Web-based Geological Hazard Monitoring in the Three Gorges Area of China

Ruiqing Niu, Liangpei Zhang, Zhenfeng Shao, and Qimin Cheng

Abstract
Many different types of geological hazards have seriously hindered sustainable development of society and its economy. It is critical to pay greater attention to effective geological hazard investigations, monitoring, early warning, mitigation, and prevention through advanced technologies. In this paper, an information system to monitor geological hazards is designed and implemented on the basis of a WEBGIS platform and a large volume of multi-source remotely sensed data; its network structure and architecture are designed and presented. Detail is provided on the key technologies and function modules. Then, a concrete system implementation is introduced using a typical instance, namely, the geological hazard monitoring of the Three Gorges Reservoir Engineering Areas, followed by conclusions and directions for future work. The focus of our work is its provision of a highly efficient means of real-time geological hazard body monitoring. In addition, information WEB publishing, geological hazard assessment and decision-making for a geological department are also important targets.

Introduction
Currently, the properties and lives of many people have been and are being seriously threatened by a variety of geological hazards, which have become serious barriers to sustainable development of society and its economy. During the past few decades, vast energy and effort have been spent on the mitigation and control of geological hazards, resulting in considerable achievements in geological investigation, reconnaissance, prediction, and prevention (Harris et al., 1994; Lee and Choi, 2001). However, the geological hazards situation is still not under control due to the scarcity of highly efficient geological hazard monitoring and prevention systems, supported by advanced technologies.

In recent years, the application of the Internet and the technologies of RS, GIS, and GPS in the field of Earth science have developed rapidly (Chavez et al., 1991; Singhroy, 2001; Tae and Moon, 2002). As is well known, data from various remote sensing systems provide plentiful information for geological hazard monitoring and, through analyzing change detection using different remotely sensed images, the development of important geological hazard points can be represented in real-time (Ramadan and Sultan, 2003; Nefeslioglu et al., 2003; Tran and Trinh, 2004). Another important technology, GPS, improves the efficiency and precision of the positioning of geological hazards, such as landslides, collapses, and debris flow. In addition, the ideal combination of the Internet and GIS (WEBGIS) can realize real-time WEB publishing of geological hazard information, as well as other functions including geological hazard data storage and management, spatial information query, complex spatial analysis, and critical decision-making. In short, the combination of Internet and technologies of RS, GIS, and GPS provides a feasible, necessary, and an effective tool for geological hazard monitoring and prevention.

In fact, the application of RS, GIS, and GPS technologies in geological hazard monitoring and prevention is not new. These techniques have had the attention of geological departments and research organizations of many countries and many scholars have expended great effort on them. For example, Lan et al. (2004) constructed a spatial database of landslides and established quantitative relationships between landslides and the factors affecting them using a Certainty Factor Model. The landslide susceptibility maps produced for different rainfall conditions are useful for making emergency decisions and reduce the effort needed in landslide hazards mitigation. Caiyan and Qiao (2006) study how slope aspect contributes to landslide growth in the Three Gorges Reservoir Area, China by applying an information value model with GIS technology. The concrete contribution of slope factors in different directions is analyzed in detail. Zhang et al. (2006) thoroughly investigated landslides and debris flows in Sichuan Province, China using spectral matching and image mosaics. Several kinds of remotely sensed data were applied, including TM images, ETM images, SPOT images, aerial photos, and other remotely sensed data. The environmental factors that induce landslides and debris flows, such as slope, vegetation coverage, lithology, and rainfall are obtained by GIS spatial analysis methods. Joy and Lu (2004) believe remote sensing and GIS technology are key tools for flood monitoring and focus their...
GSM has publishing, all simultaneously. WEBGIS PHOTOGRAMMETRIC ENGINEERING & REMOTE SENSING in high-speed data transfer quick browser, as long as the technology. GPRS publishing of geological hazards. That June 2007 levels, sensor-sensing and ground sensors, data-interpretation, and workflow management, all based on remote sensing and WEBGIS technology.

This paper aims to design and implement a geological hazard monitoring information system on the basis of a WEBGIS platform and the large amount of remotely sensed data arriving from multiple sources, which can achieve such functions as integrated storage and management of remotely sensed data, geological hazard monitoring, and geological hazard information WEB publishing, all simultaneously.

The significance of our work is its provision of the whole solution from integrated storage and management of original geological and spatial data to real-time and dynamic monitoring and WEB publishing of geological hazards. That is to say, a feasible and effective decision-making and assessment system for the comprehensive management of hazardous geological environments is proposed with the goal of realizing geological hazard mitigation and prevention by monitoring and analyzing geological hazard points through the system developed in this paper.

Our solution is based on the flow customization technologies of geological hazard monitoring in order to avoid huge costs and to improve the efficiency of monitoring. To acquire multifarious image data and monitoring data in real time, two different WEB levels, sensor-WEB and data-WEB, are constructed. While sensor-WEB includes information from various remote sensing sensors, underground sensors and ground sensors, data-WEB includes all kinds of data (remotely sensed data and non-remotely sensed data as well) and can be used for decision-making and statistical analysis.

The paper is arranged as follows: the first section gives an introduction followed by an analysis of the three-tier architecture and key technologies of a WEB-based geological hazard monitoring information system, respectively; next, the main function modules are described followed by system implementation through an example, the Three Gorges Reservoir Engineering Areas Geological Hazard Monitoring System; and finally, conclusions and suggestions for future work are presented.

Network Structure and System Architecture

The network structure of our WEB-based geological hazard monitoring information system is composed of four parts: Wireless Communication Network, Monitor Points, Control Center (server-side), and Remote Terminal (client-side), as shown in Figure 1. The Wireless Communication Network can be Global System for Mobile Communication (GSM) or General Packet Radio Service (GPRS), both of which have their different advantages and disadvantages. GSM has the advantages of wide coverage, low cost, and extensive application, but its disadvantage is that the data transfer speed is low, and so it is difficult to meet the requirements of very large data transfers. GPRS is an improvement on GSM; it is superior to GSM in high-speed data transfer quick login, and real-time online and automatic switching. That is to say, the working scheme of GPRS lets it simultaneously serve many more clients than when using second-generation GSM networks. GPRS also has its own disadvantages; for example, the real bit rate of GPRS cannot reach its maximum theoretical value due to redundancy of the transmitted data that provides protection from errors and includes control information. But considering the merits of GPRS mentioned above, it was selected as our wireless communication platform.

The basic principle of operation is that information on any potential hazard and the corresponding location information are all transferred from Monitor Points through mobile phones to the Data Collection Server of the Control Center. In our system, smart phones (a smart phone is a full-featured mobile phone with personal computer-like functionality) are used due to their capability of embedded development. Then, the information is processed, for example, coordinate transformation, change detection, and hazard assessment and will be displayed on electronic maps at the Control Terminal as well.

The server-side Control Center is composed of a WEB Server, Data Processing Server, Hazard Monitoring Server, Hazard Assessment Server, Data Collection Server, and Multiple Database servers. The client-side remote terminal can be any terminal equipment, such as a PC, PDA, or mobile phone. The only requirement of a remote terminal is that it can be connected to the Internet. All operations, including dynamic geological hazard monitoring, querying the history of geological hazards, hazard analyzing, and assessing can be achieved conveniently through a WEB browser, as long as the user is authorized.

It is well known that generally there are three different three-tier architecture modes that are adopted by most of the WEBGIS applications according to different application requirements: server-side mode (thin-client mode), client-side mode (fat-client mode), and hybrid mode.
Of these three modes, the server-side mode focuses most of the data operations on the server side. The client side, usually a web browser, only needs to provide simple user interfaces to submit a request or display a result, without the need to download any plug-ins, Applets, or ActiveX. Every time the user executes an operation, a request is sent to the server across the Internet in the form of a URL. The server will reply to the client with processed results in standard HTML format, embedded with typical images that are supported by most web browsers. Concrete implementation technologies include Common Gateway Interface (CGI) and Server Application Programming Interface (API). The disadvantages of the server-side mode include the heavy network load on the server side and the limited capabilities of the client side.

In contrast to the server-side mode, the client-side mode applies such technologies as plug-ins, ActiveX controls, or Applets to enhance user interface ability and to lower further the load on the server side and network. The disadvantages of this mode are its capabilities regarding security and universality.

Compared with the two modes mentioned above, the hybrid mode is a compromise; it has the merits of the above two modes including a balanced load on the server and client sides and flexible abilities on the client side. But to meet good performance, comprehensive configurations and correspondingly complex software development work are necessary.

As a result of comprehensive considerations, the hybrid mode of system architecture is employed. The reasons can be summarized as follows: (a) large data volume and frequent data transfer of geological hazard monitoring information would result in a considerable waste in network resource and response time; and (b) remote terminal users are endowed with qualifications of different levels, so flexible capabilities on the client side are significant.

Figure 2 illustrates our system architecture, which is composed of a Presentation Layer, a Business Logic Layer, and a Data Layer from top to bottom.

The first layer, the Presentation Layer, exploits ActiveX control technologies to realize vector data display, basic map operations, and simple spatial analysis functions on the client side.

The middle layer, the Business Logic Layer, is composed of the WEB server and application servers. The responsibility of the WEB server is to realize bi-directional communication between the client and application server, while a series of Servlets or Active Server Page (ASP) accounts for bi-directional communication between the WEB server and application servers. There are five logic Application Servers in our system: Data Processing Server, Spectral Interpretation Server, Feature Extraction Server, Hazards Assessment Server, and Communication Server. Just as their names imply, the Data Processing Server accounts for pre-processing and application processing of all data sources; Spectral Interpretation Server accounts for spectrum curve generation and automatic spectral recognition; Feature Extraction Server accounts for feature extraction of point and linear geological hazard bodies; Hazards Assessment Server accounts for assessment of geological hazard situations on the basis of certain assessment models; and the Communication Server accounts for data processing, received in real time, including potential hazard information and location information.

The last layer, the Data Layer, takes charge of the management and maintenance of remotely sensed data, GIS data, GPS data, hazard body data, and thematic data; the history database and current data are all stored in this layer. Java Database Connectivity (JDBC) and Open Database Connectivity (ODBC) are employed to realize data transfer between the Business Logic Layer and the Data Layer.

Key Technologies

Design and Construction of Integrated Database

Figure 3 illustrates the integrated database design of our web-based geological hazard monitoring information system, which is composed of five layers described from bottom to top.

1. Original data layer: composed of various kinds of data that are acquired from different sensors or by surveying.
2. Data standardization layer: composed of standardized data from original data after data format conversion or coordinate system conversion.
3. Data source layer: composed of independent databases, which constitute the data infrastructure of the whole system.
4. Data management layer: composed of multi-source and multi-scale data organization and management, regional administration management, index management, and catalog management.
5. Application layer: composed of such application operations as data browse, data query, data edit and data extraction.

From the point of view of implementation, we constructed a database supporting system in view of the very large volume and multi-source spatial data and statistical data being used. The main contents include:

1. Organization, import and export, storage and management of multi-source data;
2. Establishment of a database platform for high-efficiency data access and data query;
3. Distribution, configuration, dispatching and information flow management of real-time geological hazard monitoring tasks;
and

As for the data source, our database supporting system needs to manage importing, storage, query, extraction of spatial database (including vector data, raster data, DEM data), terrain database, hazard body database, and monitoring points database. Therefore, our system of data storage contains information of Hazard body type, Control points, Vector data, Raster data, and 3D terrain data. With the rapid development of sensor technologies, ground resolution evolves from small-scale to meter-level or even decimeter-level; spectral bands evolve from multiple to high spectral resolution. Therefore, there exists a series of problems that a remotely sensed, image processing platform must face. We consider catalog management of very large volume spatial data, directory services, seamless remotely sensed image database construction, and high-efficiency dispatching and management of multi-source and very large volume remotely sensed data. Considering the multi-scale and spatial-temporal characteristics of remotely sensed image data, we have developed the following steps to deal with these different problems:

1. Catalog, archive, storage, management, query and service mechanisms of high-volume satellite image data: a three-level storage schema (including on-line, near line, and off-line storage) is built to realize automatic catalog, archiving, storage, management, query, and services of high-volume satellite image data and therefore to provide quick and convenient entrance for potential users.
2. On-line visiting, dispatching and processing mechanisms of remotely sensed image data: as basic operations of an integrated remote sensing processing platform, on-line accessing, data dispatching and disposal mechanisms, and algorithms are given much attention.
3. The opacity of the data interface, the openness and extendibility of the storage scheme: we have designed and implemented an opaque data interface to cover the detailed information that users are not concerned with in the process of data accessing. At the same time, we establish an open and extendable storage scheme to meet the requirements of different users.

The problems needing to be further addressed include: a seamless, high-efficiency database construction algorithm and management strategy for distributed remotely sensed image data; a uniform and seamless multi-source and multi-scale remotely sensed image database; and a reasonable index schema to realize high-efficiency dispatching of data at any scale.

Dynamic Flow Customization Technologies of Geological Hazard Monitoring

A real-time and dynamic system for monitoring geological hazards needs to detect changes of information on potential geological hazards, such as displacements, quickly and exactly by employing remotely sensed image data. Undoubtedly, this is a hard task, particularly whenever a great many image recognition processes must be performed in a very short time period. Therefore, it is extremely important to adopt technologies of dynamic flow customization to avoid enormous costs and to improve the efficiency of monitoring. The actual solution, tentatively illustrated in Figure 4, can be described as follows:

1. Realization of optimized dispatching, configuration and tracking of monitoring tasks for which the authors have constructed a sensor-web based on real-time assignment and dispatch of observations;
2. Achievement of information fusion among different sensors by adopting sensor-web technologies;

Figure 4. WEB construction on sensor level and data level. The sensor-web includes various remote sensing sensors such as aerial sensors, space sensors, ground sensors, and underground sensors; and through sensor-web real-time image and data monitoring, data can be acquired. The data-web includes all kinds of data and can be used for decision-making and statistical analysis.
3. Construction of a web with remotely sensed monitoring data and non-remotely sensed monitoring data on the data level (as shown in Figure 5) by integrating ground measuring methods with remote sensing methods so as to satisfy integrated applications; and

4. Establishment of a high-efficiency information database on geological hazard monitoring.

**Establishment of a Geological Hazard Monitoring Model**

A geological hazard monitoring model is established that provides important evidence for monitoring of geological hazards. The result obtained from change detection in remote sensing images is one of the most important parameters of our model. The changed elements can be points, lines, or surfaces, and different thresholds are given to judge whether any change has occurred. For a better description, a specific type of geological hazard needs to be selected first, and then its physical causes analyzed.

For example, for landslides, we first need to analyze the causes of active conditions and the external environment (such as seismic or climatic factors) and then, on this basis, establish an elementary monitoring model to execute long-term and real-time landslide monitoring. The direction of slip, the two relative displacements, and the scope of the deformed body are considered as the parameters for the monitoring model. The changes can be examined, and the relationship between the change speed and the landslide time can be calculated and can be reflected and represented as a change curve; simultaneously, the isotropic displacements can be forecast with scientific quantification. When the landslide body enters the changing acceleration stage, the movement can be examined with this curve, which can provide a definite forecasting ability according to the displacements and the acceleration. The monitoring model can thus serve the decision-making system.

**Function Modules**

There are nine function modules in our system: remote sensing image processing, geological hazard spectral interpretation, geological hazard feature extraction, thematic database management, monitoring workflow management, geological hazard monitoring and assessment, geological hazard information web publishing, mobile terminal data collection, report and update, and user authentication management (see Figure 6).

**Remote Sensing Image Processing**

Almost all common remote sensing data formats are supported by our system, such as ERDAS (*.img), PCI (*.pix), GEOTIFF (*.tif), ENVISAT (*.nl), ECW (*.ecw), DOQ (*.doq), JPEG2000 (*.j2k; *.jp2), and USGS ASCII DEM (*.dem), and a convenient data format conversion function is also available, along with a friendly data input and output interface, which ensures universality and compatibility of our system.

Image radiation rectification, image geometrical rectification, and image mosaic are the three main image preprocessing functions provided by our system. Different rectification models can be used to adapt for different applications. For example, the radiation rectification model includes the flat calibration model, linear regression empirical model, and internal average relative calibration, and the geometrical rectification model includes the polynomial model. In geometrical rectification, four sampling modes are available: nearest neighbor method, Bi-linear method, B-spline method, and bi-cubic method.

In order to meet the needs of remote sensing image analysis, some specific image enhancement operations are usually necessary. In our system, users can accomplish this through image transformations such as piecewise linear transformation, logarithmic transformation, exponential transformation, mean-variance transformation, histogram equalization, and histogram normalization.

Remote sensing image fusion and image classification are two important application processing functions. Five image fusion functions can be adopted: weighted image fusion, image fusion based on HIS (hue, intensity, saturation) transformation, image fusion based on principal component transformation, and image fusion based on ratio transformation. As for image classification, users can choose Minimum Distance Classification, Maximum Likelihood Classification, or Mahalanobis Distance Classification for the purpose of supervised classification or K-means or the ISODATA algorithm for unsupervised classification.
Considering that users often prefer to select a Region of Interest (ROI) rather than the whole image, to execute certain image processing operations, a ROI tool is very useful. In our system, users can add a ROI, delete a ROI, save a ROI as a file, and import a ROI file at any time they desire. For a given ROI, almost all basic graphic editing and statistic analysis operations are provided.

Geological Hazard Spectral Interpretation
Generally, a spectrum of objects is represented through multi-spectral or hyper-spectral remote sensing images. Spectrum recognition of multi-spectral remote sensing images based on spectral feature extraction is a very useful method to distinguish features and kinds of geological hazards. Our system constructs a target spectrum database through field sampling and surveying by a spectrometer in advance. When a geological hazard occurs, users can judge its potential by finding geological hazards with similar spectrum curves retrieved from the stored remote sensing images. Spectrum plots are used to show spectrum curves of certain pixels and users can choose to display spectrum curves of multiple pixels at the same interface or to save spectrum curves as text files or spectral files.

Geological Hazard Feature Extraction
The detection of point, linear, and superficial geological elements in regions of geological hazards is realized in this system.

For the detection of point geological elements, the Smallest Unvalue Segment Assimilating Nucleus (SUSAN) operator is adopted due to its fine qualities in feature detection compared with other operators; it has good detection, good localization, a short response time and fast detection speed, making it suitable for extracting point elements (Perez and Dennis, 1997) and kinds of geoinformation with other operators (Skocir et al., 2002; Zhou et al., 2004). For detection of linear and superficial geological elements, a strategy of selecting the maximum variance between clusters is applied to detect the changed areas. As is known, the difference, the ratio and the relevant coefficient are three common methods of change detection. Difference methods are applied most and can be divided into gray difference, texture difference, and vegetation index difference according to the difference of targets. Ratio methods detect changed areas quickly, in which two images acquired from different periods are matched accurately. Suitable threshold value selection is the key in this kind of method. The relative coefficient methods utilize relevant functions of two signals to calculate the degree of similarity.

In our system, the Otsu algorithm (Lee and Park, 1990; Li et al., 2005) is employed for linear and superficial geological element detection. It can segment the histogram of an image into two parts with the best threshold and the maximum variance between two clusters. The actual process calculates the ratio of two input images first, and then segments the middle result with the Otsu algorithm. A two-value image can then be obtained as the final result.

Thematic Database Management
In our system, there are ten basic thematic databases, which cover a great deal of information about geological hazards, the principal database operations, such as new, insert, delete, and modify, are provided. These databases include: lithological spectrum, geological structures feature database, terrain feature database, hydrologic feature database, geological hazard body feature, geological hazard body interpretation, geological hazard body spectral feature information, vegetation feature, land-use feature, and geographical information catalog.

Monitoring Workflow Management
There are many information interactions between the Control Center, each Monitor Point and the Management Department, such as case receiving, case sending, and result browsing for which workflow technology supplies useful means and guarantees parallel communication and cooperation among them.

Geological Hazard Monitoring and Assessment
Our system performs change monitoring of vegetation and engineering activities in a region affected by geological hazards. Engineering activities are necessary for the survival and development of society. But excessive resource exploitation and immoderate city construction undoubtedly cause negative effects on the geological environments to a certain extent. Three different methods are adopted to monitor geological change due to human engineering activities: principal components analysis (PCA), change vector analysis, and post-classification comparisons.

Our system also fulfils the function of geological hazard assessment, which is an all-around analysis and evaluation process of the geological hazard body according to certain geological hazard monitoring and assessment models that are based on change monitoring. The assessment result will be given in the form of a report, graphic, or grid. In our system, four assessment models are available: debris flow, artificial high slope, landslides, and collapse.

Geological Hazard Information WEB Publishing
To provide real-time, long-range monitoring, analysis, and decision-making for multi-users with different authentications in practical applications, our system publishes geological hazard information on the WEB in real-time through its WEB publishing module. This is important in practical applications.

Mobile Terminal Data Collection, Report, and Update
Generally, each operator of a Monitor Point is equipped with a smart phone, i.e., mobile terminal, through which identity authentication, encrypted data transfer from the data gathering server, information reporting, and task receiving are all realized using GPRS. The reported information usually includes correspondingly accurate location information on where the geological hazards occur.

In addition, an automatic updating scheme is adopted to allow online updating of source data, geological hazard information and application systems.

Application Examples
Geographic and Geological Environment of the Three Gorges Reservoir Engineering Areas, China
The Three Gorges Reservoir Engineering Areas are located from longitude 105° 44’ east to 111° 39’ east and from latitude 28° 32’ north to 31° 44’ north and the total area is 56,700 km² which covers more than 20 counties or towns including the town of Yichang in the Hubei Province, China.

The geological setting of the Three Gorges Reservoir Engineering Areas is very complex, partly due to its subtropical climate. Generally, the geological hazards of this area are extensive, frequent and very harmful, resulting in this area having become one of the most seriously dangerous areas in China. Furthermore, the Three Gorges Dam construction and migration project changed the original geological situation and aggravated geological hazards to a certain
degree. Currently, landslides and debris flow constitute the three main types of geological hazard in this area. For example, counting only the collapses that have been inspected already exceeds 3,000. So, geological hazard monitoring of the Three Gorges Reservoir Engineering Areas has constituted the main part of geological hazard prevention and remediation work in China.

At present, although large efforts have been made in manual inspection and monitoring, there is still not a fully operational monitoring and early-warning system in the Three Gorges Reservoir Engineering Areas due to its vast area, inconvenient transportation network, and difficult natural conditions. Considering its automatic, quick, inexpensive and visual characteristics, a web-based, feasible,
effective, advanced and integrated geological hazard monitoring information platform on the bases of 3S (remote sensing, GPS, and GIS) technologies is significant for the mitigation, dynamic monitoring, early-warning, and decision-making of geological hazards in the Three Gorges Reservoir Engineering Areas.

Data Sources and Hardware/Software Environments

Multi-resolution satellite image data including TM, SPOT, Ikonos, and QuickBird and aerial image data are applied in our system. Terrain data with different scales from 1:25,000, 1:10,000 and 1:5,000 to 1:2,000 and DEM data with a scale of 1:25,000 are also applied. Similarly, GPS data acquired from more than 1,000 GPS monitoring stations are included. In addition, history and real-time geological hazard body monitoring data transferred using a wireless communication network are important data sources for our system. All data are stored and managed uniformly through Oracle® 9i.

The software of our system is developed using Visual C++ 6.0, ASP, JavaScript, and HTML which is to say, part of the multiple application servers on the server side and ActiveX control on the client side are developed on a Visual C++ 6.0 platform. ASP develops other modules, such as the user authentication module.

The system configuration required to run our system is as follows: operating system: Windows® 2000/Windows® NT, WEB server: Microsoft® IIS 5.0, client software: Internet Explorer® 5.0 and above, and monitor point equipment: Dopod585 or other smart phone, which supports embedded development.

Results of a Trial Run

In this section, we show part of the interfaces and results of running our system. Figure 7 illustrates the main interface. Figure 8 shows an original photo and the corresponding spectrum curve of one kind of rock (Tianhebanzu). Figure 9 and Figure 10 illustrate point feature and linear feature detection results, respectively. Figure 11 and Figure 12 give monitoring results of engineering activities based on three different methods: PCA, change vector analysis, and post-classification comparison.
Conclusion and Directions for Future Investigation

In this paper, the authors report on the design and implementation of a geological hazard monitoring information system based on a WEBGIS platform, multi-resolution remote sensing image data, and geological hazard data to realize effective geological hazard monitoring, early-warning, assessing, and decision-making. Based on the presented network structure and system architecture, the authors describe the main key technologies and function modules in detail. As an example, the Three Gorges Reservoir Engineering Areas Geological Hazard Monitoring System is constructed to provide real-time geological hazard body monitoring, information publishing, geological hazard assessment and decision-making for a geological department. This system has been working well at the Three Gorges Reservoir Engineering Areas Engineering Center for geological hazard prevention and control since 2005. The average time for one change detection is between 15 and 25 minutes. Several main landslides, including the Qianjiangping landslides, have been detected successfully. The main costs are for the purchase of high-resolution remotely sensed images. More cases are needed to further affirm the applicability of our system, although its validity has been proved in this paper.

But, there still exists much work needing further effort. First, the establishment of the geological hazard monitoring and assessment model mentioned in this paper is relatively simple and the establishment of more complicated models has not been addressed, but will become more and more important for the accuracy of monitoring based on remote sensing images. Second, in our experiments only a few representative kinds of geological hazard are monitored. To improve universality, a large number of different kinds of geological hazard need to be tested by our platform. Third, a monitoring strategy based on combined methods will also be involved in our future work.
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References


