Visualization of Seismic-center Distribution Data for Earthquake Prediction

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Abstract The Japan Meteorological Agency presents a unified data set of seismic-center distribution in the web, such as three dimensional position, magnitude and time in which the earthquake occurred. It is useful for grasping the global feature of the distribution and analyzing earthquake phenomena. About three hundred earthquakes per day occur on average, including small ones. To display those large number of seismic sources , we investigates the comfortableness of stereo display for distributed points. Effective ways to display feature quantities of the seismic-center distribution are also examined.

Keyword Earthquake, Analysis, 3D display, Visualization, Distribution data

1 Introduction

Recently, there is a greater concern of earthquake disaster prevention, because the possibility of a big earthquake such as in the Tokai region or the Nankai region occurring increases every day. About three hundred earthquakes occur per day on average , including small ones. The prediction of earthquakes and accurate estimations of the damage they will carry is necessary in order to save lives from these natural disasters. Enormous quantities of various kinds of data, not only seismic data but also diastrophism and subsurface structure, are used in order to investigate the mechanisms of an earthquake and its simulation. For that reason, technology which can visualize and analyze large-scale data is needed[1]. For example, the state of active faults can be investigated by grasping the seismic distribution, in which serious damage is predicted by boring machine use.

The Japan Meteorological Agency opened seismic data to the public a few years ago, which can be downloaded by internet, including some kinds of seismic features such as the place of the seismic source (hypocenter), time, and earthquake magnitude [2]. Especially, grasping the global state of the hypocenter distribution in three-dimensional display is important for analyzing earthquake phenomena.

At present, two-dimensional distribution maps are widely used by seismic specialists, which can only express two-dimensional distribution in cross-sections of the earth ground[3][4]. The distribution in three-dimensional display is not easily understood, because the hypocenter distribution is fundamentally expressed by a large number of dots with little relation to each other. There have been some projects to visualize three-dimensional seismic distribution. For example, reference [5] has rendered rough structure distribution in curved surfaces. Also, stereoscopic display of dots have been used in the field of random dot stereogram. There, dots are placed only on the surface of the object, because it is used for stereoscopically recognizing three-dimensional shapes through a pair of random dot images.[6] Therefore, these conventional methods are not applicable to our purpose.

The sequence time analysis of earthquake data is one of the approaches effective in forecasting a massive earthquake and seismic activity[7]. It is difficult to understand the sequence time analysis only using numerical results. We also propose a method to use three-dimensional correlation graph for visualizing implicit features. The three-dimensional correlation graph is one of the most effective ways in finding similar patterns or periodicity in sequence time analysis. It is used for predicting and identifying complex features, including a chaos phenomenon.

2. A 3D Display System of Earthquake Data

This chapter describes a three-dimensional display system for earthquake data analysis, which visualizes the hypocenter distribution, time-space distribution and three-dimensional correlation graph for the time sequence analysis (Fig.1).

2.1 Earthquake data

The Japan Meteorological Agency (JMA) opened an earthquake catalog to the public [2]. It covers a large number of earthquakes that occurred from 1923 till now. The JMA catalog records the following attributed data of individual earthquakes: origin time, hypocenter (latitude, longitude, depth), magnitude and so on.

2.2 3-D hypocenter distribution

Hypocenters are expressed by points or spheres and arranged in 3-D virtual space. The size of a sphere corresponds to its magnitude. The system colors each hypocenter based on its attributions: region to which it belongs, origin time or magnitude. Users can select one attribution. The feature of the hypocenter distribution can be analyzed from various viewpoints.

Figure 2(a) and (b) shows distribution of hypocenters

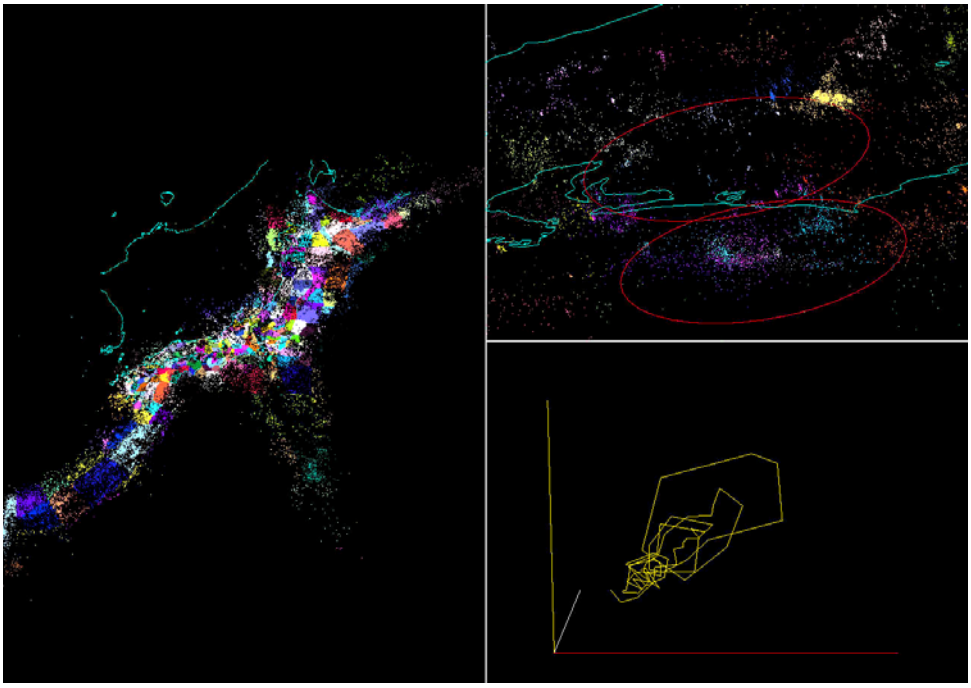

Fig. 1 3D display system of earthquake data. hypocenter distribution (the right-upper window) and correlation graph (the right-bottom window).

which occurred in 2004. Shallow hypocenters are colored in red and deep hypocenters are colored in blue. We can see there are many hypocenters on the oceanic plate.

Our system has a stereoscopic display function[8]. Figure 3 shows a stereoscopic display of hypocenter distribution for the 2004 Niigata Chuetsu Earthquake (M6.8) and its aftershock activity.

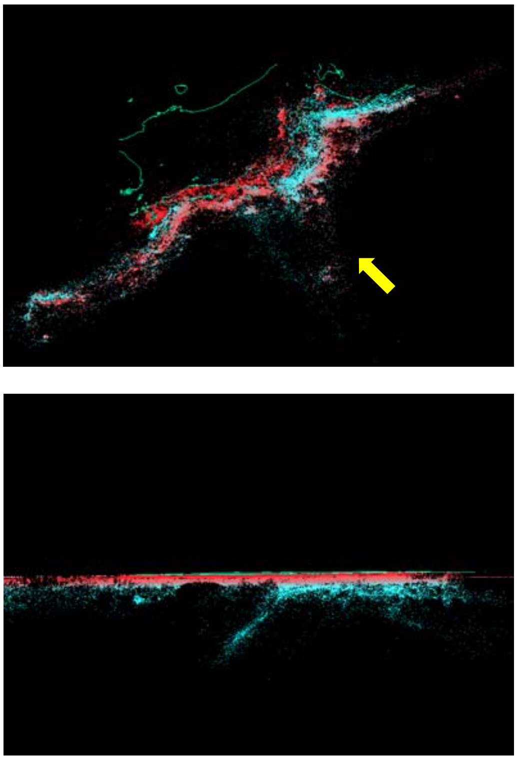

Fig. 2 Hypocenter distribution. (a) a scene from the upper side, (b) a scene from the vertical direction.

2.3 3-D Time-space distribution

Time-space distribution analysis is one of the important processes for grasping the feature of seismic activity[9]. Our system visualize three-dimensional time-space distribution by using 3 attributions, latitude, longitude and origin time. Figure 4 shows a time-space distribution for the Niigata Chuetsu Earthquake and its aftershock activity. The 2 red lines represent latitude axis and longitude axis. The yellow line represents the time axis. Each dot is a hypocenter.

2.4 3-D correlation graph for the time sequence analysis

Our system displays three-dimensional correlation graph as a tool for the time sequence analysis. In the following, the procedure for rendering the graph is described.

To obtain the graph, the embedding operation is done. The embedding operation is to generate m-dimensional points V(i)= (Ci, Ci+s, Ci+2s, …, Ci+(m-1)s) from a time series, C0, C1, …, Cn, where m is the embedding dimension and s is the delay time. The locus of V(i) obtained by increasing one by one i is called an embedded curve, which has the following

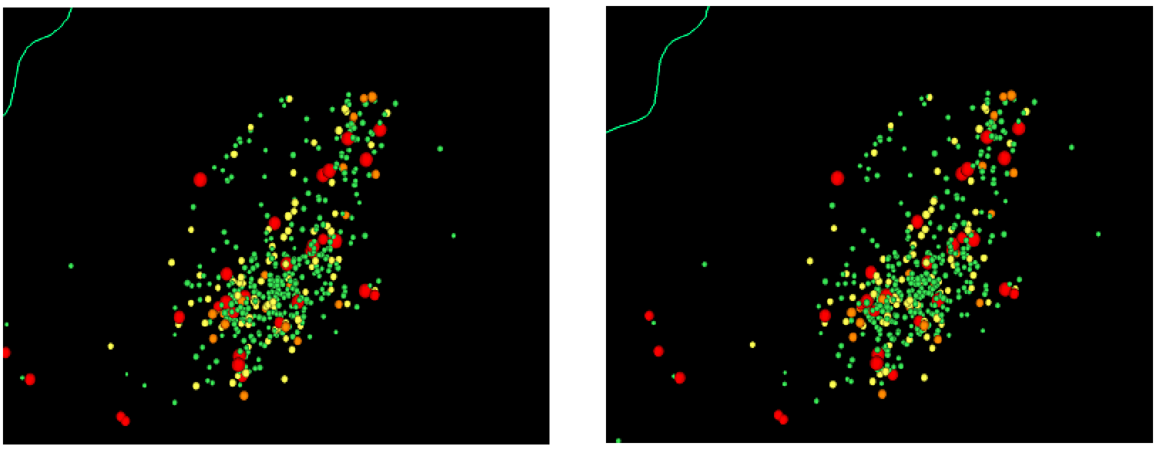

Fig. 3 A stereoscope display of hypocenter distribution.

features.[10][11]

1) It goes in a certain limited space regardless of the length of the time series.

2) The same pattern of the time series is embedded in the same curve.

3) The similarity of the time series can be evaluated by using the distance in the embedding space.

The embedding operation is an effective way of grasping features in the time-series, discovering similar patterns and periodicity and so on. Our system assumes m=3, generates the curves V(i)=(Ci, Ci+s, Ci+2s) in the three-dimensional space. The delay time s can be arbitrarily set on the system. We call the curve three-dimension correlation graph.

Our system can visualize various kinds of time series. The right-bottom image of Figure 1 is an example of three-dimensional correlation graphs. The curve is obtained from the time series of earthquake occurrence frequency for hypocenters, within the range user specified (see the right-upper image of Fig 1). Figure 5 shows a graph for the Niigata Chuetsu Earthquake and its aftershock activity.

3 Experiments for stereoscopic dots recognition

In this section, some experimental results of stereoscopic visibility of distributed dots are presented, for stereoscopically recognizing hypocenter distribution. Although lots of research is reported in the field of stereoscopy, including the depth distance perception, stereoscopic visibility in recognizing objects, consisting of a large number of dots and various shapes, has not been investigated.

Fundamentally, a large number of independent dots in the three-dimensional space aren't easily recognized, because it is difficult matching dots between the left and right view, in the stereoscopic display. To improve this difficulty, we added some visual attributions to the dots, such as giving variation in size of color to dots, adding some geometric objects to assist stereopsis and applying depth-cueing in the rendering process. In the following experiments, we used liquid crystal shutter glasses Crystal Eyes for stereoscopic display.

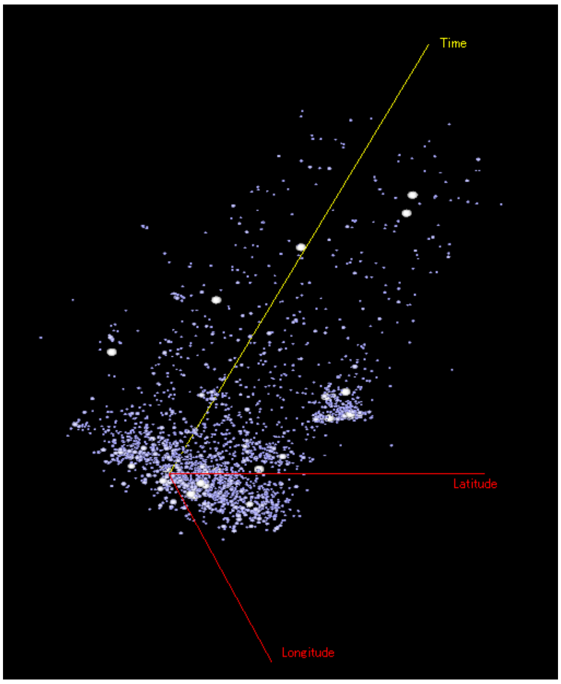

Fig. 4 Time-space distribution.

Fig. 5 3D correlation graph for the sequence time analsys.

3.1 Effects for easy stereopsis

In the preliminary stage, we did some experiments on artificially generated random dots. We supposed the following effects to facilitate dots stereopsis.

a) Coloring dots with random colors.

b) Placing an additional line in the space.

c) Replacing dots with variable sizes of spheres.

d) Applying depth-cuing in the rendering process.

Effects a), c) and d) are aimed to make distinction among dots easy. In b), the additional line works as an index in the human's stereopsis processes.

3.2 Random dot Experiment 1

The above effects, in each case are evaluated by measuring and comparing time until stereoscopic display is recognized. The first, following three cases are examined for seven subjects.

C1. Coloring dots with a single color.

C2. Coloring dots with random colors.

C3. Adding a vertical line in the center of the view.

Results of Table 1 show both C2 and C3 are effective. These effects are reasonable, because seismic sources have some attributes such as time and magnitude, coast lines of Japan islands are often drawn by them. C3 significantly improved the stereopsis. Therefore, C3 is applied in the experiments of the following section 3.3

Table 1 Results of measuring time for stereopsis. (sec.)

subject / case	A	B	C	D	E	F	G	ave
C1	18	7	46	12	38	37	12	24
C2	6	5	13	6	23	29	12	13
C3	4	4	17	8	17	19	8	11
C4	3	8	6	8	4	15	10	7
C5	6	7	3	5	4	9	9	6
C6	13	2	6	21	11	20	6	11
C7	5	5	2	6	6	14	3	6

3.3 Random dot Experiment 2

The following conditions C4 and C5 are examined.

C4. Replacing dots with variable sizes of spheres.

C5. Applying depth-cueing in the rendering process.

These effects also showed effectiveness. Compare the results of C4 and C5 with C3 in Table1.

3.4 Experiment of hypocenter distribution stereopsis

Based on the above experimental results, the following two cases are compared.

C6. Hypocenters are drawn as a single color dot.

C7. Hypocenters are drawn as spheres which have individual color and size according to magnitude value.

In C7, the radius of spheres change in proportion to magnitude value, and the color changes from green to red as magnitude value increases. Also, Depth-cueing is applied in the rendering process.

As a result, the recognition time is reduced into half by adding some attributes. Compare the results between C6 and C7 in Table1.

As shown in Fig.6, three major clusters appear in the hypocenter distribution of the 2004 Niigata Chuetsu

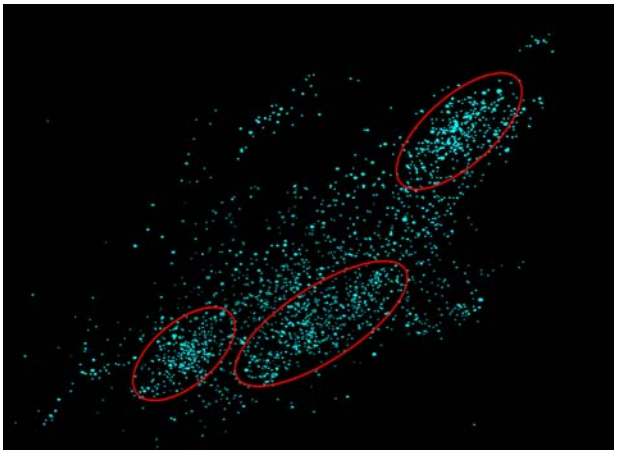

Fig.6 Three major clusters appear in the hypocenter distribution of the 2004 Niigata Chuetsu Earthquake.

Earthquake. They can be recognized only by succeeding stereoscopic display.

4 Conclusions

In this paper, we proposed a three-dimensional display system of seismic data. Effectiveness of adding some attributes were evaluated in the stereoscopic display consisting of independent dots.

As for future work, our system will be customized according to specialist's demands, for example, the function to analyze even more kinds of time sequence data or earthquake waves visualization.

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