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Virtual reality geographical interactive scene semantics research for immersive geography learning

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ABSTRACT

A virtual reality based immersive glasses technology for obtaining primary geography learning has been proposed, synthesizing a number of latest information technologies simultaneously, including HCI, namely multimodal human–computer-interaction, GIS, 3D geographical information system and VR, virtual reality. By the virtual reality glasses, a geographical software can provide an immersive environment of geographic structure. The major functions of the software part this system are consisted of 3D space intersection detection, 3D topology analysis, Space convex decomposition, Space convex hull calculation, overlay analysis and buffer analysis. The multimodal technologies have been adopted by the system to promote users' perceptions.

1. Introduction

Virtual reality (VR), or virtual environment, is the synthesis of "reality" as a mean to create an intuitive way for human computer interaction. The participants in the virtual world can complete tasks which impossible in the real world. VR emphasizes real-time interaction; it is a kind of new 3D user interface. Virtual reality human–computer interaction (HCI), similar to people in the real environment and the actual objects interaction. The semantic information of the objects oriented into the virtual scene form a semantic scene. Semantic scene refers to the semantic information of objects the user is currently interacting with, including the relationship between the objects in the virtual scene and the information the object attributed to the scene. Semantic scene and the specific application of the virtual scene composed a one-to-one correspondence, though the same virtual objects in different virtual scene may have different semantics.

With the rapid development of web, virtual reality and mobile technologies and mass adoption of mobile and smart devices by all individuals in modern society, significant chances have been created for the applications of e-learning [1]. Mobile phone software which is location-based was proven to be capable to support math, geography and biology lesson for students at campuses [2]. The most advanced technologies of the video game industry makes it efficient and easy to integrate the educational aspect and state-of-the-art interface with poor interaction and graphics [3,4]. The advanced technology in the field of video games [5] attracted great attention from the scholars to promote the motivation and participation of users, which represents to be a major concern in the design of HCI [6,7], namely human–computer interaction. Technology enhanced learning will lead to pan disciplinary, interdisciplinary and multidisciplinary education content in various forms [8] which focus on various cultures [9]. The continuous changing environments could lead to educational benefits as the education offerings which are based on different features of individual learners [10]. Synthesizing knowledge sharing and multimedia operations also attracted attention paid by the researching community [11]. The combinations of other applied information and technology enhanced learning were taken as a rather promising researching topic [12] which has considerable practical impact. It has been promoted that the integration of IT, namely information technology and GIS, will offer impressive chances for education [13]. The principles for the 3D virtual learning design were provided in above [14]. The related process has been promoted by previous scholars in their studies [1,15]. Furthermore, many previous studies also provoked us a lot during the research [16–30].

In virtual reality technology trend, geo-spatial data visualization has never been developing rapidly [31]. With the development of VR (Virtual Reality) technology and widely applications in various areas, the requirements to VR are also increasing rapidly [32]. Vir-

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tual Reality Geographical Information System (VRGIS), a combination of geographic information system and virtual reality technology [33] has become a hot topic. Accordingly, '3-D modes' has been proved as a faster decision making tool with fewer errors [34]. Meanwhile, new user interfaces with semantic computing for geodatabases is also expected [35]. With the popularity of network, the VRGIS platform based on the network environment also becomes a trend. The application of VRML, X3D and other online VR technologies have achieved networking of VR systems [36–45]. For example, VRML brings interactive 3D into the Internet which the visitors can interact with it, like experience in the real environment. VRML provides a feasible solution and a description standard for the realization of the virtual reality environment. As the virtual reality modeling language based on network, VRML satisfies the basic goal to establish a 3D interactive multimedia on Internet, that is to say, it is used to describe the three-dimensional objects and their behavior. VRML treats "virtual world" as a scene, and everything in the scene is the object for VRML's description. X3D is an open standard for publishing 3D content, it defines how to integrate the interactive 3D content in multimedia network communication. X3D is not only a kind of API program, or simply a file format for the exchange of geometric data. X3D can combine the geometric data and the run-time behavior description into a single file, and the file can be used in XML language or other different file formats. Besides, neural computing technology has been widely used in geographical information process [46–48].

WebVRGIS [32] is preferred in practical applications, especially by the geography and urban planning [49–52], which is based on WebVR [53]. Urban simulation is becoming widely noticed nowadays, and some simulation systems have been developed in this area, e.g. ArcView3D Analyst [54], Imagine Virtual GIS, GeoMedia, etc. WebVRGIS engine supports steadily real time navigation in virtual scenes which are constructed with massive, multi-dimensional data from various sources [55–61]. 3D urban landscape database with various data sources can be produced to implement spatial analysis and 3D visualization and published in the Internet environment [62–65]. There have been several research which can assess the quality of the stereoscopic images and further improve the immersive experience [66–69]. In the interactive design of the virtual environment, the connection between the function and the use of the interactive elements is built up with semantic computing. This makes it possible to achieve any kind of function and behavior on the one hand, on the other hand, the user can rely on his already known knowledge in the real world to learn the new knowledge provided by the E-learning system. Therefore, when designing an interactive VR system, it is necessary to construct and establish the semantic identity of the interactive object, so that users can understand it more easily and interact with it. In this research, we plan to use virtual reality geographic information system technology as an education and learning tool to teach the geography courses.

2. System overview

The system contains hardware and software. The hardware is an immersive virtual reality glasses. The software is a set of 3D geography geometrical analysis education/learning model. The idea of this system in education/learning is to visualize the geography structure in three-dimensional space, and employ the virtual reality to render the 3D model and further bring the anaglyph perception to the users, which could assist the users to understand the geography structure and enhance the memory. The 3D geography geometrical analysis education/learning model includes several sub-modules: '3D Topology Analysis', 'Profile Analysis of Submodules', 'Cutting Analysis of Sub-module for Geological Body', 'Iso-surface Extraction' and 'Iso-body Extraction'.

2.1. 3D topology analysis

Among various factors of spatial analysis, space topological relations is of great importance. Howe to judge and generate the space topological relation effectively carries direct influence over the spatial information system. The building up of 3D topological relations help the scholars to realize the different courses of information inquiry and space operations. Complex surface factors could be depicted from different bodies filled with hook faces, arcs composing those rings, space composing those bodies. Boundary rings composing those hook faces. In general, body serves as the fundamental constitution of the target entity. Every complex entity has been taken as the component of the body (whatever artificial or natural). Point, line, face and body represent to be dynamic concepts. They appear to be inter-convertible under different research emphases or different scales. The 6 groups of relations below have been adopted to depict the topological relation possessed by the 3D vector mechanism stored by the information system of space: connections between complex surface characteristics and body, connections among the body, complex surface characteristics, connections existed among the body, ring and hook face, connections between the hook face, arc and ring. Connections between ring, node and ac and connections between arc and node.

2.2. Profile analysis

There are many types of profile analysis, including oblique profile analysis, horizontal profile analysis and vertical profile analysis. Among all of them, it is vertical profile analysis cutting the line of multi-stage in horizontal profile analysis and vertical direction analysis which used to cut the model based on the horizontal cutting regulated by the user. Besides, the oblique profile analysis has been used to cut the model based on the given parameter equation set by the oblique profile. The results of the analysis represents to be a combination of two-dimensional analysis of the profile map, profile cutting line, profile cutting plane and three-dimensional profile cutting body.

Since the spatial forms possessed by the geologic body models represent to be changeable and complicated, the classification and segmentation in the cutting process represents to be a complicated process with high computing needs. All floating-point factors in the module has adopted double precession and adoption of code should deal with the round-off mistakes of floating points. Flexibility: every operand should use the data structure if a module is to be designed. The connection between the upper call system and operation should be built up, which has considerable flexibility in the reuse of the code. Profile analysis represents to be a rather interactive process of the system and users, enjoying the characteristics of computational complexity and data complexity. Users focus over the visual expressing effect and validity of the results of the analysis. The time demand is not that high.

The cutting analysis and profile analysis over the geological body represent to be similar with the surface cutting body's principle during the implementation of the algorithm and also the differences which has bee used in the cutting analysis on the division of the pace based on the surface object, together with the profile analysis which has been used into the division of space based on the body object. The fundamental idea is that: the division of the cutting object should be based upon the triangle disjoint. The triangle disjoint has been classified into two parts, namely external and internal parts. The entire triangle part has been intersected spatially with the cutting objects which are distinguished and resolved at the intersection and then rebuilding the relations of topology over the external and internal triangle and hence to form two objects right after the cutting.

2.3. Cutting analysis

The geological body cutting analysis covers the analysis of multiple cross-section and analysis over the single cross-section. Single cross-section analysis stands for that through regulating the spatial position and orientation of the section, it has been used to cut the geological model which has three dimensions to obtain the profile cutting line. The profile cutting body and the profile cutting place of the model have been used to carry the geological analysis. Cross-section analysis could be used to set the spatial orientation freely, which could be managed flexibly via dropping and dragging the mouse, or via the setting of functional interface.

2.4. Multiple cross-section analysis

Multiple cross section analysis has great differences with the single cross section analysis, showing the analysis outcomes with the form of profile cutting line and profile cutting plane and the management of each section has fixed the vertical axis of *X*, *Y* and *Z*, exactly as what has been shown in the chart below.

Because of that the spatial forms possessed by the geologic body models represent to be changeable and complex, the classification and segmentation processes represents to be a quite complicated process with high computing needs. Every floating variables has used the implementation mode and double precision model to deal with the round-off mistakes of the floating points. Every operand needs to use the data structure if a module is to be designed and hence it could be used to realize the connections between the upper call system and operation system, which carry great flexibility in the reuse of the code. Vector cutting analysis presents to be a highly interactive process of the system and the users. It has the characteristics of computational complexity and data complexity. The users have put more focus over the visual expressing effect and validity of the result of the analysis. The time demand is not that high.

2.5. Vector cutting

The fundamental concept of vector cutting represents to be that the division of the cutting object should be based upon the triangle disjoint. The triangle disjoint has been classified into two parts, namely external and internal parts. The entire triangle part has been intersected spatially with the cutting objects which are distinguished and resolved at the intersection and then rebuilding the relations of topology over the external and internal triangle and hence to form two objects right after the cutting. BSP has been adopted by the module to deal with this problem. The fundamental idea of BSP is the spatial division. Besides, the basic concept to the BSP spatial division is that any plane could be theoretically divided into two halves which hare mutually disjointed. These two halves have been named the negative side of the plane and the positive side of the plane. Once there is another plane, it will further divide the space into another two subspaces. The process is operated based on a polygon list. If only one single plane appears in the space, then it could be used to build up a binary tree to depict the hierarchical structure own by the three-dimensional entity. Every node of the binary tree refers to a partition plane. The left one stands for the positive side of the partition plane while the right one stands for the negative side.

2.6. Iso-surface

Iso-surface is a kind of spatial structure, adopting a series of curved graph, standing for those points which have exact same quantity value to depict the quantities distribution with sustainable distribution features, which represents to be the continuation over the contour map covering from the two-dimensional map right to a three-dimensional one. For the analysis over the spatial structure, the body which has a normal structure has been dispersed into the assembly of grid, and via the numerical calculation, it could obtain great analyzing quantity values through the node over the spatial grid. Based on these limited and discrete statistics and adopting the iso-surface method, it could obtain specific quantity value through the spatial structural body. Besides, the adoption of the iso-surface method is quite convenient to decide what the sliding surface will be like.

Iso-surface is the assembly of all points with the same value in the space, which can be represented as:

$(x, y, z)|s(x, y, z) = c,$ where c is the constant

It represents to be a cubic surface. Besides, the iso-surface has been composed by great number of iso-surface patches. The iso-surface has been used to refer to those three-dimensional space, adopting the surface fitting to build up the pints with similar quantity value. Similar unity over the physical quantity possessed by the spatial distribution over a series of the curved surface and hence to depict the distribution laws possessed by those physical quantity which has continuous distribution features. Inclosing the iso-surface with similar physical quantity and hence to build up an iso-body, it represents to be the continuation over the iso-surface.

Judging from different purposes, it could be extracted that various iso-bodies could be adopted in the same place. The extraction over the iso-body serves as the foundation of the spatial object, which has been normally adopted in the geological module. The iso-body's equivalence has not been only reflected in a plane, but also has reflected the relations between different equivalent points in every direction.

Iso-body has been used to refer to those three-dimensional spaces, fitting the quantity value with the spatial distribution's physical quantity and the similar unit, but the difference is that they are not in the same plane. To form a iso-body needs to combine the global iso-body together. In the analysis over the geologic model, it can be found that it has many layers. It has been divided into lower and upper cubes to decide the quantity value and that needs the iso-point to be a two layered cube which could finally respectively fit into the iso-surface. A curved surface has been made based on the stratigraphic boundary whose interpolation form represents to be an iso-body.

3. Implementation of stereoscopic display

The three-dimensional images generated by the mobile phone required:

A. Two separated images are provided to the left and right eye. They are referred to as left image and right image.
B. The left eye can only watch the left image, and the right eye can only watch the right image.

In this study, the problem was solved by installing the mobile phone into the VR glasses. The VR glasses can separate the view of the two eyes, and the mobile phone can provide splitted image for left and right eye.

Hence, the problem transformed to display two images on a single display. This study adopted the double center projection method and improved the method. The idea of the method was described as following. Assume projection center of a right hand coordinate was (0, 0, 0) and the visual plane was $z = b$. The right eye perspective (x_0, y_0, z_0) was the $a/2$ translation along *X* axis. The right and left eye perspective were:

$$P_{right} = \left(x_0 + \frac{a}{2}, y_0, z_0\right) \tag{1}$$

$$P_{left} = \left(x_0 - \frac{a}{2}, y_0, z_0\right) \tag{2}$$

The parameters equations of the projection line from P_{right} to the projection center was:

$$\begin{cases} x = x_0 + \frac{a}{2} + t\left[0 - \left(x_0 + \frac{a}{2}\right)\right] \\ y = y_0 + t(0 - y_0) \\ z = z_0 + t(0 - z_0) \end{cases} \tag{3}$$

At the perspective plane $z = d$, $t = \frac{(z_0 - b)}{z_0}$. Then, for left eye perspective:

$$\begin{cases} x = \frac{dx_0}{z_0} + \frac{ab}{2z_0} \\ y = \frac{by_0}{z_0} \end{cases} \tag{4}$$

For right eye perspective:

$$\begin{cases} x = \frac{dx_0}{z_0} - \frac{ab}{2z_0} \\ y = \frac{by_0}{z_0} \end{cases} \tag{5}$$

The horizontal parallax was:

$$x_{left} - x_{right} = \frac{-ab}{z_0} \tag{6}$$

In (6), $z_0 > 0$, thus the cross parallax (negative parallax) will be projected in front of the stereoscopic display window. To adjust the image, the right projection was translated with $a/2$ to the right on the X axis, and the left projection was translated with $a/2$ to the left on the X axis.

In order to set the two projection images, the parameters a and b must be calculated. a is the distance of two projection center. b is the distance of projection center to stereoscopic display. In this study, the stereoscopic display also must be defined, it is the z coordinate of the parallax plane. The coordinates on the positive direction of the z axis had the negative parallax. The coordinates on the negative direction of the z axis had the positive parallax.

The a, b, z parameters were defined with Δx, θ, P_p, P_n, $z_{\min}$, $z_{\max}$, z_{focus}.

Δx was the approximate of the stereoscopic display width.

θ was the observation level of the perspective plane. It generally set as 50°.

P_p and P_n were the maximum negative and positive parallax. Generally, the parallax was between − 3% and 3% of stereoscopic display width. Therefore, $P_p = 0.03\Delta x$, $P_n = -0.03\Delta x$.

$z_{\max}$ and $z_{\min}$ were the most important parameters in the stereoscopic display. They defined the range of z. Since the z axis was vertical to the stereoscopic display, $z_{\max}$ represented the near end, $z_{\min}$ represented the far end. $z_{\max}$ and $z_{\min}$ were adjusted with the size of stereoscopic size, they are different from the near and far end cutting plane.

z_{focus} is the center of the most important stereoscopic display element.

The three parameters in the stereoscopic were defined as followed:

$$d = \frac{\frac{\Delta x}{2}}{tg\frac{\theta}{2}} = 1.07\Delta x \tag{7}$$

$$a = \frac{a_n + a_p}{2},\ a_n = P_n\left(\frac{b}{z_{\max} + z_{focus}} - 1\right),\ a_p = P_p\left(\frac{b}{z_{focus} - z_{\min}} + 1\right) \tag{8}$$

$$z_{zero} = z_{\max} - A,\ A = \frac{P \cdot b}{P + a} \tag{9}$$

After defining of the three parameters, the next step was generating left and right images. This process was same as creating an ordinary 3D scene. The only difference was that every sub-scene had a translation along X axis of $\pm\, a/2$. This operation can be done either before or after the projection. The detailed steps were as following:

(a) Translating the left image to $(-x_{center} + \frac{a}{2}, -y_{center}, z_{zero})$, right image to $(-x_{center} - \frac{a}{2}, -y_{center}, z_{zero})$.
(b) Projection transforming the image from (0, 0, d) to xy plane.
(c) Translating the left image to $(x_{center} - \frac{a}{2}, y_{center}, -z_{zero})$, right image to $(x_{center} + \frac{a}{2}, y_{center}, -z_{zero})$.

x_{center}, y_{center} were the coordinate of the display center.

In the practical environment, the parameters of the three-dimensional rendering generally calculated with the average condition. For example, the average parallax and maximum negative parallax calculation process in this study adopted the average calculation method. Therefore, initial parameters in the implementation also adopted the average calculation method.

In general, the parameters of stereoscopic display changes with the size of the stereoscopic display window. In this situation, the parameters needed a dynamic method to modify the parameters. The software must monitoring the changes in the display window. In our case, the resolution of display window on the mobile phone was set as 1920*1080.

The relationship of the objects in the group was calculated by the following method:

4. User interaction based on the scene semantics

Scene semantics provides the basic interaction to bridge complex application conversion and learning process. With the basic interaction of semantic objects based on semantic computing and 3D interaction techniques, such as selection, translation. The general interaction design based on semantic scene is more concerned about the semantic computing and through which object interaction to execute the application.

The design strategy of 3D interaction is mainly guided by the experience of the users in the real world. This strategy, expecting the user adopts the real world knowledge, but also expecting the user go beyond the user's perception of the real world. Since with the real world knowledge the user can greatly reduce his memory load and make the interaction more natural; at the same time, the interaction of the real world though natural, but not necessarily efficient, completely accordance with the real world, the establishment of strict, one to one correspondence interaction may reduce the interaction efficiency, comfort and usability of the VR system. Therefore, rational interaction design, not only brings a natural and efficient interaction, but also avoid to the user caused interaction chaos and unexpected interaction.

In two-dimensional interaction, constraints can be defined as a kind of relationship, that is, the geometric consistency in the process of interaction between the user and the virtual scene. Although in the interactive 3D virtual reality environment, it is also able to use the theory of constraints. The reason to use restrains as the semantic scene method is that it can simplify the interaction and improve the accuracy and efficiency.

In order to make the virtual objects to interaction with user, the virtual objects can be formed as a group objects in the scene. It can avoid the user to repeat the operation to speed up the efficiency of the interaction. In mature CAD software, such as 3DMAx, Maya, grouped objects is implemented one by one through the user selected object and group command, this method is relatively

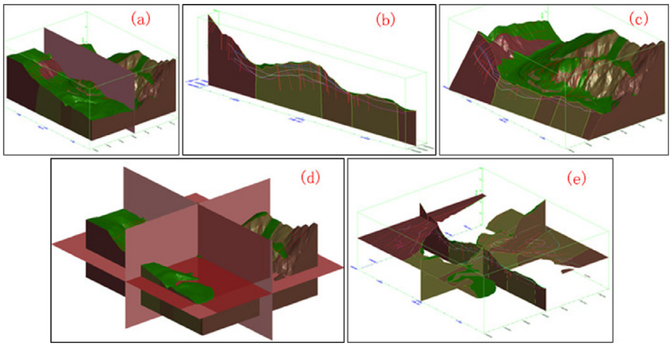

Fig. 1. System UI of cross-section analysis of geologic body. (a) Profile cutting operation; (b) profile cutting line and profile cutting plane; (c) profile cutting body; (d) multiple cross-section orientation and (e) profile cutting plane.

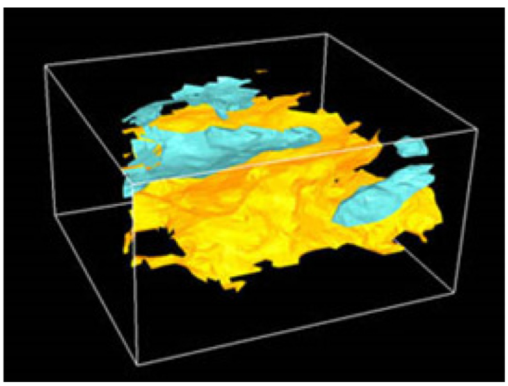

Fig. 2. Iso-body extraction.

complicated, transformation each object group members to the solutions group. The dynamic group of "magic" constraint is different, according to certain rules of the perceived group objects, the dynamic temporary interaction make these objects form a group object, when the user interact with them, they will automatically set to solutions. In the virtual E-learning layout system, user perceived rules are: according to the direction of the user walking, the moving vector is at the same level as the surrounding objects, and the objects will constitute a temporary set of objects, an object group of movement. This group objects will not disrupt the cognition of the user from the real world, at the end of the interaction, the group of objects will reset to the original status (Figs. 1–3).

5. Application scenarios

The engine of WebVRGIS has been promoted based upon the C++ and Open GL, integrating GIS and VR perfectly and hence provide great support to the massive data.

Exactly as what has been shown in Fig. 4, the register is observing the virtual geographical scene via the HMD, which is the glasses shell of VR by which registers could watch anaglyph 3D scene obtained from the screen of the smartphone.

The convergence-to-face component of the HMD designed for the light blocking has been made by the soft holster filling. Therefore, it will not be oppressive. Besides, it could modify the DOF, namely the depth of the field and PD, namely pupil distance. Therefore, it is suitable for the users because of various PD and myopia degree. The remote controller and head motion have been included in the input methods. The head motion will only support the tree axis' rotations which have been managed by the smartphone's gyroscope. The head rotation actions represent to be synchronous corresponding to the rotation of the VR's camera view, bringing the users immersive perception simultaneously.

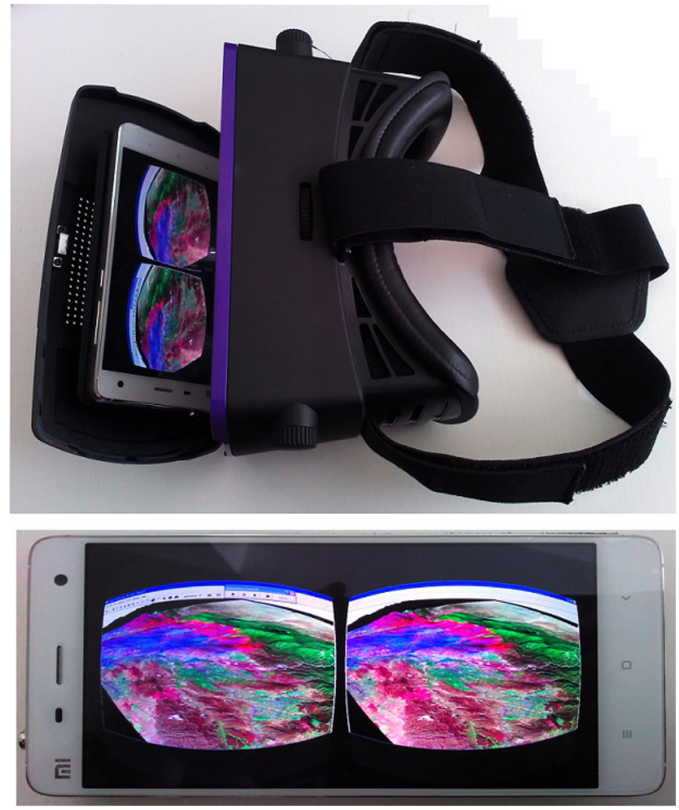

Fig. 3. VRGIS running on virtual reality glasses device.

Algorithm 1: The definition of the two elements had left conjunction in a group.

Input : The horizontal angle of objects p and q was φ with radius of r_p and r_q, the centroid distance was d_{pq}.
Output: Discrimination results H.
(1) If $d < r_p + r_q$
  Then If $\varphi \in (135^\circ, 225^\circ]$
    Then $H = true$
  End if
 Else
  Then $H = false$
 End if
(2) Output H

Algorithm 2: The definition of the three elements had left and upper conjunction in a group.

Input : Object p and q had the left conjunction relationship H. The horizontal angle of objects p and q was φ with radius of r_p and r_q, the centroid distance was d_{pq}.
Output: Discrimination results K.
(1) If $H = true$ and $d < r_p + r_q$
  Then If $\varphi \in (45^\circ, 135^\circ]$
    Then $K = true$
  End if
 Else
  Then $K = false$
 End if
(2) Out put K

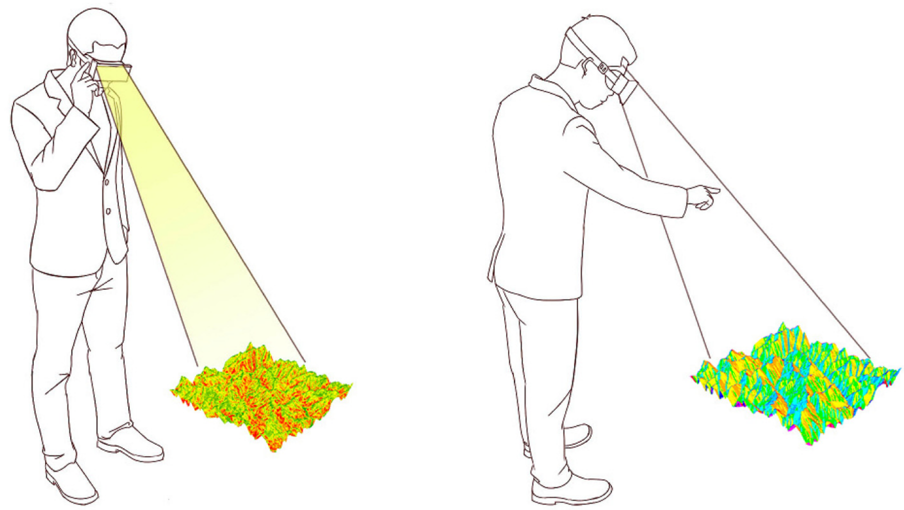

Fig. 4. Left: the user wears the virtual reality Glasses to look at the virtual 3D GIS. Right: the user wears the virtual reality Glasses and use touch-less interaction to manipulate the 3D GIS.

Coming to the interaction of the user, the system has been facilitated with the 2D user interface and hence to adapt to the 3D environment. This interface represents to be user friendly since it could be used to simulate the interface of the computer desktop. The old 2D GUI has been attached with the 3D scene, which includes text boxes, scroll bars and menus. This interaction represents to be highly intuitive for the inherent information interactions and E-learning system. Another merit of this method represents to be that 2D GUI has always been displayed with a specific position of the users. More likely, this position does not change corresponding to the mobile viewpoint. At the same time, the remote controller has been adopted to input the 3D scene displacement and hence to manipulate the software configuration menu. The touch-less interaction via fingers swinging also serves as important option [70,71]. The similar technology could also be used for medical industry [72,73].

6. Conclusion

WebVRGIS has been adopted to present the geographical information and also the enhanced learning tool. The geographical information enjoy the features as follows, namely real-time, predictable, diverse and large scale, falling in the definition range of Big Data [74]. Virtual reality represents to be a suitable and promising technology to stand for the geographical big data. In the coming days, the advanced technology will assist the learning process. For instance, the teacher might be supported by the multiple users to conduct a class simultaneously.

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