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Immersive Visual Data Mining Based on Super High Definition Image

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1. Introduction

In recent years, a large amount of data has been generated and recorded in various fields according to the advances of computer simulation, sensor network, and database technologies. However, it is generally difficult to find valuable information or knowledge from the huge data. Therefore, the establishment of a methodology to utilize these data effectively is an important issue. Though data mining is one of the methods to solve such a problem, it is difficult for the user to understand the process of mining data and to evaluate the result intuitively, because the data is processed in the computer (Kantardzie, 2002). On the other hand, the visualization technique can be used effectively to represent the data so that the user can understand it intuitively. This study focuses on the method of visual data mining in which the user performs the data mining by visualizing the data (Wong, 1999) (Keim, 2002).

In the visual data mining, the user can analyze the data interactively with the computer by visualizing the process and the result of the data mining. Then, it is expected that a new information or knowledge can be found by combining the ability of high-speed calculation of the computer with the human's ability such as intuition, common sense and creativity. Particularly, this study aims at improving the effect of visual data mining by enhancing the ability of expressing data and interaction function by using the immersive virtual environment based on super high-definition stereo images. In this system, it is expected that the user can perform accurate and intuitive data mining by using the high resolution stereo images.

This paper discusses the system architecture and the visualization ability of the super high-definition immersive visual data mining environment that was developed in this study, and the effectiveness of this method is evaluated by applying the platform of super high-definition immersive visual data mining to the seismic data analysis.

2. Concept of super high-definition immersive visual data mining

Visual data mining supports the user to analyze a large amount of data and to find new information by combining the abilities of computer and human. The computer has large memory and high speed calculation capability. On the other hand, the human is superior in intuition, commonsense and creativity based on the visual information. By combining the

information processes performed by computer and human, a large amount of data could be analyzed effectively to find new information.

In the researches by Wong (Wong, 1999) or Keim et al. (Keim, 2002), data mining is effectively performed in the visualization environment. In these cases, visualization technology is used to transmit the information from the computer to the human and interactive interface technology is used to support the collaboration between human and computer. If the expression abilities of information visualization and the interaction function between human and computer were increased, the performance of visual data mining would be improved based on the improvement of information processing in both human and computer.

As for the increase of the expression ability in the information visualization, super high-definition image would enable the transmission of the detailed information from the computer to the human, and three-dimensional stereo image would be used effectively to represent the relationship among several kinds of data in the three-dimensional space. In the researches by Renambot (Renambot, 2006), high-resolution image is effectively used in the data visualization. And as for the interaction between human and computer, immersive virtual environment would be used to enable the user to operate the visualized data directly and to explore data space as first person experience. Ammoura (Ammoura, 2001), Wegman (Wegman, 2002) and Ferey (Ferey, 2005) discuss the effectiveness of immersive virtual environment in visual data mining.

In this study, super high-definition immersive visual data mining environment was constructed to utilize the effect of advanced visualization and interaction technologies. Figure 1 shows the concept of super high-definition immersive visual data mining that is proposed in this study. In this figure, it is shown that the performance of visual data mining can greatly be improved by increasing the expression ability and the interaction function between computer and human.

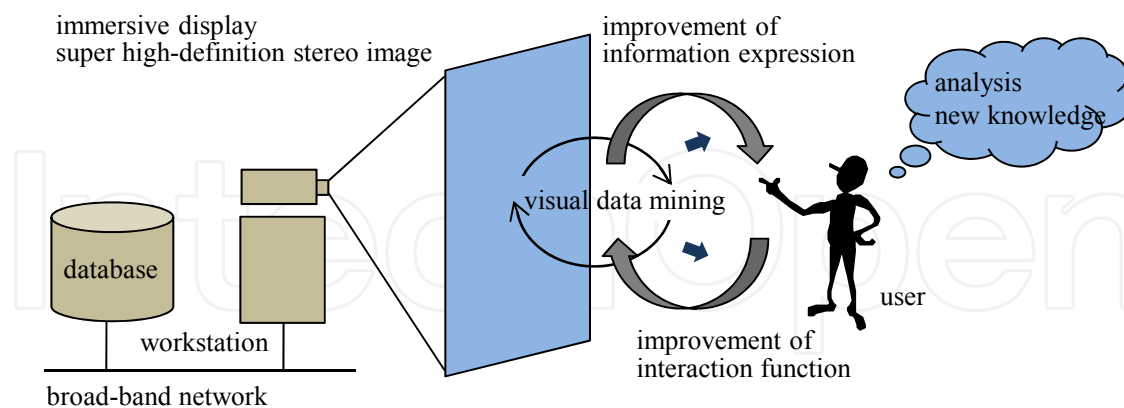


Fig. 1. Concept of super high-definition immersive visual data mining.

3. Immersive visual data mining environment

3.1 4K stereo image

In this study, immersive visual data mining environment using 4K stereo projection system was constructed as shown in figure 2 (Ogi, 2008). 4K means super high resolution image of

4,096 × 2,160 pixels, and its image quality is more than four times of the usual high-definition image. In this system, two stacked projectors (SONY SRX-S110) are used, and the images seen from the right eye and left eye positions of the user are projected. The images output from the projectors are rear projected onto the 180-inch acrylic rear projection screen (Nippura, Blue Ocean Screen) through the polarizing filter. In this condition, 1 pixel in the projected image has approximately 0.97 mm width on the screen. Then, the user can see the high resolution passive stereo image based on the binocular parallax by wearing the polarized 3D glasses. In this system, since two 108-inch LCD monitors are placed at both sides of the 4K screen, various kinds of information can be displayed in the multi-display environment. Figure 3 shows the system configuration of the super high-definition immersive visual data mining environment.



Fig. 2. Super high-definition immersive visual data mining environment.

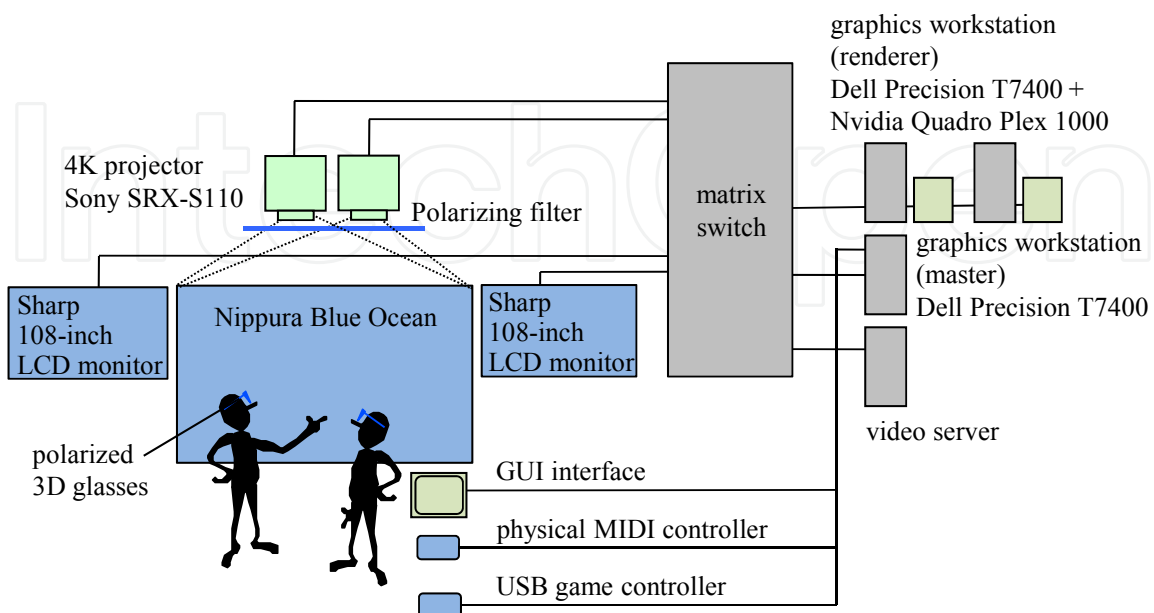


Fig. 3. System configuration of immersive visual data mining environment.

In order to generate and render the 4K stereo image, two high-end graphics workstations (Dell Precision T7400, 2xQuad Core Xeon 3.2GHz) with the graphics engine (NVIDIA Quadro Plex 1000 Model IV) that has a genlock function are used for right eye image and the left eye image, respectively. In this system, interface devices such as a USB game controller and a physical MIDI controller are connected to the graphics workstation. The USB game controller is used to walk through the visualized data space or to change the visualization method. On the other hand, the physical MIDI controller is used to change the visualization parameter minutely. By using these interface devices, the user can perform accurate and intuitive interaction with the visualized data, and the immersive visual data mining using 4K resolution stereo image can be realized.

3.2 Software structure

Figure 4 shows the software structure of the immersive visual data mining environment. As for the software library to develop the visual data mining application in the immersive virtual environment, Open CABIN Library was used (Tateyama, 2008). Open CABIN Library is a software platform to develop the immersive virtual reality application. This library has features of master-renderer programming and plug-in mechanism.

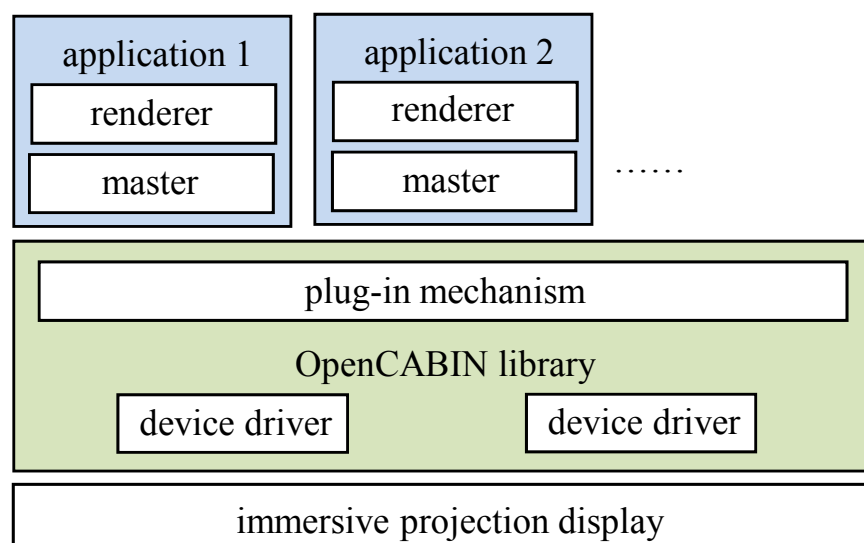


Fig. 4. Software structure of immersive visual data mining application.

The master-renderer programming is a style that constructs an application program consisting of a master part that calculates the state of the virtual world and renderer parts that render the image of the virtual world. This software configuration is effective to construct the network application that needs to access to the database or needs to transmit data to other system through the network, because master process has only to communicate with the remote processes.

On the other hand, the plug-in mechanism is a method to construct an application program in the form of dynamically loaded library. When API of the usual library is used, it is necessary to rewrite the source code of the program to add a certain function to improve it. For example, in order to construct an application program that visualizes several kinds of data simultaneously, the integrated visualization program must be developed specially

besides the visualization program for each data. However, the plug-in mechanism can add a visualization function for necessary data to the application program that is being executed. Namely, the integrated visualization environment for several kinds of data can be constructed, by executing several visualization programs for each data simultaneously by using the plug-in mechanism.

4. Data representation ability of 4K stereo image

In the data visualization using the 4K image, detailed information can be represented based on the high resolution image compared with the conventional visualization using the SXGA or WUXGA resolution image. Particularly, when the 4K stereo image is used, it is expected that the detailed three-dimensional information can be displayed with high accuracy in the three-dimensional virtual space. In this study, the representation ability of the 4K stereo image in the immersive visual data mining was examined.

4.1 Perception of spatial resolution

First, the spatial resolution with which the visualized data can be perceived in the three-dimensional space was experimentally measured. In this experiment, the subjects sat at a position 3m away from the screen, and two vertical parallel lines with the gaps of 0.5mm, 1mm, 2.5mm, 5mm, or 10mm were displayed randomly in the direction from the front to left as shown in figure 5. The subjects were asked to move the parallel lines in the depth direction and to stop them at the boundary position where they can recognize the displayed image as two lines by using the USB game controller. The boundary positions of the parallel lines with various gaps and in various directions were recorded.

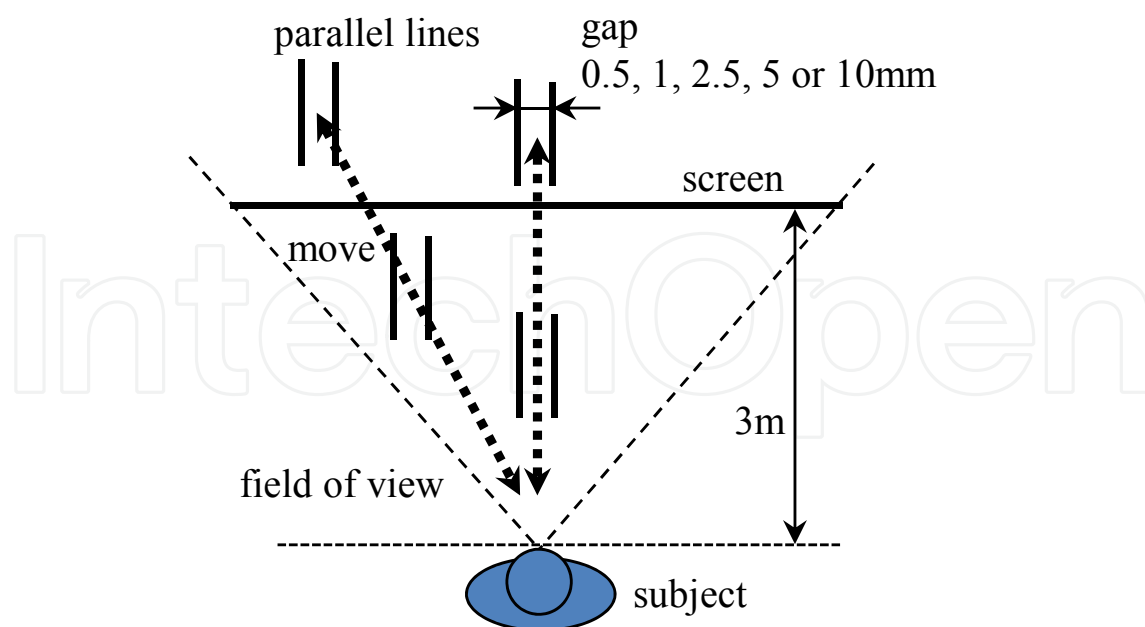


Fig. 5. Condition of experiment on the perception of spatial resolution.

Figure 6 shows the result of the experiment for five subjects with visual acuity of more than 1.0. In this graph, the contour lines are drawn by connecting the average values of the

boundary positions for each direction and for each gap of the parallel lines. From this graph, we can see that the subjects could recognize 0.5mm gaps between lines when the parallel lines were displayed at the distance of about 50cm, and they could recognize 10mm gaps between lines when they were displayed at the distance of about 10m. This recognition ability is equivalent to visual acuity of about 0.3, and it is a little bad compared with the visual acuity (more than 1.0) of the subjects. From this result, we can consider that the effect of stereo image caused the decrease of the visual acuity in the visualization environment. However, the resolution of the parallel lines recognition at near distance (0.5mm) was higher than the pixel width (0.97mm) of the projected image. We can consider that this result is also caused by the effect of high resolution stereo image.

Therefore, it is understood that the 4K stereo display can represent the detailed information with high accuracy, though the recognized spatial resolution of the displayed image depends on the distance and direction from the user. Namely, this means that the visual data mining using the super high-definition stereo image has an ability to transmit a large amount of information from the computer to the user with high accuracy.

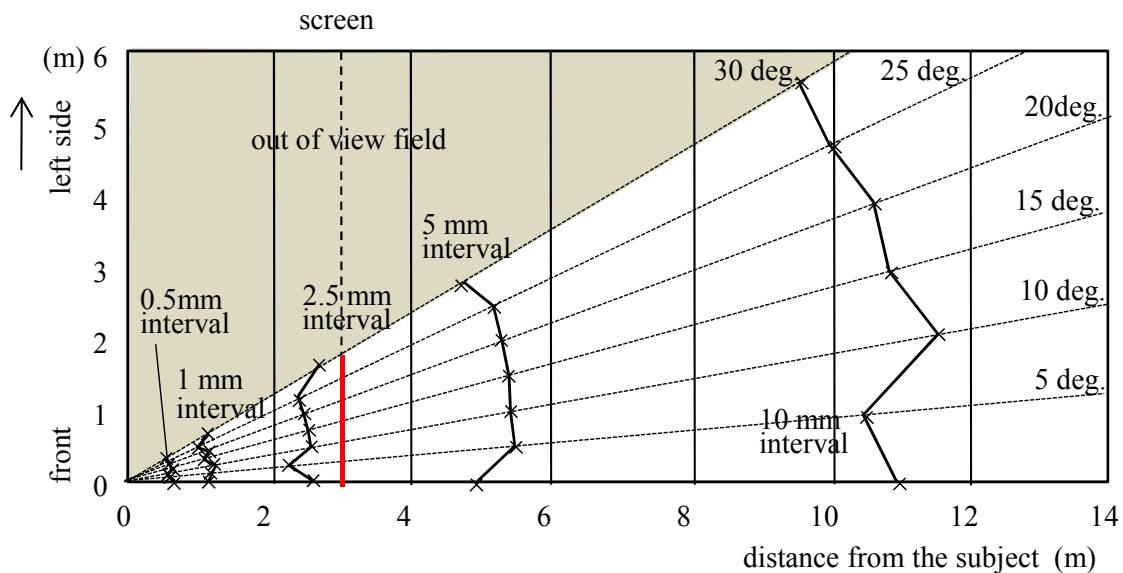


Fig. 6. Result of experiment on perception of spatial resolution.

4.2 Representation of point cloud data

Though this system can visualize detailed data with high accuracy using the super high-definition stereo image, it has a limitation in transmitting large amount of information from the computer to the user. Next, in this study, the ability of representing three-dimensional information in the visualization of large amount of point cloud data was experimentally examined.

In the experiment, the subjects stood at the position 3m away from the screen and the image of the colored point cloud that was distributed uniformly in the rectangular solid area was displayed. In this case, the number of point cloud data was changed up to 500,000 points, and the distance to the near side of the rectangular solid area was changed among 1m, 2m and 3m. In addition, the depth of the volume of the rectangular solid area was changed among 1.0m, 1.5m, 2.0m, and 2.5m, as shown in figure 7. Then, the subjects were asked to

evaluate the three-dimensional sensation that was felt from the displayed image using the three-grade system (2: clear three-dimensional sensation, 1: unclear three-dimensional sensation, 0: no three-dimensional sensation).

Figure 8 shows the result of this experiment for nine subjects. Each plotted point means average value of the evaluation for each depth condition and for each near distance condition. From the results, there was significant difference among the condition of the distance to the near side at 1% level, though there was no significant difference among the condition of the depth of volume. From the graph, we can see that the evaluation of the depth sensation felt by the subjects decreased according to the increase of the number of the displayed points. This means that the subjects could not recognize the three-dimensional scene from the left eye image and the right eye image when too many point clouds were displayed. Namely, the representation ability of the super high definition display for the three-dimensional point cloud image would decrease when a large amount of point data are displayed simultaneously. In addition, the ability of representing three-dimensional point

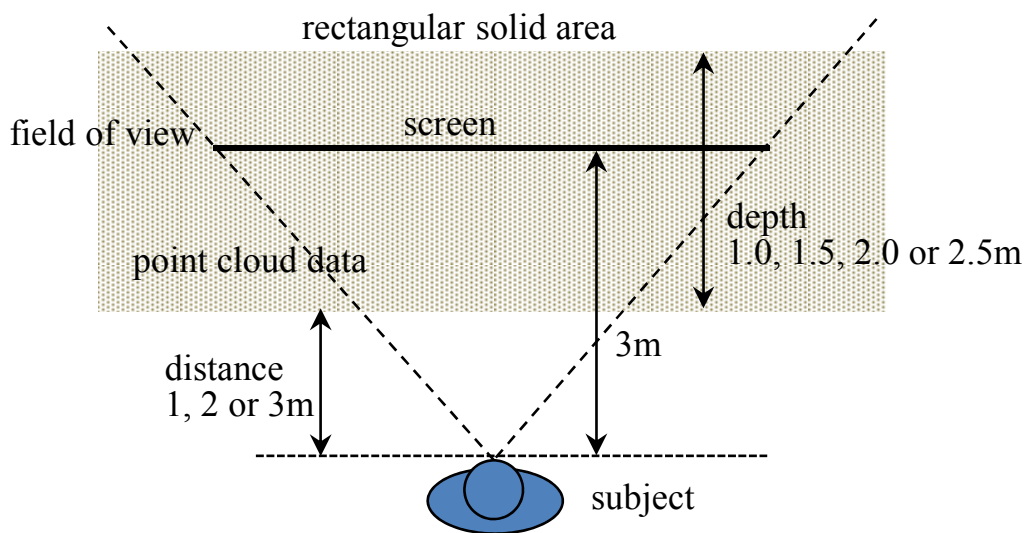


Fig. 7. Condition of experiment on representation of point cloud data.

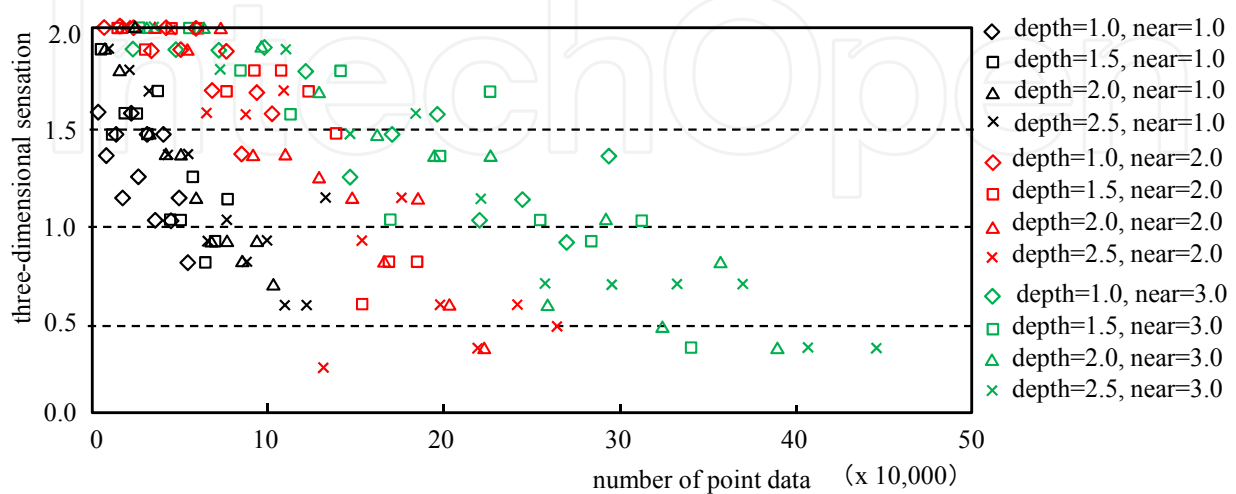


Fig. 8. Result of experiment on representation of point cloud data.

cloud image decreased steeply when the data were displayed near the subjects. We can consider that this is because the binocular parallax was large when the point image was displayed close to the subject in front of the screen. Therefore, we can understand that the control of the number of the visualized data is very important when a large amount of point cloud data are visualized.

5. Visual data mining platform

In general, effective visualization method used in visual data mining depends on the visualized data or the purpose of data analysis. In particular, in the early phase of the data mining, visualization method or visualization parameter are often changed in trials and errors. Therefore, the development of the platform of immersive visual data mining in which the user can easily analyze data by changing the visualization method or visualization parameter interactively is required. In this study, the platform of immersive visual data mining for the point cloud data was developed, because the super high-definition display can be used effectively to represent the point data.

5.1 Process of visual data mining

In the platform of immersive visual data mining, multi-dimensional data that is stored in the database table managed by RDBMS (relational database management system) can be visualized. This database table consists of ID field and eight floating point number fields (d_1, d_2, \dots, d_8). Then, data in various application fields can be visualized in the immersive visual data mining environment by storing them in the database table.

Figure 9 shows the data flow in the process of immersive visual data mining. In order to visualize the data in the three-dimensional space, several attributes such as the three-dimensional position, color, and filtering condition should be specified. In this system, five visualization parameters such as the position (X, Y, Z), color (C) and reference parameter for filtering (R) are made from the values in the floating point number fields of the database table, and the data is visualized based on the five parameters. Thus, the user can perform the visual data mining independently from the domain or type of the target data.

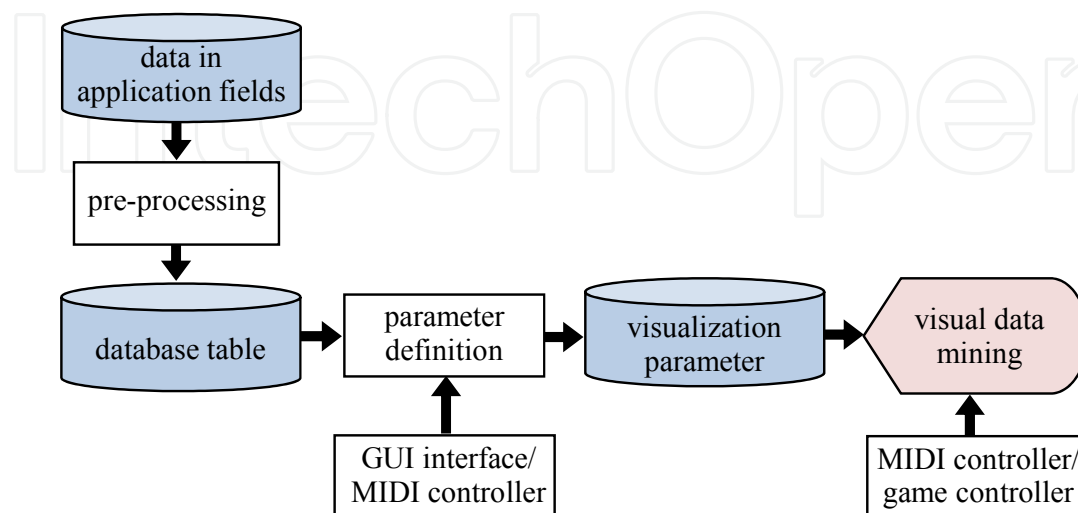


Fig. 9. Data flow of visual data mining in platform.

5.2 Interface

In the data visualization, it is important that the user can interact intuitively with the visualized data to recognize the phenomenon. In addition, in the visual data mining, it is also important that the user can operate the visualized data precisely. Therefore, in this system, GUI interface and physical USB controller are used to realize the intuitive and precise operation.

Fig. 10 shows the screen image of the GUI interface. The visualization parameters X, Y, Z, C, and R are defined using the linear equation,

$$X = a_{11}d_1 + a_{12}d_2 + a_{13}d_3 + a_{14}d_4 + a_{15}d_5 + a_{16}d_6 + a_{17}d_7 + a_{18}d_8$$

$$Y = a_{21}d_1 + a_{22}d_2 + a_{23}d_3 + a_{24}d_4 + a_{25}d_5 + a_{26}d_6 + a_{27}d_7 + a_{28}d_8$$

$$Z = a_{31}d_1 + a_{32}d_2 + a_{33}d_3 + a_{34}d_4 + a_{35}d_5 + a_{36}d_6 + a_{37}d_7 + a_{38}d_8$$

$$C = a_{41}d_1 + a_{42}d_2 + a_{43}d_3 + a_{44}d_4 + a_{45}d_5 + a_{46}d_6 + a_{47}d_7 + a_{48}d_8$$

$$R = a_{51}d_1 + a_{52}d_2 + a_{53}d_3 + a_{54}d_4 + a_{55}d_5 + a_{56}d_6 + a_{57}d_7 + a_{58}d_8$$

where d_1, \dots, d_8 are data values in the floating point number fields of the database table, and a_{11}, \dots, a_{58} are coefficients that are specified by the user. Each tab in the right side on the GUI screen corresponds to the visualization parameter, and the user can define these visualization parameters by moving the sliders to adjust the coefficients.

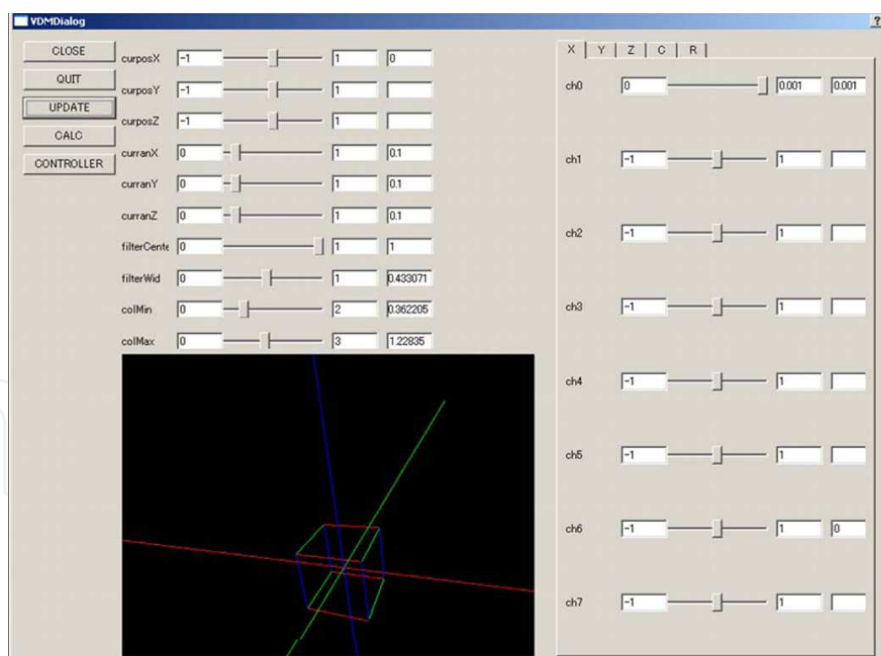


Fig. 10. GUI interface.

The data is displayed at the position specified by parameters of X, Y, Z. In this case, visualized data can be selected by specifying the rectangular region in the three-dimensional space. This area is defined by giving the center position of the rectangular region and the width along each axis using the sliders displayed on the left side of the GUI interface.

Point cloud data can be displayed in various colors according to the value of the color parameter C. In this system, the color of the displayed data is defined by specifying minimum value and maximum value of the color parameter using the sliders, and the value of the color parameter is mapped to the displayed color. In this case, when the color value is less than minimum value, the data is visualized with gray color, and when the color value exceeds the maximum value, the data is visualized with white color.

The displayed data can be filtered using the value of the reference parameter R. When the center value and the range are specified using the sliders on the left side of the GUI screen, the visualized data is filtered by comparing the value of reference parameter with the filtering range.

In addition, the view point for the visualization image in the three-dimensional space can be controlled by dragging the cursor in the lower left area of the GUI interface. This function supports the rotation of the view point around the arbitrary axis as well as the movement along the screen and perpendicular to the screen. Then, the user's view point can be controlled minutely using the GUI interface as well as the user can walk through the visualization space using the game controller.

Though the parameter values are controlled using the sliders on the GUI interface, these sliders are assigned to the MIDI control channels. Then, the parameter values can also be controlled by using the physical MIDI controller connected to the interface PC shown in Figure 11. Since the MIDI controller communicates with the interface PC using USB protocol, the control data are sent to the visual data mining system through the interface PC. Therefore, the user can control the plural parameter values interactively in the immersive virtual environment by operating the physical MIDI controller without looking at the console. Figure 12 shows that the user is operating the platform of immersive visual data mining using the GUI interface on the interface PC and the MIDI controller.

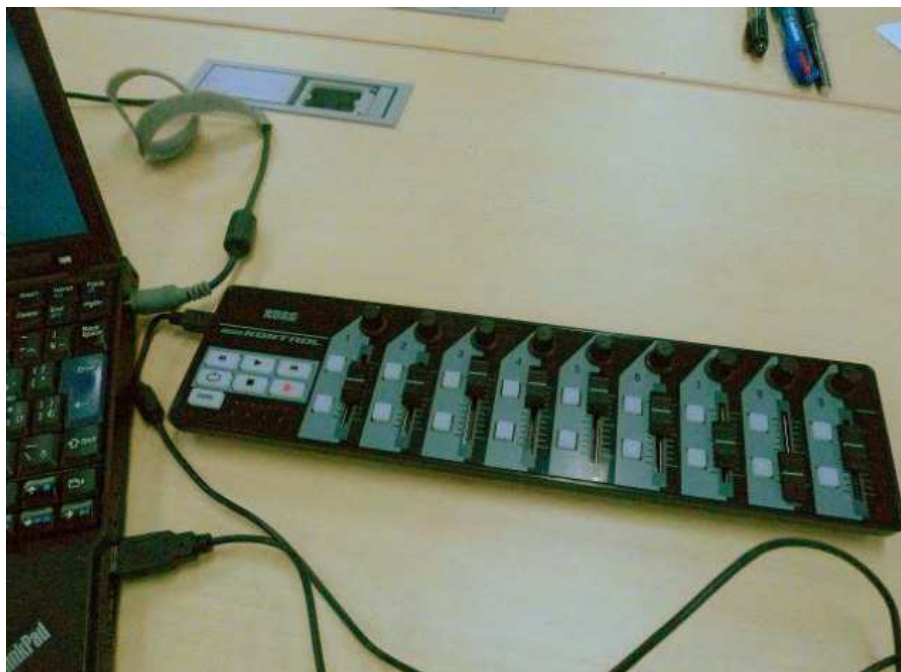


Fig. 11. Physical MIDI controller.



Fig. 12. Operation using GUI interface and physical MIDI controller.

6. Application to seismic data analysis

In this study, in order to evaluate the effectiveness of the developed system, the platform of immersive visual data mining was applied to the seismic data analysis. In Japan, a lot of earthquakes occur every year. Then, it is important to analyze large amount of past data to predict next earthquake and estimate damage (Furumura, 2005). Particularly, this problem has been very important after Great East Japan Earthquake on March 11, 2011. As original data for the immersive visual data mining, the seismic hypocenter data in last five years that is stored in Hi-net system (Okada, 2004) constructed by National Research Institute for Earth Science and Disaster Prevention was used.

6.1 Visualization of hypocenter data

In the visualization using the conventional two-dimensional display, it is difficult to observe both the individual location and the overall distribution of the hypocenter data and to understand the feature of three-dimensional distribution of the earthquake. Therefore, first, the seismic hypocenter data was visualized using the platform of representing point cloud data in the super high-definition immersive visual data mining environment. In this system, about 600,000 seismic hypocenter data with magnitude and occurrence time were stored in the database table and they were visualized as point clouds. From the hypocenter data, statistical data of b-value in Gutenberg-Richter (GR) relation were calculated. GR relation is a typical model to represent the distribution of magnitude of the earthquakes. In this case, more than 2,000,000 b-value data were calculated in the area specified by time and place, and they were stored in another database table to visualize them in the platform. In this application, these data were visualized overlapped with the coastal line of Japan using the plug-in function of Open CABIN Library.

Figure 13 shows the visualization image of the seismic hypocenter data that is colored according to the magnitude value. From the high resolution stereo image, the user can recognize the tendency of the earthquake distribution. Figure 14 shows another example of the visualization image in which the occurrence time of the earthquake is mapped to the z-axis. From this image, the user can see how long a lot of small aftershocks continued after big earthquake.



Fig. 13. Visualization of seismic hypocenter data

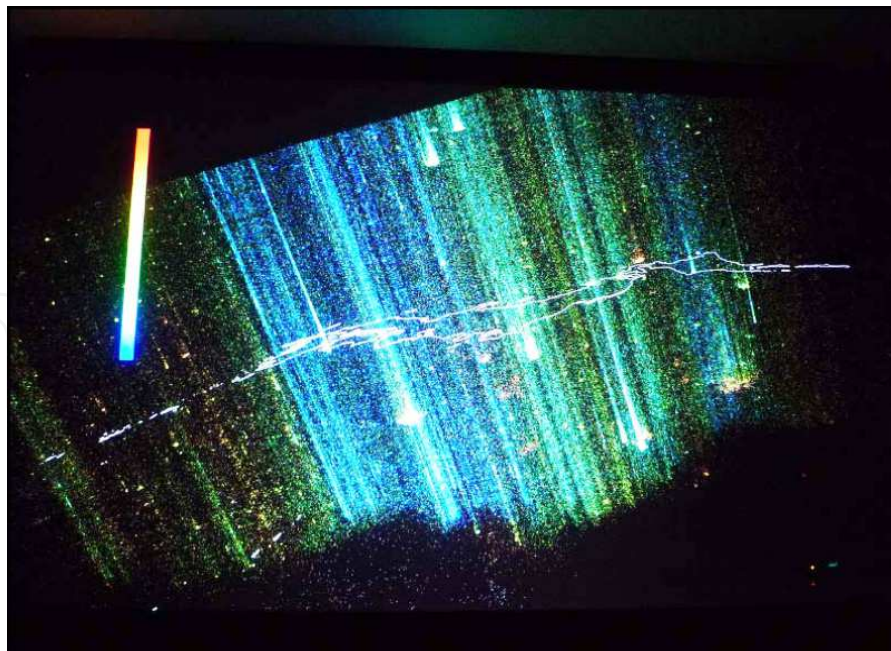


Fig. 14. Visualization of seismic hypocenter data by mapping occurrence time to z-axis

Figure 15 shows the visualization of b-values calculated from the seismic hypocenter data. In this case, it was difficult for the user to recognize the distribution of the visualized b-

value data, because too many point clouds were visualized simultaneously. Figure16 shows the visualization image of b-value data filtered by time parameter interactively. With the reduction of the number of displayed point data, the users can recognize the feature of spatially distributed data. These visualization images were rendered in real time through the user's interactive operation using the physical MIDI controller. Thus, in this application, the user could effectively examine the feature of the distribution of the earthquakes interactively.

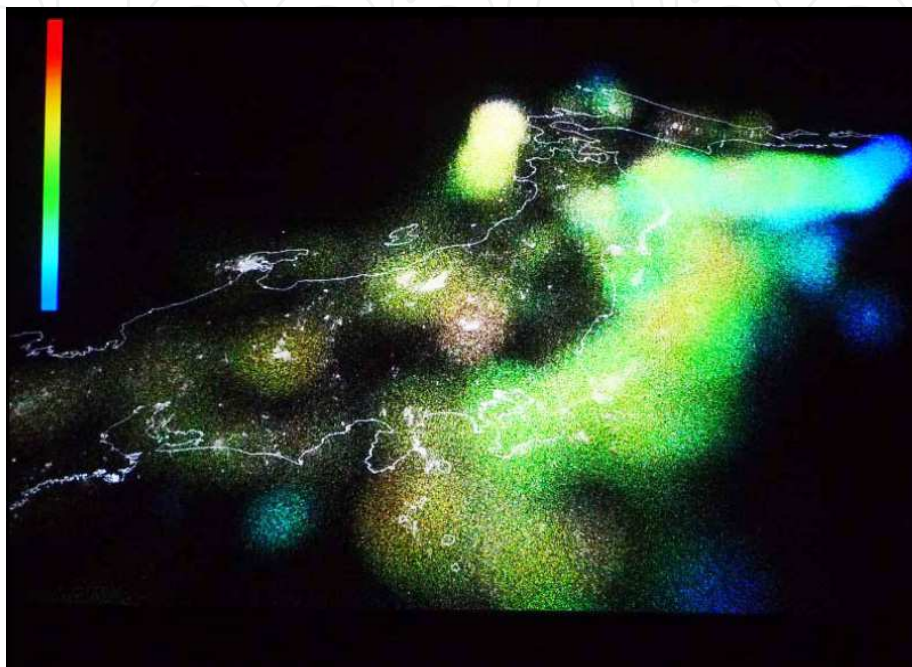


Fig. 15. Visualization of b-value data

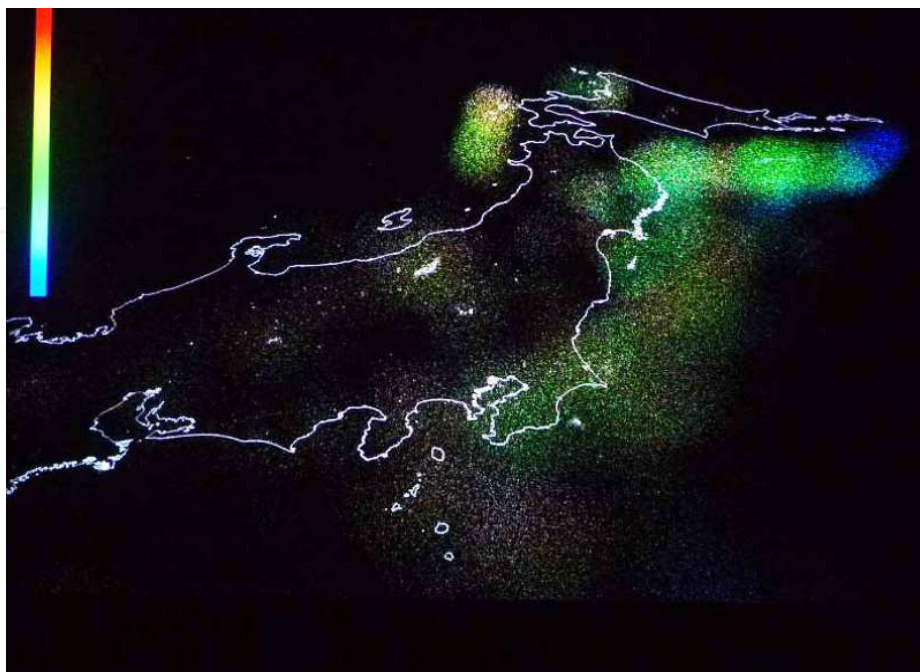


Fig. 16. Visualization of b-value data filtered by time

6.2 Visualization of integrated data

Next, this system was applied to analyze the relationship between several kinds of data by visualizing integrated image. In this case, several application programs that visualize hypocenter data, terrain data, basement depth data and plate structure data were integrated in the super high-definition immersive visual data mining environment. Though these data are stored in different database, every data has location information. Therefore, they can be related with each other using the location information as a reference key. Table 1 to Table 4 show the database table used in this system. Though the terrain data originally consist of altitude information corresponding to the latitude and longitude on the lattice, they are stored as data sets for the divided areas in the database.

latitude	longitude	depth	magnitude	date
36.3005	139.9837	40.68	0.8	2003-01-01
36.0927	138.7390	153.97	1.7	2003-01-01
36.2901	139.6655	121.42	1.3	2003-01-01
.....

Table 1. Database table of hypocenter data.

latitude	longitude	depth
36.505	138.510	3.057
36.505	138.515	2.801
36.505	138.520	2.661
.....

Table 2. Database table of basement structure data.

latitude	longitude	depth
36.510	138.460	151.827
36.510	138.465	151.103
36.510	138.470	151.371
.....

Table 3. Database table of plate depth data.

north edge in latitude	west edge in latitude	south edge in latitude	east edge in latitude	filename
36.6051	139.8046	36.5895	139.8202	N36.6051_E139.8046.dat
36.6051	139.8202	36.5895	139.8358	N36.6051_E139.8202.dat
36.6051	139.8358	36.5895	139.8514	N36.6051_E139.8358.dat
.....

Table 4. Database table of terrain data

In this system, the user can access these databases from the virtual environment and visualize the retrieved data by specifying the condition. Thus, this system enables the user to understand the relationship among the hypocenter, terrain, basement depth, and plate structure data intuitively, and to analyze the feature of the earthquake phenomenon, by overlapping these data in the three-dimensional visualization environment.

As for the mechanism of integrating the visualized data in the virtual space, the plug-in function of the OpenCABIN library was used. In this system, each data is visualized by different application programs and they are integrated in the three-dimensional space in the runtime. Figure 17 and figure 18 show that several visualization data are integrated in the same space. In these examples, visualization programs for hypocenter data, terrain data, basement depth data and plate structure data are plugged-in to represent the relation among the data. When the hypocenter data were visualized using the sphere, the

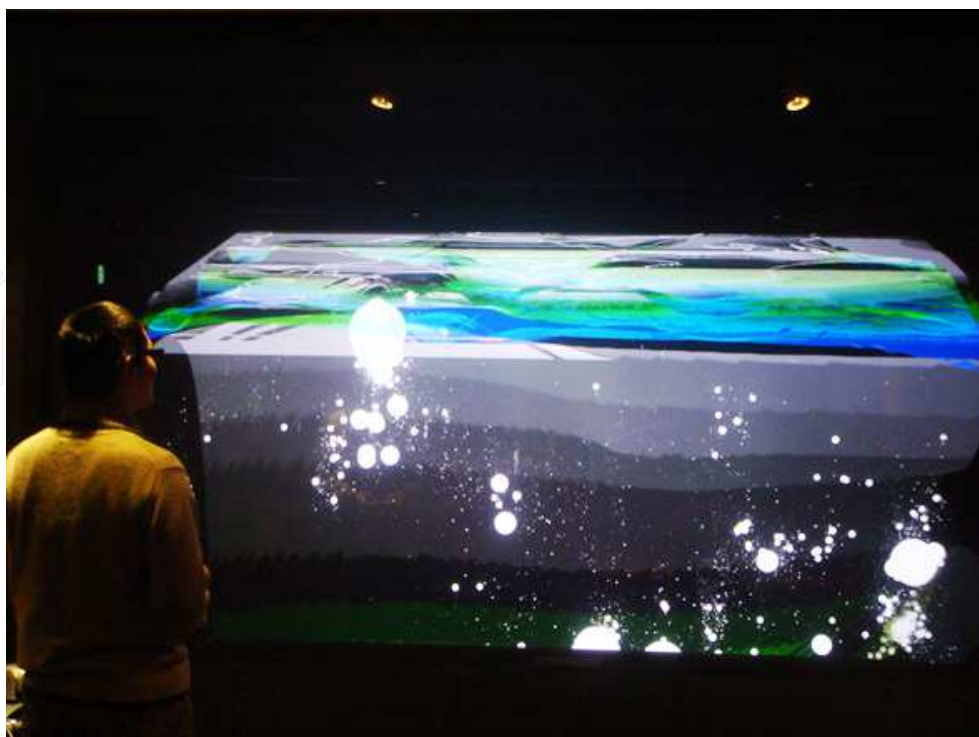


Fig. 17. Visualization of relationship between terrain data and hypocenter data

size of it indicates the magnitude of the earthquake. The terrain data is created by mapping the texture image captured from the satellite onto the shape model. And the basement depth and the plate structure data are represented using the colors that indicate the depth values.

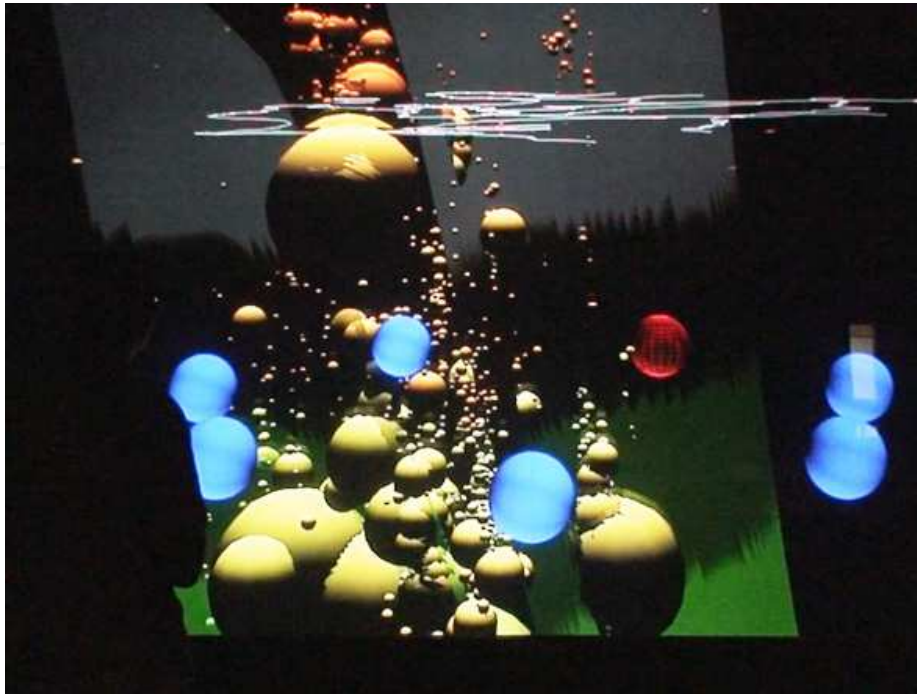


Fig. 18. Visualization of relationship among hypocenter data, basement depth data and plate structure data.

In this system, when the several visualization programs are plugged-in, the toggle buttons that show the conditions of each data are displayed. The user can switch the visible condition of each data by using the toggle button in the virtual space. For example, the user can change the visualization data from the combination of hypocenter data and basement depth data to the combination of hypocenter data and plate structure data, while running the application programs in the visualization environment. By using this method, the user could intuitively understand the feature of the distribution of hypocenter and the relation with other data. For example, the user could see whether the attention data of the earthquake occurred on the plate or in the plate structure. Thus, this system could be effectively used to represent the relationship among several kinds of data in the three-dimensional space and to analyze the earthquake phenomenon.

7. Conclusion

In this study, the super high-definition immersive visual data mining environment that uses 4K stereo projectors was constructed. In this system, it is expected that the effect of visual data mining is greatly improved, since the super high-definition stereo image transmits a large amount of information from the computer to the user and the interactive interface enables the user to explore the data space. However, the result of the experiments also suggested the limitations of representation ability of the super high-definition image. Therefore, the platform of immersive visual data mining for point cloud data was developed

so that the user can easily visualize the data by changing the visualization method and visualization parameter in trials and errors. This platform was applied to the seismic data analysis, and several kinds of data such as map, terrain model, depth of basement and plate structure were visualized overlapped with the hypocenter data. Then, the effectiveness and possibility of the intuitive and accurate analysis in the immersive visual data mining environment were confirmed through the interaction with the visualized data.

Future research will include developing more effective visual data mining method through the collaboration with the earthquake experts and applying this technology to other application fields.

8. Acknowledgment

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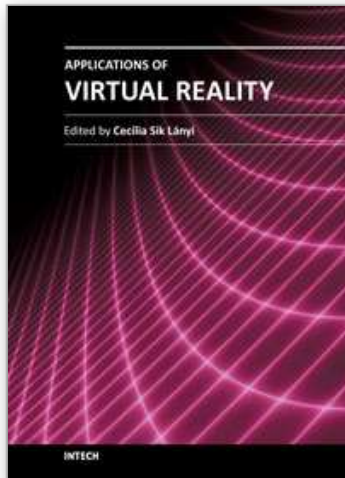
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Information Technology is growing rapidly. With the birth of high-resolution graphics, high-speed computing and user interaction devices Virtual Reality has emerged as a major new technology in the mid 90es, last century. Virtual Reality technology is currently used in a broad range of applications. The best known are games, movies, simulations, therapy. From a manufacturing standpoint, there are some attractive applications including training, education, collaborative work and learning. This book provides an up-to-date discussion of the current research in Virtual Reality and its applications. It describes the current Virtual Reality state-of-the-art and points out many areas where there is still work to be done. We have chosen certain areas to cover in this book, which we believe will have potential significant impact on Virtual Reality and its applications. This book provides a definitive resource for wide variety of people including academicians, designers, developers, educators, engineers, practitioners, researchers, and graduate students.

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