# The Research of Three-dimensional Integrated Framework of Landslide Disaster Monitoring Data

Zhang Junqiang[1], Wu Chonglong[1, 2, 3], Liu Junqi[2], Liu Fei[4]
[1]School of Computer Science, China University of Geosciences
Wuhan 430074, China
[2]Three Gorges Research Center for Geo-hazard, Ministry of Education
China University of Geosciences, Wuhan 430074, China
[3]State Key Laboratory of Geological Processes and Mineral Resources
China University of Geosciences, Wuhan 430074, China
[4]School of Land Sciences and Technology
China University of Geosciences, Beijing 100083, China

***ABSTRACT:*** *In this paper a three-dimensional visualized integrated framework of landslide monitoring data is presented. The proposed framework presents a strategy for the integration of the data in landslide monitoring based on a thematic point-source landslide monitoring database and three-dimensional geological model of landslide. The framework is applied to the HuangTuPo landslide monitoring project in Three Gorges Reservoir of China. Comparison of the result with the common method shows a more efficient fusion of landslide monitoring data with the feature of multi-source, multi-class, large quantity and multi-themes.*

**Keywords:** Landslide Monitor, Data Integration, Geological Modeling, Thematic Point-Source Database

**Received:** 19 September 2015, Revised 9 October 2015, Accepted 13 October 2015



## 1. Introduction

As landslide is one of the main types of geological disasters that cause significant casualties and property losses, landslide monitoring is drawing more attention. With increasing availability of affordable sensor and geological survey methods, the integration and fusion of landslide monitoring data has become a question to be addressed for the reason that landslide monitoring data is the important basis for trend analysis and forecasting of landslide. The use of a geographic information system (GIS) technology can aid in data management and decision making of landslide forecast, based on database technology and scientific visualization. (e.g. Li Shaojun,2004; e.g. Wang wei,2009; e.g. Renaud,2010; e.g. Xie Mowen,2011). However, in most landslide disaster monitoring information system, the construction of landslide monitoring database is to meet the need of a particular function or a mathematical prediction model in landslide monitoring information systems. Consequently, different factors of every early warning and forecasting mathematical model caused the differences in database structure, which led to difficulties in data sharing between databases (e.g. James D, 2008). Furthermore, the integration of landslide monitoring data in current study is completed in two-dimensional map. Little research has been done attempted to visualize the true three-dimensional spatial feature of landslide monitoring data. The existence of these problems not only makes the modifications of mathematical model in early warning and forecasting information system difficult, but also increases the difficulty for decision-makers in getting quick analysis of the monitoring results and trends speculate landslide when facing complex monitoring data.

The optimization of landslide early warning and forecasting mathematical model is a continuous process. Thus the improvement of the model will inevitably lead to the change of disaster factor and database structure. Therefore, the integration of landslide monitoring data should be adapted to the change of landslide early warning and forecasting mathematical model. Moreover, The evolution of landslide is the combined effect of spatial featured multi-physics factors (displacement field, temperature field, electromagnetic field, stress field, seepage field, acoustic emission ...), So the integration of landslide monitoring data should serve the visualized integration to express the spatial nature of monitoring data (e.g. Cheng,M.Y.,2012). However, few studies have been done with respect to this question. This paper presents the design of a three-dimensional framework for landslide monitoring data integration. It was developed to meet the requirement of three-dimensional visualized integration and analysis of landslide monitoring data.

## 2. The Integrated Framework based on Thematic Point-source Landslide Monitoring Database

Due to the inherent factor in the formation of landslides have the characteristics of complexity and diversity, Therefore, the focus of the monitoring work is not the same among different landslide. Various monitoring methods should be used according to the landslide's own geological conditions to monitor the possible trigger factor (e.g. Morgenstern, 2008). Usually, the monitoring work starts from the following aspects: geological trail monitoring, surface deformation monitoring, deep displacement monitoring, groundwater monitoring, the sound monitoring, stress monitoring, ground water monitoring, surface water monitoring, meteorological monitoring and monitoring of human activities. The diversity of monitoring method makes landslide monitoring data with the character of multi-source, multi-class, heterogeneous, multi-temporal characteristics. Therefore, if the database does not have a reasonable structure and available information, the daily queries and processing of landslide monitoring data can not be met, and the improvement of landslide prediction mathematical model cannot be done conveniently ( e.g. Yu, F.C,2007). Thematic point-source database provides a new way for the management of landslide monitoring data.

Thematic point-source database includes two meanings, one is the thematic database and the other is the point-source database (e.g. Wu Chonglong, 2005). As for landslide monitoring, the point-source database can be understood as database to store the data in each monitoring point, which is used to store the spatial and attribute data of monitoring point within the valid monitoring range of landslide. It is not only the basic unit to collect, store, manage, process and use of monitoring information in the monitoring area, but also the foundation for the establishment of landslide predictive and forecasts mathematical models. The thematic database is refers to the construction of the landslide monitoring database should not only take a particular topic or forecasting model as the core. Instead, the integrated management of monitoring data in monitoring range should be taken as core. Therefore, the storage and management of monitoring data should unify conceptual model and data model, realizing the standardization of terminology and codes. Forming the database associated with a variety of business topics function by systems analysis and models design. This can separate the management of monitoring data from the forecasting mathematical model or a particular demand. The aim is to ensure monitoring data can be efficiently retrieved and shared among multiple functional topics. We design the integration framework of landslide monitoring data based on thematic point-source landslide monitoring database according to the commonly used methods of landslide monitoring. The framework divides landslide monitoring into 15 functional topics, the landslide monitoring is the total application theme.(Fig.1)

Each theme meets different monitoring need, then the appropriate data tables and specific table structure were designed according to the need of topic to provide support for functional theme, such as the drawing of engineering geological survey maps(measured sections, drill column, etc.) and thematic maps(temperature contours, water level contour maps, etc.) of landslide monitoring, the calculating of mathematical model of landslide prediction and the generation of landslide monitoring reports. For example, the groundwater monitoring theme needs the following tables, monitoring equipment overview table, underground water table, gap pressure table, water table, water temperature table, water quality table, soil moisture content table and water filling cracks table. The development and evolution of most landslides is greatly affected by groundwater. These data tables nearly cover all the information used when analyzing stability of landslide. As a result, the theme functions likes compilation of thematic maps of groundwater, landslide prediction and three-dimensional visualization of groundwater are met well.

## 3. The Visualized Framework based on the Three-dimensional Geological Model

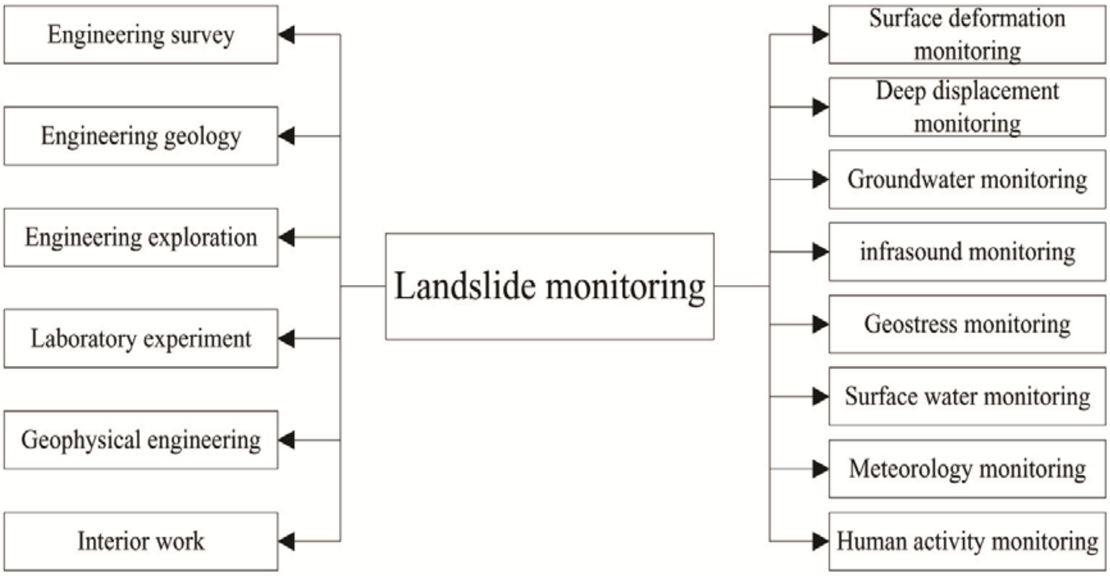



Figure 1. Thematic model of landslide monitoring point-source database

We propose a visualized framework of landslide monitoring data at the core of three-dimensional geological model of the landslide, the aim of the framework is to study the relationship between the spatial structure of the landslide and the change of monitoring data. The specific idea is: First, build the three-dimensional geological model of the landslide. Then, take it as the spatial foundation. A variety of methods for the spatial visualization of monitoring data was used to enhance the intuitive and analysis efficiency of monitoring data. In the following sections, we will discuss the process in detail.

### 3.1 Build the Three-dimensional Model of Landslide

Building the three-dimensional geological model of the landslide has inherent characteristics of three-dimensional geological modeling, but the distinctive feature of complex structures and the requirement to understand the state of landslide accurately make it more difficult compared with common three-dimensional geological modeling. We proposed the method of building the three-dimensional geological model of landslide as follows based on previous experience and exploration studies.

First, we divide the landslide into individual spatial object based on its characteristics, and then select the appropriate spatial data model for its visual expression. Specifically, a landslide is divided into those spatial objects: landslide body, slide belt, sliding surface, scarp and bed (e.g. Culshaw, M. G. 2005). Then the surface data mode was used for the visualization of surface shaped landslide object like sliding surface and scarp. As for the expression of body shaped object like landslide body and bed, B-Rep data model was utilized to express these spatial objects through the boundary of entities when only need to display its surface. At the same time, the topological relations between the border are considered. But when the expression of its internal composition and physic-chemical properties of substances is needed, we should establish the appropriate space voxel model. By taking this mixed model, we can build a three-dimensional geological model avoiding the shortage of a single data model.
.

Second, we integrate multi-source geological exploration data and make it standardized taking the borehole data as a constraint (Lan,H.2012). That is to say, when sections and other data is in conflict with borehole data, we correct those data with borehole data as a standard. After this process, these data become valid for three-dimensional geologicalmodeling. The data used in this process comes from the thematic point-source landslide monitoring database, such as borehole data, sections data, plane geological map data, remote sensing data, digital maps. The aim of this integrated multi-source data modeling approach is to ensure the accuracy of three-dimensional model.

Then, the stratigraphic was divided based on comprehensive analysis of integrated multisource data. We can get stratigraphic control point (line) through the stratigraphic division, and interpolate sparse data with constrained Delaunay Triangulation to fitvarious stratigraphic. Afterwards, we should reconstruct the stratigraphic with the same attributes within the specified depth range. With the operation above, the creation of the three-dimensional geological model of landslide was achieved automati cally. At last, Cut analysis was taken over the built three-dimensional model of the landslide, the aim of this operation is to compare the result with the original data that participated in modeling to verify the accuracy of the model. If there is unreasonable thing, we can correct the model partly until getting a reasonable and accurate model.

The above process can be represented by Figure 2:

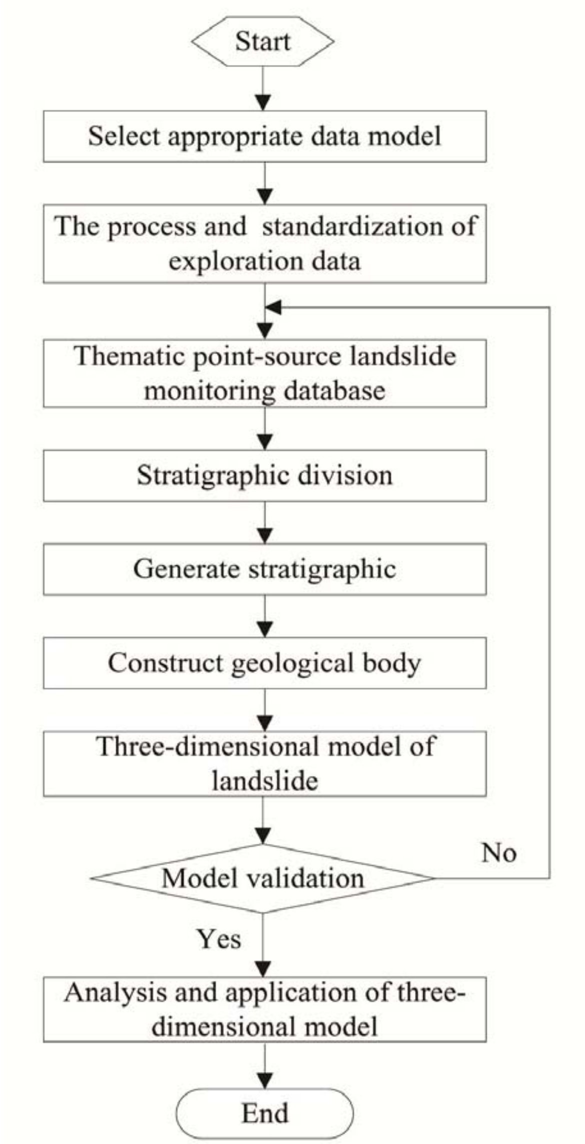



Figure 2. The flowchart of building the three-dimensional model of landslide

**3.2 The Visualization of Monitoring Data**

We divide monitoring data into: raster data, vector data and scalar data based on the it's characteristics (Renaud,2010). In the following content, we discuss the method of visualization for monitoring data respectively.

**3.2.1 Raster Data**

Remote sensing data in landslide monitoring is raster data. The spatial visualization of those data can be done as follows: First, we should do the georeferencing of the remote sensing image based on feature points in remote sensing image and coordinat-es map corresponded with this image, Then match it with landslide on the basis spatial coordinates of its location. Then realize its spatial visualization with Digital Elevation Model (DEM) or its own elevation information. Meanwhile, time snapshot model was used in the storage of raster data. As a result, we can displaying raster images dynamically according to the timeline. Furthermore, the analysis of the situation and trends on surface deformation landslide can be realized. Figure 3 depicts the process for the three-dimensional visualization of remote sensing data.

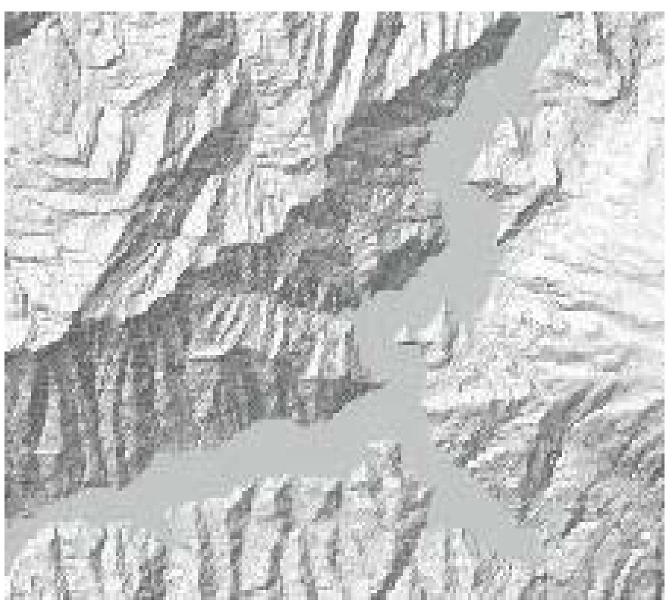
### 3.2.2 Vector Data

The monitoring variables of surface deformation monitoring, deep displacement monitoring and stress monitoring in landslide monitoring have a direction and magnitude. Therefore, the spatial visualization of these two aspects must be considered. In addition, these variables always have temporal characteristics, so it had better to meet the need of the dynamic visual display.

#### (1) Surface Deformation Monitoring Data

Surface deformation is the most direct phenomen-on of landslide development and evolution, it is easy to get the change of these variation. The common monitoring method likes: crack measurements method and GPS displacement monitoring method. The visualization of surface deformation can be realized by deform isosurface which is obtained by interpolating deformation of each monitoring point at a time range, The displacement direction can be indicated with an arrow line starting from monitoring point(Fig.4).

a. Remote sensing data of a region



b. DEM of a region

c. The spatial visualization of remote sensing data

Figure 3. The processfor the three-dimensional visualizationof remote sensing data

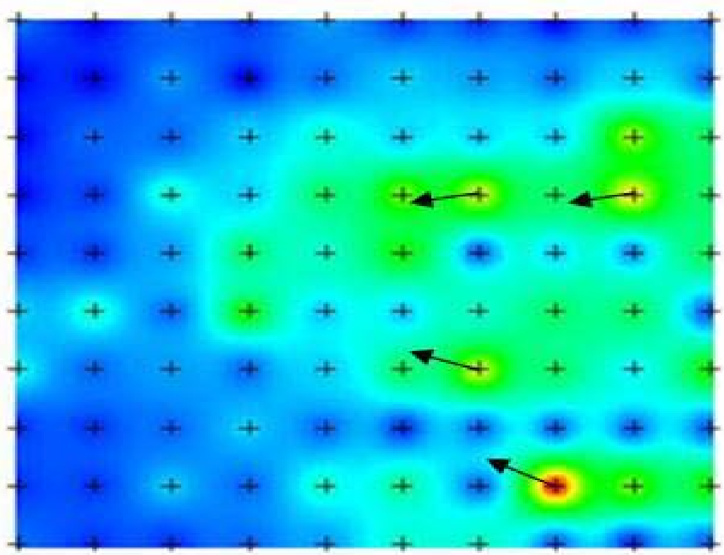


Figure 4. Schematic of surface deformation isosurface

**(2) Deep Displacement Monitoring Data**

Deep displacement monitoring is to monitor the internal deformation in landslide by certain instruments. Deep displacement and deformation is of important guiding significance when evaluating the status and trends of landslide. The common measuring instrument is inclinometer. The visualization of deep deformation can be carried out according to the following ideas: Firstly, build the original three-dimensional model of the inclinometer with the original state parameters of the inclinometer. Then build a three-dimensional model of the inclinometer at different time with the original state parameters and deformation values. That is to say, by building series of three-dimensional model of the inclinometer with its state parameter at different time to express the deep displacement variable. Then compare the model at different time, the amount of change is clear. Fig.5 is series model of inclinometer built with state parameters at different time displayed in cross-sectional direction. We can see the changes in the deep displacement clearly from it.

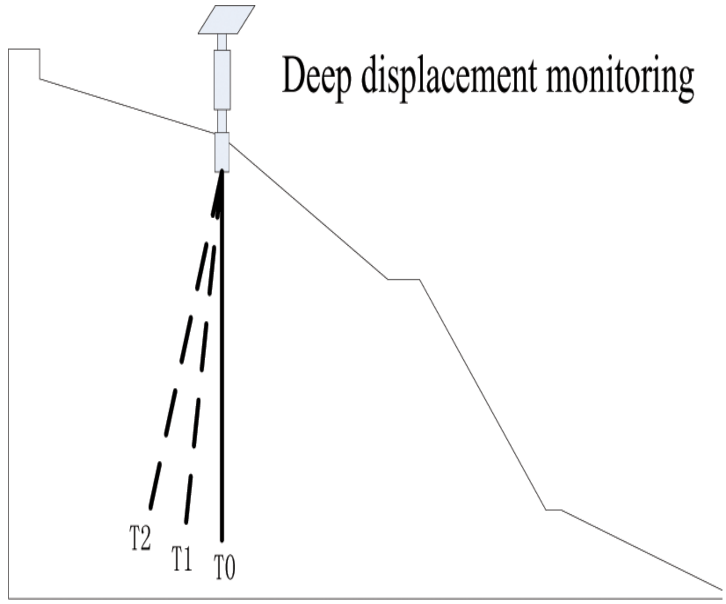



Figure 5.Schematic of deep displacementand deformation

**3.2.3 Scalar Monitoring Data**

Temperature data, sound data and ground water level data in landslide monitoring has the characteristics of field data, with numerical size but no direction. The best form to visualize these data is spatial entity. However, considering the existence of three-dimensional model of landslide, we use three-dimensional isosurface to visualize these field data in order to avoid blocking the body. The isosurface is the interpolation results of monitoring variable collected as a Z coordinate, combining X, Y coordinates of the monitoring point. A time stamp was assigned to these isosurfaces to create a series of time-based isosurface. This can help us to realize the three-dimensional dynamic visualization of monitor variables. At the same time, trend graphs of monitoring points variable was generated. From point to plane, all this can lead to the accurate spatial distribution of monitor variables. Here, we only take the visualization of temperature and groundwater data as example.

**(1) Temperature Data**

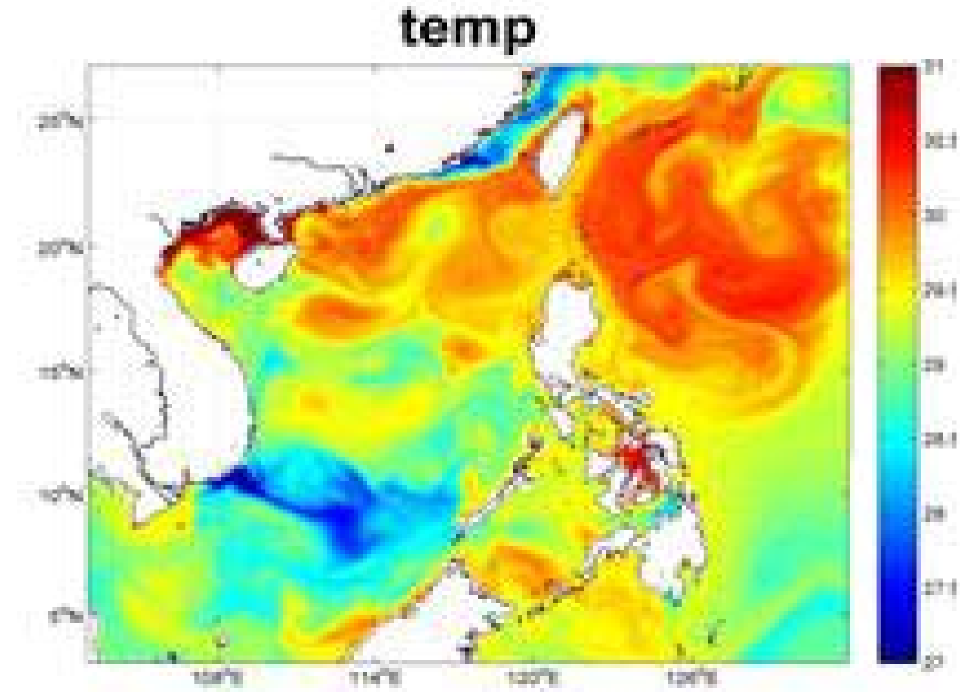
The temperature field exist in landslide is the general term of temperature distribution in the landslide at a time. Landslide movement is always accompanied with change of its internal temperature field. Therefore, we can find out the internal state of the landslide by monitoring the change of internal temperature field. Landslide temperature monitoring data can be obtained through the temperature sensor that deployed in the main body of the landslide. The horizontal section or vertical section diagram of temperature field can be calculated with the use of spatial interpolation methods. Fig. 6 shows two methods of temperature visualization.

**(2) Groundwater Data**

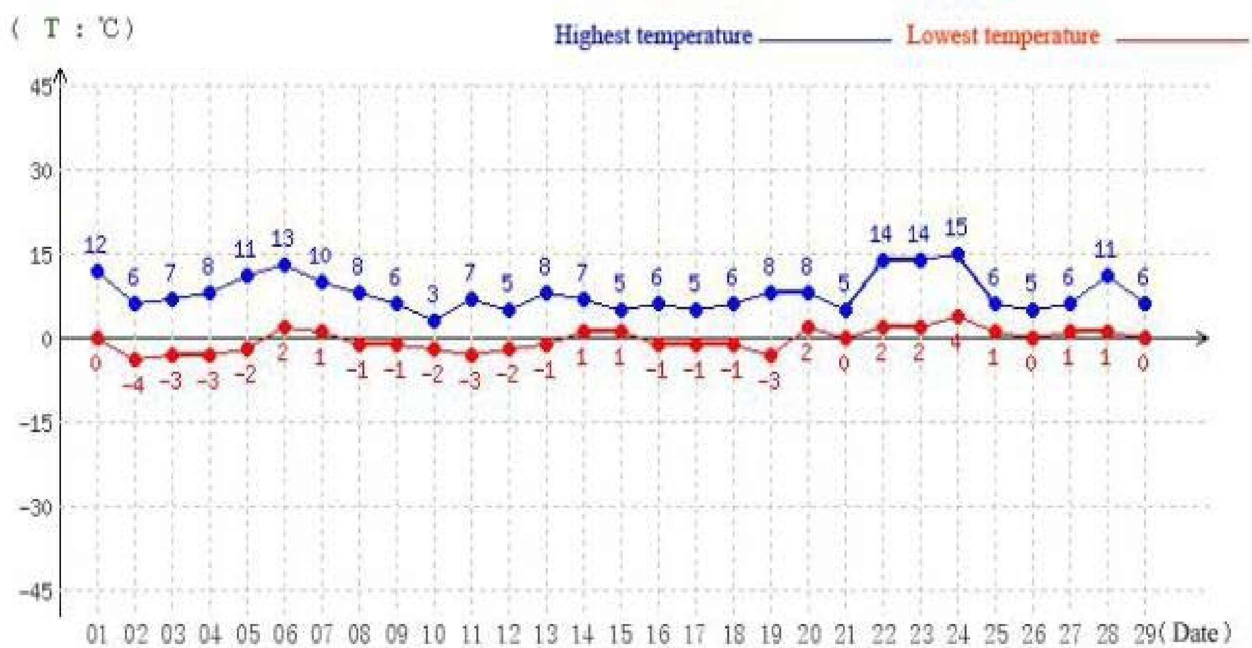
Groundwater level monitoring has an important reference value in landslide prediction. The change of groundwater level can be obtained by the radar level gauge. The visualization of groundwater can be achieved throng the three-dimensional surface of the groundwater level, which is the interpolation results of X and Y coordinates and elevation values of water monitoring points. So the change of water surface in landslide can be seen clearly when we set the three-dimensional geological model of landslide at a certain degree of transparency.

**4. Application Example**

HuangTuPo Landslide is located in Badong County, Hubei Province, the Three Gorges Reservoir of China. It is a multi-stage, a large complex landslide consisting of multiple sliding masses. It is composed by Riverside 1 slumping mass, Riverside 2 slumping mass, substation landslide and horticultural field landslide. It has an area of 135 $\times 10^4 m^2$, a volume of about 6934 $\times$ $10^4 m^3$. As there is much slope surface deformation and many cracks in it, so it has a direct impact on the stability of people's lives and property safety of local people. Taking into account the importance and representative interdisciplinary research of Huang Tu Po landslide, China University of Geosciences (Wuhan) build a large-scale comprehensive field test site in HuangTuPo landslide. A series of landslide monitoring equipment were installed, and the multidimensional information integrated monitoring system was deployed (e.g. Liu Junqi,2012).




a. Horizontal isothermal surface




b. The trend of temperature in monitoring points

Figure 6. The visualized form of temperature

We collect the basic geographic data (topography, geomorphological, transportation), basic geological data (structure, faults, stratigraphic information), engineering survey data (drilling, profile, test data), and the sensor monitoring data gained from the monitoring instruments, such as water level observation instrument, drilling inclinometer, GPS displacement monitoring, distributed fiber optic monitoring, TDR Time domain reflectometer monitor, 3D laser scanners, SNMR monitoring, surveying robot, thermal infrared monitor etc. Then we build the thematic point-source landslide monitoring database with Oracle database. With the integrated framework introduced above, the combination of geographic data, geological data and engineering data was achieved in a three-dimensional geological information platform named QuantyView.(Fig.7) The three-dimensional geological model of the landslide was built in this visualized environment with the use of modeling methods described above. The visualization of monitoring data based on this visualized frame also was realized. We do cut processing over landslide model in order to avoid monitoring data block the landslide model. The effect can be seen from the Fig.8. The effect of the landslide monitoring data was improved significantly with the visualized integration of landslide spatial data and monitoring data. And the interpretation efficiency of monitoring information on the landslide was greatly improved.

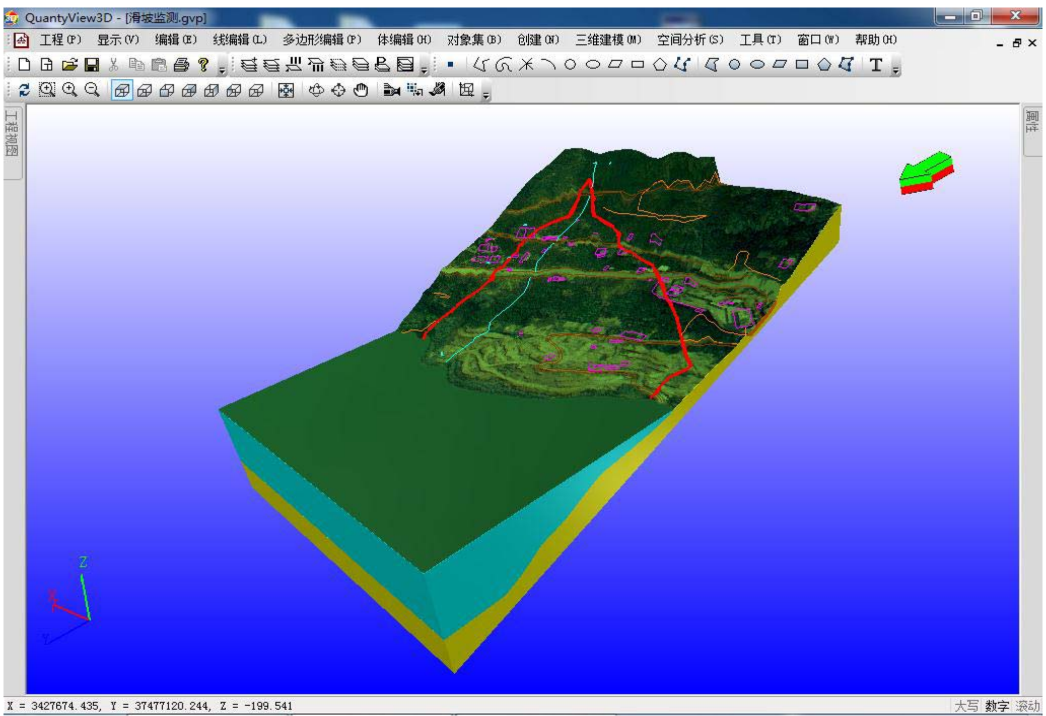



Figure 7. The visualized integration of geographic data, geology data and engineering data

**5. Conclusions**

This article starts from the urgent need of landslide monitoring data integration. We present the integrated frame work based on thematic point-source landslide monitoring database and the visualized framework based on the three-dimensional geological model. The three-dimensional visualization of landslide hazard body was realized based on this frame with the modeling method which integrates multi-source data and takes drill data as constraint. According to the characteristics of monitoring data, we did the spatial display of monitoring data in different ways based on the three-dimension model of landslide. So the integration of landslide data and monitoring data was accomplished. The results show that the three-dimensional integration framework of lands-lide and monitoring data we proposed can manage landslide monitoring data effectively, Separate the management of monitoring data from the forecasti-ng mathematical model of landslide. At the same time, it makes the visualization of monitoring data more vivid. And the interpretation efficiency of the landslide monitoring data was improved. All this provides a good data foundation for analyzing the state of the landslide and forecasting landslide trends.

**Acknowledgement**

This paper is supported by the software development of 3D area disaster geology map in 3GR (No.SXJC-3ZH1A6, China).

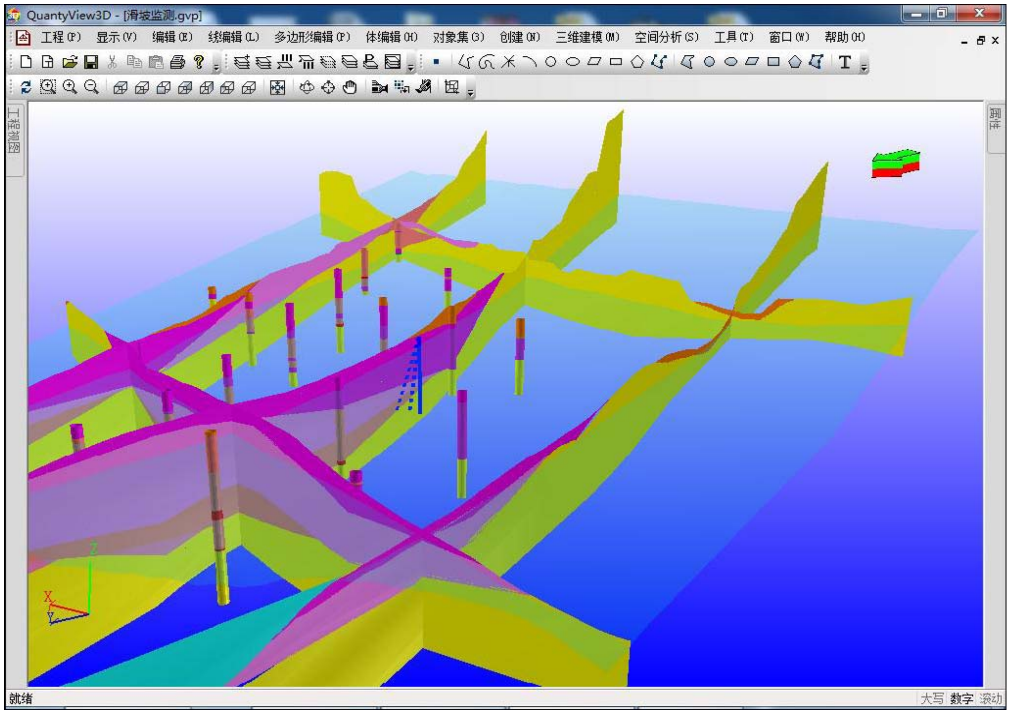



Figure 8. Three dimensional visualized integration of landslide monitoring data

**References**

[1] Bulmer, M. H., Farquhar, T. (2010). Design and installation of a Prototype Geohazard Monitoring System near Machu Picchu, Peru. *Natural Hazards and Earth System Sciences,* 10 (9), 2031-2038.

[2] Cheng, M. Y., Chien-Ho, K, Chang, C. H. (2012).Computer -Aided DSS for Safety Monitoring of Geotechnical Construction. Automation in Construction, 11, 375-390.

[3] Culshaw, M.G. (2005).The Seventh Glossop Lecture From concept to-wards reality: developing the attributed 3-D geological model of the shallow subsurface, *Q. J. Eng. Geol. Hydrogeol*, 38, 231–284,

[4] McCarthy, James D., Graniero, Phil A.., Steven M. Rozic (2008). An integrated GIS-Expert system framework for live hazard monitoring and detection. *Sensors,* 8 (2), 830-846

[5] Lan, H., Martin, C. D. (2012). A digital approach for integrating geotechnical data and stability analyses, *In:* Rock Mechanics: Meeting Society's Challenges and Demands, edited by: Eber- hardt, E., Stead, D., and Morrison, T., London, *Taylor & Francis*, 45–52.

[6] Shaojun, Li, Xiating, Feng., Chengxiang, Yang. (2004). Landslide monitoring and intelligent analysis on deformation prediction based on three dimensional geographic information. *Chinese Journal of Rock Mechanics and Engineering*, 23 (21), 3673-3678.

[7] Junqi, Liu., Guang, Qi., Wenming, Chen. (2012). Reaearch and Applicaton of hyaline landslide: An example of Huangtupo landslide, 31 (6), 52-58

[8] Morgenstern, N. R., Martin, C. D. (2008). Keynote lecture, Landslides: Seeing the ground, *In*: Proceedings 10$^{th}$ International Symposium on Landslide.

[9] Chen, Z., Zhang, J., Li, Z., Wu, F., Ho, K. Ed. Landslides and Engineered Slopes, Xi'an, China, *Taylor & Francis*, London, 1, 3–23.

[10] Renaud, J. P., Anderson, M., Wilkinson, G. (2010). The importance of visualisation of results from slope stability

analysis, *In*: Proceedings of the Institution of Civil Engineers-Geotechnical Engineering, 156 (1), 27–33.

[11] Wei, Wang.,Shuilin, Wang., Huazhou, Tang. (2009). Application of 3-D GIS to monitoring and forecast system of landslide hazard, 30 (11), 3379-3385

[12] Chonglong, Wu., Gang, Liu., Yiping, Tian., Junqi, Liu. (2005).Theory and Method Problems of Infor-matization of Geological Surveying and Mineral Resource Exploration. Earth Science - *Journal of China University of Geosciences*, 30 (3), 359-364.

[13] Mowen, Xie., Xiaoqing, Chai. (2011). Development and of application of Real-time monitoring WEB-GIS for Landslide. 30 (10) 2090-2102.

[14] Yu, F. C., Chen, C. Y., Lin, S. C., Lin, Y. C., Wu, S. Y. (2007). A Web-Based Decision Support System for Slopeland Hazard Warning. *Environmental Monitoring Assessment*, 127 (5), 419-428.