A New Earthquake Analysis and Prediction System Based on OpenGIS

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***Abstract* — GIS technology has strong visualization facility and rich information resources which makes it very suitable for the needs of the earthquake industry. With the development of open GIS it has become the mainstream of software tool for developing such applications. By reforming the function of DotSpatial using C# development language and combining it with earthquake precursor analysis algorithm, this paper introduces Open GIS to an Earthquake Analysis and Prediction System to optimize MapSIS based on non-open source. The paper focuses on functions related closely to Open GIS such as map display of earthquake catalogue, the spatial display of earthquake modulation ratio, B value and abnormal earthquake precursor observation data. The realization of the system can give reference for the introduction of the open source GIS to other seismic systems.**

Keywords - openGIS; DotSpatial; Earthquake Analysis and Prediction System.

I. INTRODUCTION

Geographic Information System (GIS) is a comprehensive discipline, combined with geography, cartography, remote sensing and computer science, and is used for inputting, storing, querying, analyzing, and displaying geographic data in a computer system. Because of its strong advantage of visualization and spatial analysis, GIS has penetrated into every aspect of our lives since the 1960s when it was put forward for the first time.

Meanwhile, with the development of science and technology, open source has become one of the mainstreams of software development, GIS is no exception. Open GIS is a cross technology formed in the development of open source software and GIS. It uses pure open source libraries and methods to complete the traditional GIS functions. Compared with the traditional GIS software, open GIS has the following advantages: First, open GIS is free. So it will not take developers who develop softs based on open source software a lot on the software copyright license. Second, the source codes of open GIS are visible to all. This means that developers using open GIS in development work can change the basic code according to their actual need. Open GIS has been widely used in various fields since 1982 when GRASS, the first open GIS software, was released.[1]In 2009, Professor Chun Liu, master Qun Lu and Dr. Hangbin Wu designed a Traffic Analysis Software Based on Open Source GIS. [2] Shuyan Chen Master and Dr. Neng Chen developed Taining World Geopark Tourism information platform based on open webGIS at the same year.[3] In 2014, Dr. Wei Zhang and others built 2D visual geophysical information management based on open-source GIS platform.[4] Renhui Hao and Li Liu of Institute of Remote Sensing and Digtial Earth Chinese Academy of Sciences developed Monitoring and warning system for forest pest based on open source GIS.[5]Master Qiyang Liang and Professor Yan Zhang developed Kunming Tourism Geographic Information System Based on OpenGIS.[6] Xu Kan of National University of Defense Technology studied and designed situation chart based on uDig, one of the open GIS software.[7]

The research of GIS in the field of earthquake prevention and disaster reduction began in the United States, Japan and other developed countries. And GIS has been applied to the earthquake, hurricane and flood disaster fields.[8-10]GIS technology with its strong visualization, rich information resources is very suitable for the characteristics of the earthquake industry. Therefore, we introduce GIS into traditional industry of earthquakes the underlying platform. On this basis, we combine the professional knowledge of earthquake to develop the professional system for earthquake field. Not only are the satellite images resourcefully utilized to display the earthquake related information more vividly, but also it plays an important role in saving system development costs, shortening period of the development, popularizing earthquake professional knowledge, and improving work efficiency.

Open GIS has been used in earthquake industry at some fields. In 2012, Master Hao Zhu of China University of Petroleum analyzed Meteorological Disaster Risk Zoning supported by the open source GIS.[11] Jianxing Guo of Institute of Earthquake Science China Earthquake Administration developed Remote Sensing Data Dissemination System for Earthquake Emergency Based on OpenGIS and Digital Earth Platform together with others.[12] In 2014, Dr. Ya Ban developed earthquake emergency response system based on OpenGIS.[13]Being one of the important software, MapSIS, which are supported by MapInfo, a non-opensource GIS software, such as map display of earthquake catalogue, the spatial display of earthquake modulation ratio, B value and abnormal earthquake precursor observation data. In order to ensure the normal use of the software, earthquake industry need to pay for license every year, which brings great economic burden. For this reason, our project group decided to improve the Earthquake Analysis and Prediction System under the support of DotSpatial, an open source GIS software.

II. SELECTION OF OPEN GIS PLATFORM

GRASS, uDig and DotSpatial are the most commonly used openGIS software in C/S architecture. GRASS, originally developed by the US military, can provide a lot of analysis functions which are provided by ArcGIS and has been used by many government agencies, universities and companies. However, its interface is not friendly enough, a lot of functions can only be run by codes. It is not easy for users without professional knowledge. uDig is simple to operate, and supports a variety of spatial data sources, including many commercial space databases, but its analysis is relatively weak.

Compared with other openGIS software, DotSpatial has the following advantages:

DotSpatial with good structure, maintains a good independence between the different modules.

DotSpatial is powerful at symbolization and it has extended symbol set a lot, and can support font symbol which has been vectored.

Because all codes of DotSpatial are open source, developers can study and analysis of its underlying principle by studying the source code to improve the deficiencies or design more efficient GIS algorithm, which can better meet the actual needs by modifying the source code.

We decide to optimize Earthquake Analysis and Prediction System on DotSpatial due to the above reasons.

III. SYSTEM DESIGN

Three-tier architecture and MVC design pattern are used in the system design. Firstly, based on the precursor database, the system adopts indexing technology and stored procedure for database to realize the data synchronization and format conversion. Making open source GIS technology as the core, ECharts technology as a tool, ASP.Net as the development platform, the improved system realizes the functions including basic control function of map(zoom in, zoom out and map moving), spatial processing and analyzing (buffer analysis, overlay analysis, spatial measurement),epicenter distribution map drawing, sequence diagram (M-T diagram, dT-t diagram, R-T diagram, D-T diagram, focal depth variation diagram) drawing, seismic cross-section image drawing, Dynamic demonstration of epicenter distribution, calculation and display of focal mechanism solution, sequential scan processing, spatial scan processing, profile scanning processing and the daily data processing functions of deformation, electromagnetic, fluid and other disciplines.

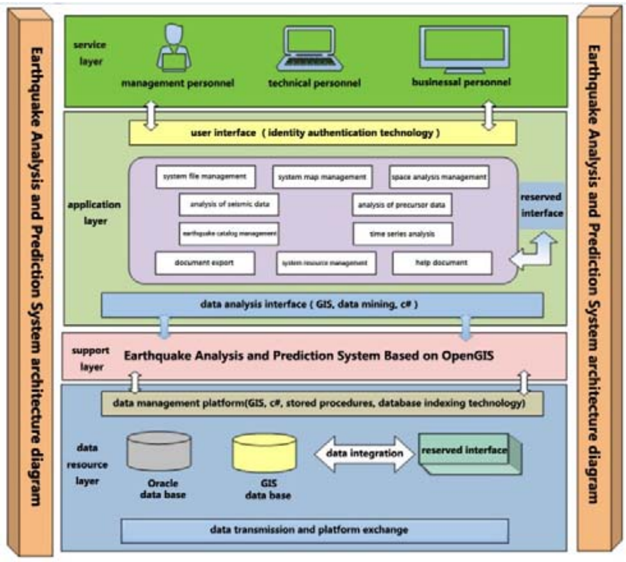

Figure 1. System Architecture Diagram

This paper mainly expounds the realization of the main functions based on GIS.

IV. MAP MANAGEMENT

Map management is the basic function of GIS software. If a system based on ArcGIS or MapInfo and other non-open source software, it mostly uses the component of the form and the packaged class libraries. As a result, the developers' understanding of the underlying support for the system will not be deep enough. Based on the above reasons, our project group did research on open source DotSpatial deeply. We add the property view and layer management functions to the algorithm besides its own layer editing function. Compared with the original system, MapSIS, the optimized system has reached the requirements of the application.

A. Property Viewing

During the work of seismic analysis forecasting, users often need to view the attribute information of a certain place. Seismic workers may need to know the basic information of a certain area on the administrative division layer and the fracture zone information of the same place on the fracture zone layer at the same time, for example. However, although containing property-viewing function, MapSIS uses a built-in fixed module to show the fixed information. And is not flexible enough. The property-viewing function in FeatureLayer class of Dotspatial.Symbology class library is optimized at the new system, based on the above requirements. The original property-viewing function of DotSpatialonly allows users to view the attribute information of one layer

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each time. So Select () and SelectByAttribute () are overloaded at our system to improve work efficiency and enhance the flexibility of the system by allowing users viewing properties of multiple layers at the same time.

The body of Select():

```
IFeatureSelection sel = _selection as IFeatureSelection;

for (int i = 0; i < DataSet.Features.Count;i++ ){

  sel.Add(DataSet.Features[i]);}
```

The body of SelectByAttribute():

```
List<int> newSelection = DataSet.SelectIndexByAttribute();

List<int> cond = new List<int>();

cond.AddRange(fs.Select(feature=>DataSet.Features.IndexOf(feature)));

IEnumerable<int> result = cond.Intersect(newSelection);

Select(result);
```

After function overloading, the attribute information of all layers about the selected place will be displayed at the results window in tabular form. Here is an example：

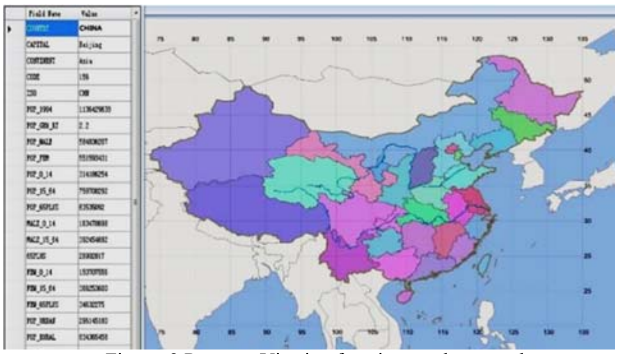

Figure. 2 Property Viewing function result screenshot.

B. Layer Management

Layer management is one of the basic functions of GIS software. DotSpatial comes with a Legend control that supports function of opening workspace, creating new layers, adding layers, and layer editing. However, in practical application, batch-processing layers can greatly improve the efficiency of user while the MapSIS does not support this function. In the optimized system, we optimize DotSpatial.Controls.Map class and add function CloseAllLayers() to achieve batch closing layers to meet the needs of the project.

Here is the main part of the CloseAllLayers() function:

```
List<ILayer> _layers = MapFrame.GetAllLayers();

if (_layers == null) return;

int _layersCount = _layers.Count;

for (int i = 0; i < _layersCount; i++) {

  IMapGroup _layerParent = (IMapGroup)_layers[i].GetParentItem();

  _layerParent.Remove(_layers[i]);

}
```

V. ANALYSIS OF EARTHQUAKE CATALOGUE

Earthquake catalogue which records the time of earthquake occurrence, the location of the epicenter, the depth of the source, magnitude and epicenter intensity and other information is the basic data of earthquake research and earthquake tendency prediction. According to the location of the epicenter, the historical earthquake can be displayed on the map in accordance with the magnitude of the earthquake, to express the earthquake information intuitively and to make it easier for the earthquake workers to study. In MapSIS, earthquakes are displayed as different size and color according to earthquake magnitude. Based on DotSpatial, our earthquake analysis and prediction system realize this function by automatically creating an earthquake catalogue point map layer, on which earthquakes are expressed as circles in different sizes. In addition, the statistical result of earthquakes of each levels can be displayed in the pop-up window of the lower-right corner of system at the same time. The staff can choose whether to export the layer or not.

When performing this function, the system first use FileReader () function to deal with the selected earthquake catalog file, and the data is converted to the EQ Form a object group, which will be introduced into the EQstatistics () function for the statistics of the earthquake catalog, and be introduced into AddPointsLayer () function to generate a new point layer.

AddPointsLayer is realized on a base of FeatureSet class,IMapFeatureLayer and IMap class of the DotSpatial software , the main steps are as follows:

Build a new FeatureSet object, myPoints and set its type as point type;

Build a new IMapFeatureLayer object, pointLayer;

Read the object's longitude, latitude and magnitude properties of the EQForma to MyPoints through the loop;

Call Layers.Add method to pass myPoints to pointLayer, and set the myScheme property of object through grading result of magnitude (Used to set the size and shape of each point when the layer is displayed);

Load layer to display in the system;

We use China's earthquake catalogue in 2014to test the system before and after optimization. The following table is the result of our test.

TABLE1. COMPARISON OF FUNCTIONAL EFFICIENCY

Software	Size of directory file	Number of records	Time of system call	Have statistical result
Optimized system	98KB	2493	2.13s	yes
MapSIS	98KB	2493	2.13s	no

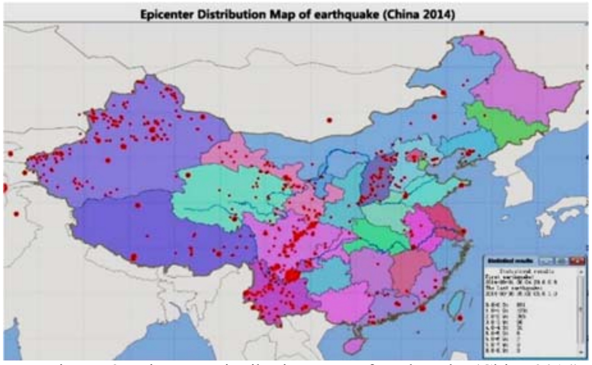

Figure. 3 Epicenter Distribution Map of earthquake (China 2014)

VI. CALCULATION AND DEMONETRATION OF SMALL EARTHQUAKE MODULATION RATIO

The method small earthquake modulation ratio is a kind of earthquake prediction method to detect the risk area of strong earthquake by using the small earthquake activity induced by the periodic action of the solid tide on the earth's crust. In 1983, researcher Baoyan Qin made a more detailed definition: take two interval period of 1st,2nd, 29th and 30th each mouth of lunar calendar and 15th, 16th,17th of full moon, statistic the number of small modulated earthquakes happening in these eight days and the total number of small earthquakes in the whole mouth.[14]The number of modulated small earthquake is m, the total earthquake number is N, and the modulation ratio

Before the earthquake, hypocentral region and the surrounding stress level are very high, and the modulation effect of solid tide is enhanced. As a result, the number of small earthquakes in the total number of earthquakes is increased during the period of the solid tide. If the earthquake is considered as an equal probability event, the earthquake occurrence probability P during higher earth tides of each mouth is

$$p = \frac{\text{new moon period} + \text{full moon period}}{\text{lunar month}} = \frac{4+4}{29.5} = 0.27$$

The natural probability of occurrence of earthquake in the high period of the solid tide under the normal condition is P=0.27.If Rm > P, it should be considered to have reached an exception indicator. Considering the natural probability has slight fluctuation around 0.27and combining with the earthquake experience, the lower limit of the anomaly value P1 can be set at 0.33, which can be combined with the local actual situation. If R + > P1, the anomalous ratio of small earthquakes modulation during that period can be identified and anomalous initial time is started from RM > 0.27. [15]

The specific implementation of the function is as flowers:

Create DivideMapGrid object, divide the grid according to the input parameters, and calculate the center point of the grid;

Read the earthquake catalog, and screen the directory through the DirectorySelection() function;

Calculate the small earthquake modulation ratio by calling GetRM() function;

Call the DrawSpacescan() function to display the results on the map;

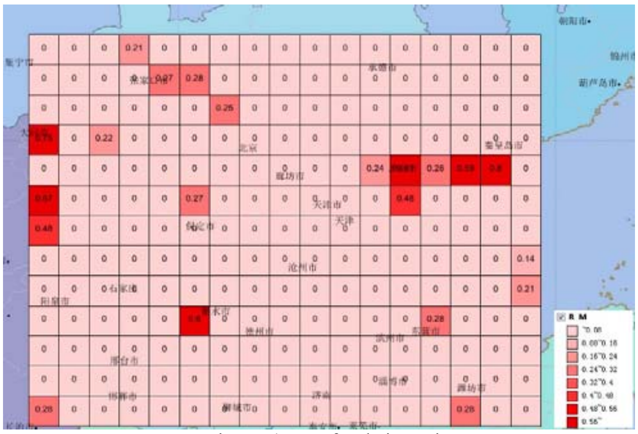
Figure. 4 Rm of Hebei Province

The following table is the running comparison which we test this function in the system before and after optimization.

TABLE2. COMPARISON OF FUNCTIONAL EFFICIENCY

Software	Range of Latitude and Longitude	Size of directory file	Number of records	Time of system call
Optimized system	Longitude：97.5-106.1 Latitude：21-29.1	45.4MB	423003	48.05s
MapSIS	Longitude：97.5-106.1 Latitude：21-29.1	45.4MB	423003	48.05s

After testing, the optimized system can meet the needs of earthquake workers.

VII. CALCULATION AND DISPLAY OF B VALUE

According to the statistics of the number of earthquakes of magnitude 6 or more in the world's major earthquakes region when Gutenberg and Richter research the earthquake activity in the world, they find that the magnitude and frequency of earthquake have the following relations:

This is the famous G-R relation. A and B of the formula can be get by statistical estimation of the earthquake catalogue of a certain area and a certain period. And b reflects the ratio of the big earthquakes and small earthquakes. According to the statistical analysis, Gutenberg believed that different region have different b value, and b value is different for shallow source and deep source earthquake. Later researchers also found that the b value varied along with the change of space and time. People's extensive and deep research on b value, especially after the earthquake in Tangshan, 1976, found that the b value exist significant abnormal in time and space before the earthquake.

Earthquake analysis and prediction system uses grid method to divide the study area into a number of regions and calculates the b value for each area respectively then display them on map by different colors. Earthquake researchers can determine the abnormal region directly with the help of this map. The realization of this function is as follows:

At first, we create a DivideMapGrid object, divide the grid according to the input parameters and calculate the center point of the grid;

Then, read the earthquake catalog, and screen the directory by DirectorySelection() function;

After this, we call the GetB() function to calculate the value of B;

At last, we call the DrawSpacescan() function to display the results on the map.

The following table is the operation contrast of this function that we test by MapSIS and the optimized system.

TABLE3. COMPARISON OF FUNCTIONAL EFFICIENCY

Software	Range of Latitude and Longitude	Size of directory file	Number of records	Time of system call
Optimized system	Longitude：97.5-106.1 Latitude：21-29.1	45.4MB	423003	35.82s
MapSIS	Longitude：97.5-106.1 Latitude：21-29.1	45.4MB	423003	35.4s

The optimized system can meet the needs of earthquake workers.

VIII. THE ABNORMAL OF PRECURSORY DATA

Being an important work of earthquake analysis and prediction department, abnormal earthquake precursor observation data is the basic parameter used to judge whether the earthquake will happen or not when doing earthquake consultation. However, the thresholds for the "exception" decision are different when observation conditions and types of data are different because of the huge amount and various types of data. In order to ensure the applicability of the abnormal data detection method for various types of data, the system optimize the method to judge the abnormality of data On the basis of the method of anomaly data mining based on pattern anomaly that proposed by Congcong Zhang and Xiuying Wang researcher in the Institute of crustal stress of China Earthquake Administration.[16]

The processing flow of the method is shows as follows:

(1)At first, we need to determine the data segmentation point and divide the original sequence. We get the data sequence segmentation point by the time series linear segmentation algorithm based on sequence important points.

(2)Then we model each sequence, determined in step 1. Length, range, mean value and standard deviation are chosen as 4 characteristic values to model each subsequence.

(3)In the end, we use anomaly detection methods to identify abnormal patterns. The degree of difference between the model and other modes is measured by using the local outlier factor based on density.

After determining the exception, we need to import the exception data into the exception library, and then display the data points on the map according to demand. There is an example:

The main processes of the map display are as follows:

Read the judgment results of abnormal earthquake precursor observation data. Store them into preExterOnMapList object after removing duplicate items;

Call AddAbnormalPointsLayer() method to create a new abnormal point layer.

IX. CONCLUSIONS

In this paper, the open source GIS software is applied in the field of earthquake analysis and prediction. By comparing the optimized Earthquake Analysis Prediction System with MapSIS, we can know that the modified system can satisfactorily realize all functions of the original system at the functions such as the map display of earthquake catalogue, the spatial display of earthquake modulation ratio, B value and abnormal earthquake precursor observation data. We also added some map management functions, such as batch shutdown layers and attribute view to comply with the needs of earthquake workers more accurately. At present, there are still some deficiencies in the optimized system. The extraction efficiency of earthquake precursor anomaly algorithm is not high enough, and other functions of the software are not perfect enough. In further research, we will continue to improve and optimize the system. Finally, the realization of this system provides a reference for the introduction of the open source GIS into the earthquake industry in the future.

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