Application of Multi-data Fusion Technology in Landslide Monitoring

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Abstract. At present, there are more than 280,000 hidden danger points of geological disasters in China. It has been proved that one of effective ways of reducing geological disasters is using professional equipment to monitor and mobilize the masses. The commonly professional devices include slope radar, crack gauge, laser radar and optical images in early warning period and in rescue phase. Each device has its own unique advantages and we developed a reasonable technical route to achieve the aim that combining the advantages of these various data. The mainly steps: the first step is to process the various data separately; secondly, to fuse the data that can be merged; thirdly, to perform overlay analysis and display on non-integratable data. We takes the high-level landslide of Xinmo Village, Sichuan Province on June 24, 2017 to verify the route’s effective. The results show that the multi-data fusion method can not only achieved the all-round monitoring of key hidden points, but also combined the advantages of multiple data and achieved millimetre-level monitoring accuracy and clear and intuitive effects.

1. Introduction
Geological disasters are one of the major disasters that threaten human life and property. Especially landsliding, with a wide distribution and a large number, are one of the major geological disasters causing casualties over the years. In recent years the interest in the assessment of hazard and risk of landsliding has increased greatly, and the reasons for the increasing interest in landslides are twofold: firstly an increasing awareness of the socio-economic significance of landslides and secondly, the increased pressure of development and urbanization on the environment (Alotti and Chowdhury 1999).

The risk assessment and management is an important work before landslide hazard happened and has had developing in the world-wide that described by Whitman (1984), Fell (1994), Wu, et al. (1996), Nadim and Lacasse (2003) and Lee and Jones (2004). Some guidelines have been developed (Fell, et al. 2005). The main elements of a risk assessment and management system are shown in Fig.1. Landslide risk and management is an integral part of risk management that the estimated risks are compared to acceptance criteria (either quantitative or qualitative). Geotechnical professionals are likely to be involved as the risk analysts, and may help guide in the assessment and decision process, but ultimately it is for owners, regulators and governments to decide whether the calculated risks are acceptable or whether risk mitigation is required (Fell, et al. 2005).
Figure 1. Flow chart for landslide risk management (after Chowdhury 1998 and Fell, et al. 2005).

The landslide early identification and the monitoring warning for landslide hazard have gradually matured in China (Qi 2019). In general, most of the landslide hazard will be discovered through early identification using remote sensing technology and then make professional judgments on all landslide points based on factors such as deformation volume, deformation speed and threatening population. Multi-phase satellite remote sensing images were used for continuous observation for deformation points which without population threat and low deformation rate. For hazards with large damage, but the development trend of deformation is not clear, professional monitoring and early warning methods are needed to grasp the trend of deformation development, so as to carry out corresponding prevention or damage range prediction (Qi X, et al. 2018). And many more sophisticated slope-stability models are exist (Chowdhury RN 1978, Qi X et al. 2014, Vasseur J et al. 2018, Segalinia A et al. 2018, Xu Q et al. 2009). In recent years, our country has vigorously promoted professional monitoring and early warning work for geological disasters. Many practices have proved that the professional monitoring can provide early warning from a few minutes to several hours before the disaster happen (advanced instruments must be arranged scientifically and reasonably), and the threatened people have time to transfer to a safe place (Qi 2019).
2. Professional monitoring technique

In order to monitor hazards from active landslides and to understand the processes involved, both spatial and temporal measure are needed (Niethammer U, et al. 2012). The monitoring ways are as mentioned above. In order to understand the development trend and speed of the landslide comprehensively and accurately quantitatively, it is necessary to capture the characteristic information of the landslide timely, and the landslide professional monitoring can provide scientific basis for the correct analysis, evaluation and prediction of landslide (Zhao YH, et al. 2018).

2.1. Contact deformation monitoring

It means that the sensor’s sensing element of monitors in contact with the surface of the measured object. It plays an important role in landslide hazard monitoring, mainly includes geodetic precision measurement technology, GNSS displacement monitoring technology, TDR monitoring technology, optical fiber monitoring technology, etc.

2.1.1. Geodetic precision measurement technology

This technology is the most traditional technical for monitoring the deformation of landslide surface, mainly uses traditional measuring instruments(such as theodolite and total station)with geodetic methods(for example front intersection and ranging method)to achieve deformation monitoring purposes (Wei JD 2007). This methods are maturely, reliable, simple to operation, and relatively low
in equipment cost. However this method has its drawbacks, such as susceptible to terrain conditions, meteorological conditions, time-consuming, high labor intensity and poor continuous observation capability (Huo DP, et al. 2015). This method has basically been replaced by the measuring robot and greatly improved the working efficiency of landslide deformation monitoring, and can realize automatic continuous monitoring in all-weather natural environment, and the data has high precision and strong timeliness that has broad application prospects in automatic monitoring of landslide deformation (Wu YK, et al. 2007).

2.1.2. GNSS monitoring technology

Global navigation satellite system (GNSS) consists of satellite navigation systems such as GPS, GALLIEO, GLONASS and COMPASS. This technology is widely used in the field of landslide deformation monitoring because of its high precision, automatic and all-weather monitoring (Wei HB, et al. 2008). As a technical means of modern geodetic survey, GNSS has been widely used in geological disaster. This method acquires the 3D coordinates of the monitoring points continuously, and uses the change of coordinates to reflect the motion of the target, thereby achieving the purpose of supervising the deformation by arranging a plurality of GNSS devices in the deformed area. And the 3D coordinate data is transmitted to the monitoring platform through the network. However, the limitation is that satellite signals are easily blocked where in the high mountain areas. Currently, the precision of this method is millimeter level.

2.1.3. TDR monitoring technology

Time domain reflectometry (TDR) is an electronic measurement technique and is based on the deformation of the landslide to cause local deformation of the coaxial cable, thereby affecting the time of the reflected signal in the cable and the magnitude of the reflection coefficient, and then the position and size of the deformation will be located by the nature of the reflected signal, so as to achieve the purpose of monitoring the landslide. When using the TDR for landslide monitoring, the coaxial cable that is connected to the tester is placed below the slip layer by drilling holes in the landslide. This method has the advantages of low cost, safety and remote monitoring continuously. It has been widely used in landslide monitoring. However, this method cannot determine the direction of landslide movement and cannot be used to monitor the slope and the area without shearing.

2.1.4. Optical fiber monitoring technology

The emergence of distributed optical fiber technology has changed the traditional point monitoring in landslide deformation monitoring. The principle is that the external signal is along the optical fiber transmission path, and the optical wave in the optical fiber is continuously modulated in a certain manner, thereby forming a modulation information band in the optical fiber, and detecting an demodulating the modulated signal band to obtain an external signal. By providing sensing fibers in the interior and surface of the landslide body, a sensing monitoring network is formed, and then the monitoring system can sense the internal correlation of the slope. The distribution and size of the parameters will be captured and realize distributed monitoring of the landslide. The limitation is high cost and high operating costs.

2.2. Non-contact deformation monitoring

It is another important ways of landslide disaster monitoring technology, mainly including aerial photogrammetry, 3D laser scanning and synthetic aperture radar differential interferometry(satellite and ground-based), etc.

2.2.1. Aerial photogrammetry
Since the 1980s, the rapid development of unmanned aerial vehicle (UAV) has provided a new platform for aerial photogrammetry and mainly uses multi-rotor, fixed-wing and unmanned helicopters as platforms to capture high-resolution image data through bottom-mounted optical or multi-spectral cameras (Yan L, et al. 2004 and Cui HX, et al. 2005). Because the UAV platform has the characteristics of convenient carrying, flexibility, low flying height and self-propelled to the pre-set area by route design, and are widely used, such as surveying and mapping, power inspection, mine monitoring, geological disaster monitoring (Li DR, et al. 2010, Xu YA, et al. 2013, Jahanshahi MR, 2013, Keemink AQL, 2012). This technology uses the method of photogrammetry to obtain close-range target images information to determine its 3D spatial data (Wang JX, 2012).

2.2.2. 3D laser scanning monitoring technology

The technology can obtain the 3D surface geometric information of the landslide body by scanning the point cloud data with high precision, and quickly and efficiently complete the digitization of the slope body to realize the 3D modeling and virtual reproduction of the landslide (Xie YY. 2012). It can be mounted on UAV or ground. It is possible to directly and quickly acquire the 3D point cloud data of the landslide body without prior burying the monitoring equipment. By calculating and analyzing the acquired 3D “face” point cloud data, the real-time changing and true morphological characteristics of the landslide body can be reflected directly (Zhao XP, et al. 2002). However, due to limitations of the technical characteristics and monitoring requirements, 3D laser scanning monitoring technology still has some difficulties such as difficult analysis of massive point cloud data and limited scanning distance.

2.2.3. Synthetic Aperture Radar Differential Interferometry(InSAR)

The method uses the phase information of the acquired radar data to extract the 3D information and elevation deformation of the surface. The method has the characteristics of full day time and high resolution. In theory, the method can detect ground changes of millimeters. It mainly includes low-orbit InSAR and ground-based InSAR. The accuracy of the deformation monitoring data of the low-orbit InSAR can reach sub-centimeter. This technology has the advantages of wide coverage, high spatial resolution and accurate measurement. However, since landslides often occur in field with complex terrain and harsh weather, the measurement accuracy is susceptible to application, and is limited by the inherent operating cycle of satellites, which cannot meet the requirements of highly dynamic deformation monitoring (Zhang SH, Ji ZS, 2004). Ground-based InSAR is a terrestrial microwave quantitative remote sensing technology. Compared with low-orbit InSAR, ground-based InSAR has the advantages of short observation time (5 min order), flexible operation and high data accuracy (sub-millimeter scale) (Yang HL, et al. 2012). This technique is particularly suitable for solving large-scale landslides, collapses, debris flows, and monitoring and forecasting of geological disasters such as ground fissures and ground subsidence.

3. Experiment and analysis

The study was carried out on the high-level landslide which happened on June 24, 2017. And then we used the multi-data fusion method to process the data of multiple professional monitoring devices.

3.1. Research area

The study area located in Xinmo Village, Sichuan Province, China (shown as Figure 3). And the landslide caused 64 rural houses and 1500meters of roads to be buried, blocking 2100 meters of rivers, 10 deaths and 73 missing due to the disaster. Traffic, power communication and cultivated land were damaged, and caused widespread concern.
Figure 3. Location of the study area and upward view of the landslide

In May 6-8th, 2019 a UAV flight and a variety of professional monitoring equipment tasks was carried out covering the whole sliding area of the landslide, acquiring 1175 airborne photographs and 3D points and GBSAR data.

3.2. Data acquiring

3.2.1. Airborne photographs
The data acquisition was used five-lens multi-rotor drones (D200, produced by Shenzhen Feima Robotics Co., Ltd). The flight was divided into 2 sorties because the limit of the flight time. Finally we got 1175 photographs with ground resolutions of 2.4cm and all the images quality is better after checked.

Figure 4. Ortho-mosaic (A) and 3D model (B)

3.2.2. 3D point cloud
The data was acquired using the Optech Polaris vertical 3D laser scanner. There are three models of this product: HD (500kHz, 250m max.range), ER (200-500kHz, 750m max.range), LR (50-500kHz, >2000m max.range). This data acquisition was used the LR that the accuracy is better than 4mm at 100 meters, which takes 8 hours to work in the field and a total of 7.51GB of data.
3.2.3. GBSAR
The device that used was MPDMR-HSA (Inner Mongolia Mypattern Technology Co., Ltd), which is combined with the actual needs of application scenarios such as geological disaster emergency rescue. The system can realize 360° monitoring with high precision, the components is small in size, light in weight, and quick to deploy and install.

We spend 40 hours to monitoring this area, and the collection interval 10min/360°, deformation data processing time 30s/piece. The observation area covers 15.2 square kilometers, and 111 pieces monitoring data.

3.3. Data processing
The processing of the photographs was decided into two steps. In the first step, optical (barrel) distortion was corrected using the common third degree polynomial approach (Niethammer, et al. 2009). In the second processing step, all photographs were merged to a uniform high-resolution ortho-mosaic with a spatial resolution of 2.4cm (Figure 4A) and used the software made the 3D model products (Figure 4B).

The software that we used was corresponding to the device of the 3D point cloud and GBSAR data. After the point cloud denoising, filtering and other operation, we can got better quality point clouds that it is helpful for the 3D model. And it will be merge d with the photographs in order to get a finely 3D model.

4. Results and discussion
The 3D point cloud data and UAV oblique photographic data are merged can get a fineness of the 3D model, it has been proved by many research. And many software of building 3D model has this function.

The GBSAR monitoring parameters are mainly based on the cumulative shape variable and the deformation speed, and several pixels are selected for monitoring in the region with large deformation. Among them, the positive deformation (positive number) indicates the deformation near the radar
which is shown in red in the deformation map; the negative deformation (negative number) indicates the deformation away from the radar which is shown in blue. The details are as follows:

4.1. Deformation area
According to the monitoring results of HAS, most of the slope area is relatively stable, but there are three small areas with obvious deformation. The position of these areas have been marked in the fan map and the corresponding real map, shown as Figure 7. And the maximum value of the deformation at the 2 mark is close to 20mm. However, due to the difference in equipment placement angle and imaging resolution, the specific values of monitoring results in 1 and 3 mark will not be exactly the same, but at the same order of magnitude. And Figure 8 is a gradation diagram obtained by superimposing the monitoring results in time series, and the interval between adjacent two images is 12 hours.

Figure 7. The deformation areas founded by MPDMR-HSA
4.2. Cumulative deformation
In Figure 9, it can be seen that the variable of Area 2 is larger. On the other side of the hillside, there is also a tendency to accelerate deformation (zone 3). Due to the limited of data, it is not possible to say the trend will continue. There also is a small amount of deformation at the top of the mountain on the back side of the equipment, but the overall stability is relatively stable. The values of these three monitoring points do not represent the overall shape variables of the area in which they are located.

4.3. 3D display
The radar monitoring results are superimposed on the 3D model data of the drone, and the position of the unstable points can be clearly seen from the figure10. When the marking tool is used, the deformation points can be displayed clearly.
5. Conclusions
In this paper, the UAV tilt data, 3D laser scan data and radar data are processed separately, and then the 3D laser data and UAV images data are combined to obtain a more refined 3D model. Through the analysis of the radar data, the deformation region of the landslide point is obtained. Then the result is superimposed on the refined 3D model so that it can be seen clearly, thereby helping the command decision maker to grasp the deformation trend and help the launch of rescue operations.

However, this method is a research method, and the data processing time has yet to be strengthened. It is hoped that through the development of software and hardware in the later stage, the data processing speed can be improved greatly, and thus it is more suitable for the emergency scene.

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