigli, and Davide Leva. "Integrating Radar and Laser-Based Remote Sensing Techniques for Monitoring Structural Deformation of Archaeological Monuments." Journal of Archaeological Science 40, no. 1 (2013): 176-89.

[9] Zhang, Bochen, Xiaoli Ding, Charles Werner, Kai Tan, Bin Zhang, Mi Jiang, Jingwen Zhao, and Youlin Xu. "Dynamic Displacement Monitoring of Long-Span Bridges with a Microwave Radar Interferometer." ISPRS Journal of Photogrammetry and Remote Sensing 138 (2018): 252-64.

[10] Zhao, Q., H. Lin, L. Jiang, F. Chen, and S. Cheng. "A Study of Ground Deformation in the Guangzhou Urban Area with Persistent Scatterer Interferometry." Sensors 9, no. 1 (2009): 503.

[11] Massonnet, Didier, Kurt Feigl, Marc Rossi, and Frédéric Adragna. "Radar Interferometric Mapping of Deformation in the Year after the Landers Earthquake." Nature 369, no. 6477 (1994): 227-30.

[12] Martinez-Vazquez, Alberto, and Joaquim Fortuny-Guasch. "A GB-InSAR Processor for Snow Avalanche Identification." IEEE Transactions on Geoscience & Remote Sensing Letters 46, no. 11 (2008): 3948-56.

[13] Qiao, G.; Lu, P.; Scaioni, M.; Xu, S.; Tong, X.; Feng, T.; Wu, H.; Chen, W.; Tian, Y.; Wang, W. Landslide Investigation with Remote Sensing and Sensor Network: From Susceptibility Mapping and Scaled-down Simulation towards in situ Sensor Network Design. J Remote Sensing 2013, 5, 4319-4346.

[14] Hu, X.; Tan, F.; Tang, H.; Zhang, G.; Su, A.; Xu, C.; Zhang, Y.; Xiong, C.J.E.G. In-situ monitoring platform and preliminary analysis of monitoring data of Majiagou landslide with stabilizing piles. 2017, 228, 323-336.

[15] Luo, L.; Ma, W.; Zhang, Z.; Zhuang, Y.; Zhang, Y.; Yang, J.; Cao, X.; Liang, S.; Mu, Y.J.R.S. Freeze/Thaw-Induced Deformation Monitoring and Assessment of the Slope in Permafrost Based on Terrestrial Laser Scanner and GNSS. 2017, 9, 198.

[16] Yang, I.T.; Park, J.K.; Dong, M.K. Monitoring the symptoms of landslide using the non-prism total station. Ksce Journal of Civil Engineering 2007, 11, 293-301.

[17] Kasperski, J.; Delacourt, C.; Allemand, P.; Potherat, P.; Jaud, M.; Varrel, E. Application of a Terrestrial Laser Scanner (TLS) to the study of the Séchilienne landslide (Isère, France). Remote Sensing 2010, 2, 2785-2802.

[18] Scaioni, M.; Roncoroni, F.; Alba, M.I.; Giusi, A.; Manieri, M. Ground-Based Real-Aperture Radar for Deformation Monitoring: Experimental Tests. Cham; pp. 137-151.

[19] Turner, D.; Lucieer, A.; De Jong, S.M. Time Series Analysis of Landslide Dynamics Using an Unmanned Aerial Vehicle (UAV). Remote Sensing 2015, 7, 1736-1757.

[20] Zhao, F.; Mallorqui, J.; Iglesias, R.; Gili, J.; Corominas, J. Landslide Monitoring Using Multi-Temporal SAR Interferometry with Advanced Persistent Scatterers Identification Methods and Super High-Spatial Resolution TerraSAR-X Images. Remote Sensing 2018, 10, 921.

[21] Ciampalini, A.; Raspini, F.; Lagomarsino, D.; Catani, F.; Casagli, N. Landslide susceptibility map refinement using PSInSAR data. Remote Sensing of Environment 2016, 184, 302-315.
[22] Ye, X.; Kaufmann, H.; Guo, X.F. Landslide Monitoring in the Three Gorges Area Using D-INSAR and Corner Reflectors. Photogrammetric Engineering & Remote Sensing 2015, 70, 1167-1172.
[23] Casagli, N.; Catani, F.; Ventișette, C.D.; Luzi, G. Monitoring, prediction, and early warning using ground-based radar interferometry. Landslides 2010, 7, 291-301.
[24] Tarchi, D.; Casagli, N.; Fanti, R.; Leva, D.D.; Luzi, G.; Pasuto, A.; Pieraccini, M.; Silvano, S. Landslide monitoring by using ground-based SAR interferometry: an example of application to the Tessina landslide in Italy. Engineering Geology 2003, 68, 15-30.
[25] Tarchi, D.; Casagli, N.; Moretti, S.; Leva, D.; Sieber, A. Monitoring landslide displacements by using ground-based synthetic aperture radar interferometry: Application to the Ruinon landslide in the Italian Alps. Journal of Geophysical Research Solid Earth 2003, 108, -.
[26] Tarchi, D.; Antonello, G.; Casagli, N.; Farina, P.; Fortuny-Guasch, J.; Guerri, L.; Leva, D. On the Use of Ground-Based SAR Interferometry for Slope Failure Early Warning: the Cortenova Rock Slide (Italy). Landslides 2005, 337-342.
[27] Antonello, G.; Casagli, N.; Farina, P.; Leva, D.; Nico, G.; Sieber, A.J.; Tarchi, D. Ground-based SAR interferometry for monitoring mass movements. Landslides 2004, 1, 21-28.
[28] Leva, D.; Nico, G.; Tarchi, D.; Fortuny-Guasch, J.; J. Sieber, A. Temporal analysis of a landslide by means of a ground-based SAR Interferometer. IEEE Transactions on Geoscience & Remote Sensing 2003, 41, 745-752, doi:10.1109/TGRS.2003.808902.
[29] Pieraccini, M.; Noferini, L.; Mecatti, D.; Atzeni, C.; Teza, G.; Galgaro, A.; Zaltron, N. Integration of Radar Interferometry and Laser Scanning for Remote Monitoring of an Urban Site Built on a Sliding Slope. IEEE Transactions on Geoscience & Remote Sensing 2006, 44, 2335-2342.
[30] Pieraccini, M.; Casagli, N.; Luzi, G.; Tarchi, D.; Mecatti, D.; Noferini, L.; Atzeni, C. Landslide monitoring by ground-based radar interferometry: A field test in Valdarno (Italy). International Journal of Remote Sensing 2003, 24, 1385-1391.
[31] Lingua, A.; Piatti, D.; Rinaudo, F.; Lingua, A.; Piatti, D.; Rinaudo, F. Remote monitoring of a landslide using an integration of GB-INSAR and LIDAR techniques. In Proceedings of The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, Beijing; pp. 361-366.
[32] Xiangtian, Zheng.; Xiaolin Yang.; Haitao Ma, et al. Integrated Ground-Based SAR Interferometry, Terrestrial Laser Scanner, and Corner Reflector Deformation Experiments. Sensors Basel 2018, 18(12), 4401.