DESKTOP VIRTUAL REALITY (VR) & ISPACE FOR GIS EDUCATION THROUGH INTERACTIVE VIRTUAL LEARNING ENVIRONMENTS

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In this research, the authors present GIS instructional materials via a low-cost desktop Virtual Reality (dVR) framework and a high-fidelity, immersive CAVE-based technology named iSpace. While the affordable desktop Virtual-Reality framework lacks the high fidelity and immersion of CAVE (Computer Assisted Virtual Environment), it can be accessorized with additional devices (enhanced dVR) to enhance functionalities such as immersion, navigation, and presence. On the other hand, while CAVE systems can offer good immersion, navigation, and fidelity, they are expensive and space-consuming. In this paper, the authors have designed virtual environments for GIS instruction and implemented them using two modes: desktop virtual reality (VR) framework and a CAVE-based framework (iSpace). The authors use different modes of VR to serve as a medium GIS instruction and to facilitate delivering interactive learning materials for Geographic Information Systems (GIS). The proposed framework helps realize the ultimate goal of nurturing GIS/Geo-Informatics students with advanced geospatial skills while contributing to enhanced critical thinking and problem solving skills due to the interactive delivery of modules. The 'interactive' nature of the framework allows the transition from conventional methods that are passive and uni-directional to active learning through involvement driven by the event-response mechanism. As a result, GIS academic programs can give advanced state-of-the-art training to their students, thereby increasing their graduation rates, employability, and overall career success. This paper delineates some of the common examples employed in geospatial education and elaborates with visualizations how the proposed framework can be used for the generation of static and dynamic virtual environments. Finally, the results are discussed from the points of view of the desktop virtual reality mode as well as the iSpace mode.

Keywords—Technology-based learning environment, desktop virtual reality, GIS, CAVE

Background and Related Work

Over the decades, Geographic Information Systems (GIS) have become an extremely inherent part of various branches of engineering including civil engineering, geomatics engineering, environmental engineering, etc. Despite the tremendous advances made in GIS disciplines in the last few decades, academic institutions with GIS programs are struggling with attracting more students (increasing program enrollment) and retaining students due to the lack of innovative instructional approaches. Interaction and collaboration are key to important academic practices such as active learning (AL), problem solving (PS), critical thinking (CT), and project-based learning (PBL). These skills are not only inevitable for academic success, but are also extremely valued in the industry. Unfortunately, the vast majority of the academic curriculum for current GIS courses, as well as the related infrastructure, are not well equipped to adjust the demands imposed by the modern technological landscape. While numerous opportunities are available for GIS students, higher-educational (higher-Ed) institutions are faced with the challenge of preparing students to take advantage of these opportunities. One of the important problems that needs to be addressed in GIS education is the over- reliance on conventional approaches that are ill-suited and

outdated, which has in turn adversely affected students' attitude towards GIS learning. There is an imminent need to transform this attitude and hence, the design approach to teaching and learning GIS concepts. To stimulate students' interest, an interactive platform that can facilitate a fun-learning environment is proposed. As is evident from the above discussion, besides serving to enhance the geospatial skills of students, this research will also contribute to the development of an innovative design paradigm that can serve various other related academic disciplines. This research can result in notable impacts in the following areas: enhancing GIS curricula by contributing to increased Critical Thinking/Problem Solving (CT/PS) skills, training Geoinformatics graduates with superior skills, improving student employability, enhancing mode of instruction, and increasing student graduation success. GIS education is interrelated to numerous other disciplines and GIS knowledge and skills can promote a student's ability to understand spatial concepts, facilitate spatial thinking, and learn class subject matter [2,4]. These capabilities can help students understand spatial analysis concepts such as distance, location, proximity, or distinct boundaries [13]. In view of these methods and their effectiveness, this research framework has been designed to facilitate learning both basic and advanced spatial analysis methods. The methods presented here include the integration of diverse spatial information, spatial-temporal context, spatially explicit modelling, and place-based organization.

GIS discipline in particular deals with representation geographical features like buildings, trees, landuse/landcover in three/four-dimensional (3D/4D) space. The 4D space can be used to include an additional dimension such as time (temporal component). Besides GIS, many academic disciplines in Science, Engineering/ Technology deal with representation of three dimensional objects like earth surface in two dimensional space. Conventional methods of teaching are not quite effective in Active Learning (AL) of these geographic concepts, thus leading to a lack of interest and aversion among students. Use of VR based methods with improved visualization of the concepts like map projection, coordinate system, geographic datum, etc. help better understanding and in turn facilitate CT/PS skills of the students. Virtual environments created for GIS instruction can be visualized using a range of user interfaces and platforms such as desktop virtual reality (dVR), CAVE, Head Mounted Displays (HMD), and augmented VR etc. As seen from Figure 1, each one of these platforms has their advantages and disadvantages with respect to the degree of immersion, presence, navigation, interaction, etc. CAVEs offer high end fidelity, immersion and navigation, but, involve large spaces and cumbersome installation procedures. In addition, CAVEs also involve considerable costs associated with installation, operation and maintenance. On the other hand dVR (desktop Virtual Reality) systems offer good functionalities for dissemination and interaction, but have compromised functionalities in terms of immersion, navigation, fidelity, etc.
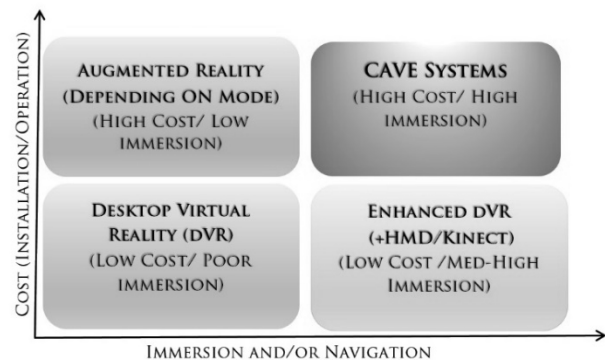

Figure 1. Cost vs Functionality Comparison of VR Systems for GIS.

The lack of effective and innovative practices for GIS instruction can lead to negative effects. Some of the important ones are listed as follows:

- the lack of spatial thinking and problem solving skills can affect the employability of GIS students.

- the lack of in-depth domain GIS knowledge prevents students from exploiting their creativity and applying to it to innovative

learning practices such as active learning (AL) and project-based learning (PBL).

- The inability to grasp concepts can increase student drop-out rates and often times affects successful graduation and overall university enrollment.

The researchers have actively considered these factors while designing and implementing the framework and hence decided on using these 3 modes. A plain desktop VR without any accessories, enhanced dVR with MS Kinect and HMD, and the CAVE-based iSpace virtual environment. The modes proposed in this study (dVR, enhanced dVR, and iSpace) are intended to be capable of the following (although with varying levels of fidelity, immersion, and navigation)

- Demonstrate visualization, animations, and simulation applications related to GIS.

- Develop and demonstrate applications for GIS consulting.

- Facilitate PBL and AL in GIS curriculum.

- Supplement departmental laboratories and augment current pedagogical practices

In addition to the above mentioned factors, the researchers emphasize methods like Discovery-based Learning (DL) with emphasize on intrinsic motivation, intuitive thought-process, and student-centered learning [12]. Founded on the above learning concepts, the proposed framework aids learning geospatial applications in domains like environmental modeling, land use planning [7-9] transportation planning & optimal site location [14] , disaster-mitigation etc. Especially, processes such as deformation analysis entail modeling [7,19] of spatio-temporal events which can be better depicted in VR environment in object oriented domain. Spatial modeling facilitates interactive problem

solving by defining spatial and temporal event markers, thus and hence advanced practices involving VR models enable instructional environments concentrate on dissemination of materials, hence missing interaction and problem solving [11,18]. In this paper, we discuss both the iSpace technology and affordable dVR technology and explain the benefits of both. The methodology explains the design and implementation of both frameworks with applications that were tested in both. GIS and GIS-related courses cover a wide range of topics spanning areas including the development of GIS, principles of cartography, spatial data analysis and overlaying, terrain analysis, buffer analysis, 3D GIS application, Remote Sensing, GPS technology, and Web GIS, Mobile GIS, ArcGIS manipulation. In each GIS case study, students have been taught to know the geographic meaning, collect spatial data and then use ArcGIS software to analyze spatial data. As they analyze spatial data, they can connect to a GIS hub to get the data they need including satellite images, aerial photos, and vector data. More specifically, the Problem Based Learning (PBL) method encourages teachers and students to apply these data and skills through this platform to investigate a real-world issue.

Methodology

In this study, the researchers have designed a three-tiered framework consisting of:

1. Tier I / Component 1 (Concept model for GIS Instruction- Examples for using VR).

2. Tier II /Component 2 (Mapping Component-1 Concepts/examples to CG modules).

3. Tier III /Component 3 (customization for mode-specific delivery of design materials) .

These three need to be generated with careful consideration of the fact that the objects need to be customized for VR modes. The modules developed should be generated in such a manner

that they can be customized for the specific VR environment. To this end, the virtual environments are developed with an 'object-based' approach, wherein the entire scene is created with customizable virtual nodes (programmable 3D elements). These nodes are programmed with geometric and appearance attributes corresponding to the objects within the GIS instructional design modules. Such objects can be 3D virtual representations of GIS software components or can be abstract components used in teaching notions such as GIS modeling or spatial logic. The overall framework will be extremely customizable (due to individually programmed virtual scene elements) and hence highly flexible. However, the primary reasons for choosing the proposed interactive VR modality are the ability to collaborate (for promoting Active Learning) and interaction (for Project Based Learning involving team-dynamics.

Figure 2a illustrates the overall VR-compatible framework for GIS Instruction and Figure 2b shows a dVR framework with enhanced capabilities for: 1. Immersion, 2. Navigation, 3. Multiple levels of detail (LOD), 4. Multiple points of view (POV) using various modes of interaction. The framework augments the exploratory capabilities of the geospatial visualization environment by interfacing it with Touchpad$^©$ and Hydra$^©$, which are devices with advanced navigational and motion-control capabilities. The different navigational icons on the left of the imported file show different forms of navigation such as walk, fly, and study. Evidently, these functionalities allow the users to better interact with the geospatial data and perform active exploration.

Tier I / Component 1 (Concept model for GIS Instruction- Examples for using VR)

Design of materials for GIS instruction that can be used with the proposed framework. This step involves selecting and designing conceptual examples. Figure 3 illustrates an example developed to illustrate how dynamic and interactive visual examples are used to explain basic GIS notions such as points, lines, polygons, and coordinate systems. Failure to grasp fundamental concepts is one of the major reasons for attrition rates as basic spatial skills are becoming inevitable in all branches of engineering and technology. With interactive and collaborative pedagogy, courses can be transformed into a fun-learning experience thereby reducing the cognitive overload on students. The mathematical **and** geometric theory form very important foundational aspects of GIS. A basic knowledge of the following is essential for any student of GIS: Points, lines, and polygons. Figure 4 illustrates one very common, but frequently confused form of representations, namely the right handed and left handed systems. Presenting such concepts in an interactive manner through the virtual reality modes explained here reduces the cognitive load on students and stimulates their interest in the field.

Using our VR-compatible framework, students are given more detail-oriented and enriched examples for learning various programing concepts, which can be solved together by interaction and collaboration. These AL and PBL-based activities will result in enhanced understanding and will facilitate experiential learning. For example, understanding the concept of cartographic projection, various projection systems and their implications on spatial measurements is critical in GIS. The accuracy achieved in spatial analysis largely depends on the type of projection adopted for representation of spatial data in GIS database and characterization of projection. The student shall understand the utility of each projection, its limitations by applying the various projections on given spatial dataset. The implication of various projections on length, perimeter and area of geographic feature can be understood by students by varying the projection, its characteristics like origin, scale, aspect. The students can play in the virtual environments by changing various parameters to quantify their impact on the outcome.
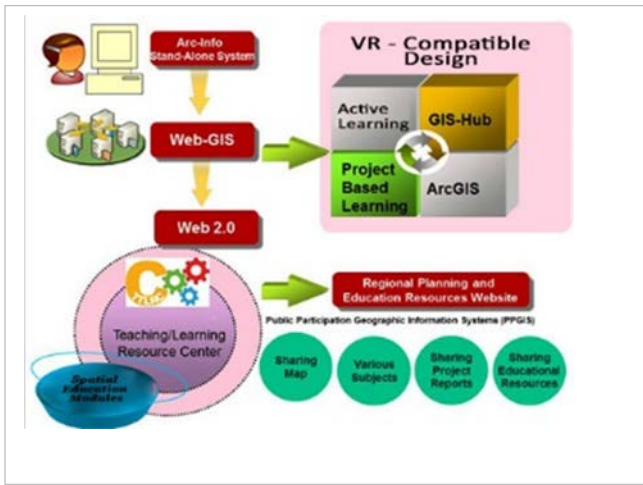
Figure 2a. VR-Compatible Instructional Framework Used in Study for GIS education.

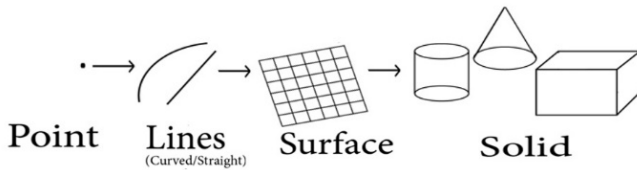2b. VR-Compatible Instructional Framework Used for GIS.

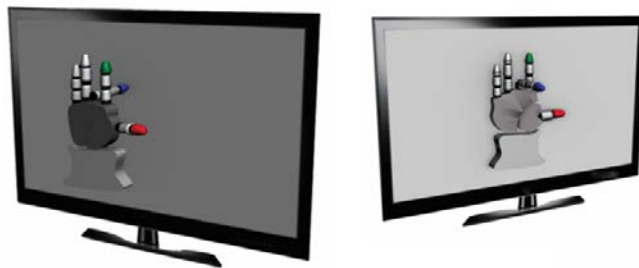Figure 3. Pipeline Illustrating 3D Model Creation from Points, Lines, and Polygons.

Figure 4. Left and Right Handed Coordinate Systems.

Even though different platforms use different formats of spatial data, the layer based presentation and storage of geospatial features is a typical feature to be found in most systems. Based on the type of data being presented, there are two major formats, namely raster and vector. Raster format (or bitmapped format) presents data in the form of a rectangular grid (matrix) of cells. On the other hand, vector data format represents geospatial features using points, lines, and polygons. ArcGIS© Shape Files and ArcInfo© Coverages are examples are examples of popular vector formats, while Images and raster datasets are examples of raster formats.

Fundamental Geospatial Concepts Using Interactive Navigational Framework

In geospatial instruction, deep insights may be obtained from the visual representations and the users can navigate within these virtual worlds, move, rotate or scale the objects, and transform them in multiple ways. This kind of VR setup greatly helps the demonstration of geospatial concepts involving spatial coordination such as transformation and projection (Figure 5 and Figure 6). The framework can be used to explain basic and sometimes tedious concepts such as projective and Euclidean geometry to students. Projective geometry is concerned with how something seems or appears, while Euclidean geometry is all about what things are actually. Understanding the relationship between Euclidean and projective geometry is a very inevitable aspects of geospatial education. Next, let us look at how the concepts of transformation can be explained using the interactive frameworks.

One transformational notion is to consider that an object itself is transformed, either by translation, rotation, or scaling. In such a case, if a geospatial object (represented by a shape) is translated, this can be thought of as the transformation being directly performed on the shape itself. It is also possible to approach transformation from another standpoint wherein the coordinate system itself is transformed and the object or objects in it are also subject to the transformation (to which the coordinate system was subjected to). Figure 5 shows a geosphere object (geosphere is a particular type of spherical object in computer graphics that has more modeling plasticity than a sphere object) within a Cartesian coordinate system. This is done by embedding sensor objects within the scene, which can sense (detect) user events such as mouse click, keyboard click, right click, double click etc. and respond accordingly.

Typically, as shown in Equation (1), the notation (X, Y, Z) is used to refer to the original coordinate system and (X', Y', Z') denotes the transformed coordinate system. A point in 3D in projective geometry is denoted as (x, y, z, w). Graphics modeling environments control transformations using what are known as transformation matrices. In case of 3D coordinate transformation from one geographic space to another, we normally apply three basic manipulations on the source geographic space namely, rotation, translation and scale change. A point in 3D in projective geometry is denoted as (x, y, z, w). When represented as a *matrix*, a rectangular array of numbers that are organized in rows and columns, this is shown as a column:

$$\begin{bmatrix} X \\ Y \\ Z \\ W \end{bmatrix} \tag{1}$$

Let us say that the point P (X, Y, Z, W) is to be transformed. Point P is to be translated by a distance T (T_x, T_y, T_z, T_w). So, the points new position (transformed position) can be obtained as shown in Equation (2) as follows:

$$X' = X + T_x$$
$$Y' = Y + T_y$$
$$Z' = Z + T_z$$
$$W' = W + T_w \tag{2}$$

This is represented by Equation (3) as follows in matrix transformation

$$\begin{bmatrix} X' \\ Y' \\ Z' \\ W' \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 & T_x \\ 0 & 1 & 0 & T_y \\ 0 & 0 & 1 & T_z \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} X \\ Y \\ Z \\ W \end{bmatrix} \tag{3}$$

Similarly, rotation and translation of axes of original geographic space to final geographic space can be expressed by equations
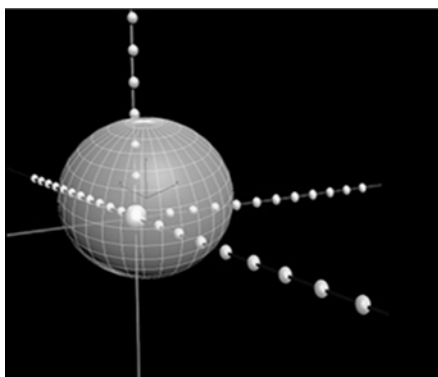

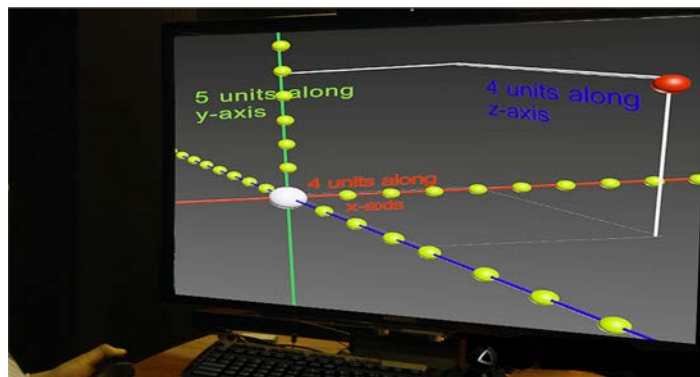Figure.5: Geosphere Object in Cartesian coordinate.

Figure.6: Interaction with Framework for a demo of Basic Geospatial Concepts.

$$\begin{bmatrix} X_i \\ Y_i \\ Z_i \end{bmatrix} = \begin{bmatrix} m_{11} & m_{12} & m_{13} \\ m_{21} & m_{22} & m_{23} \\ m_{31} & m_{32} & m_{33} \end{bmatrix} \begin{bmatrix} X_s + x \\ Y_s + y \\ Z_s + z \end{bmatrix}$$

Where,
$$m_{11} = \cos\phi\cos\kappa$$
$$m_{12} = \cos\omega\sin\kappa + \sin\omega\sin\phi\cos\kappa$$
$$m_{13} = \sin\omega\sin\kappa - \cos\omega\sin\phi\cos\kappa$$
$$m_{21} = -\cos\phi\sin\kappa$$
$$m_{22} = \cos\omega\cos\kappa - \sin\omega\sin\phi\sin\kappa$$
$$m_{23} = \sin\omega\cos\kappa + \cos\omega\sin\phi\sin\kappa$$
$$m_{31} = \sin\phi$$
$$m_{32} = -\sin\omega\cos\phi$$
$$m_{33} = \cos\omega\cos\phi$$

(4)

However, for students of GIS, especially those at the beginner level, these equations representing projections and transformations are not quite easy to understand. However, when these are explained using the intuitive representations as shown in Figure 6 through Figure 8, the learning process becomes quite stimulating. Figure 5 and Figure 6 represent parts of the framework, where the concepts of transformation and projection are instructed to students through interactive exercises. Similarly, the concepts behind the above equations can be explained to students by 'demonstrating' the actual actions in real-time using practical examples.

The demonstration of the actual transformation in terms of real-world geospatial coordinates is quite straightforward when using the interactive framework. Hence, the above equations (1) (2) (3) (4) become much easier for students to understand when performing interactive manipulations using various modes of operation. Three broad categories of transformations include: Translation, Rotation, & Scaling are illustrated subsequently in Figure 7. *Translation* refers to moving an object from one position to another, either in 2D or 3D. When done in 2D, this involves moving the object along either the x-axis, the y-axis, or both. In 3D, this involves any combination of x-axis, y-axis, and z-axis. For instance, if the translation occurs only on the XY

plane, there is no change in the z value. *Rotation* refers to orienting (moving) an object about an axis and center. *Scaling* refers to modifying the size/proportion of objects.
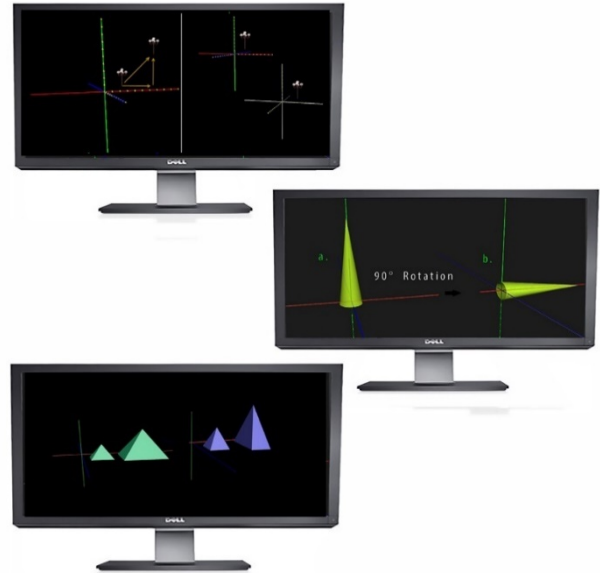

Figure 7. Transformations via Interactive Examples.

Tier II /Component 2 (Mapping Component-1 Concepts/examples to CG modules)

Mapping the concepts and examples from Tier-I to modules that can be presented using the rich dVR interface for optimal design value. The modules (for the conceptual examples from earlier step) wherein the virtual worlds are generated for viewing the explanations in the form of animation and interaction in the dVR environment. Figure 8 illustrates the many different types of geodata formats generated in the Tier II. These object-based geospatial objects were created for all the 3 VR frameworks mentioned earlier namely desktop VR (dVR), enhanced dVR, and iSpace (CAVE). Many hierarchical representations were created to visually organize the concepts and then link them to the 3D conceptual models generated (Tier I). Authors evaluated various alternative ways in which these models can be viewed and interacted with using the 3 frameworks used in this study.
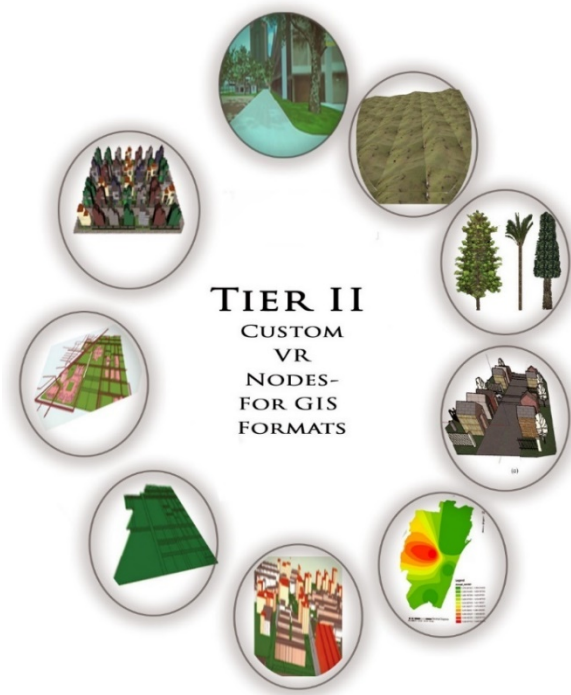
Figure 8. Tier II – Custom VR-Compatible GIS Objects.

These virtual scene objects are made with custom-built virtual nodes that can represent a wide range of geospatial objects (Figure 8) including:

- 3D geospatial representations
- Shape files
- Vector graphics
- DEM (Digital Elevation Models)
- TIN (Triangular Irregular Network)

- Land use Data
- Satellite Imagery & Image Data
- Coverages & Grids

Subsequently, the paper discusses more complex topics that are derived from what we discussed thus far. Moving to more advanced geospatial concepts, the framework can be used to generate different kinds of models for visualization and simulation. For instance, the framework can be used to construct the landslide evaluation model, geographical data of landslide locations, rainfall distribution, DTM (5m x 5m), SPOT images, and typhoon events were collected and processed into a GIS database (Figure 9a). The landslide evaluation model was developed using the fragility curves by the application of maximum likelihood estimation (MLE). The warning of landslides was determined by the rainfall thresholds of each slope unit surrounding the protected area. Figure 9 shows the influential slope units around the study area and the fragility curves, the landslide probability, of each slope unit. When given a rainfall condition, the probability of landslides can be determined from the fragility curves. Therefore, the warning levels of landslides can be expressed as green, yellow, and red colors depending on the probability criteria of landslide. Most importantly, the disaster prevention plans and response can be illustrated and evaluated under conditions using dVR technology. A dVR-based technology is a good solution for this situation (Figure.9b showing the study area for the dVR example of landslide warning model).
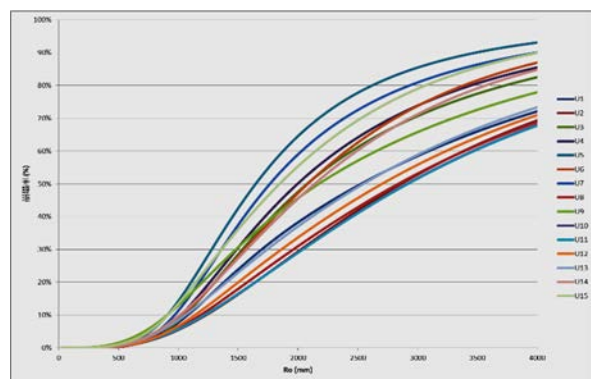

Figure 9a. Study - Influential slope units.

Figure 9b. Fragility curves of landslide.

Tier III /Component 3 (customization for mode-specific delivery of design materials)

In this component, the external authoring interface (EAI) is programmed to facilitate user to customize the VR scene layout by means of the interaction capabilities accomplished earlier. Java/JavaScript plugins are used to accomplish dynamic interaction with the VR world objects. In order to create the virtual objects that can be 'interacted with', they should be created with built-in event recognition features. A virtual scene model is composed of many individual objects that together make up the entire virtual environment. In an urban landscape scene, this will include elements such as roads, buildings, trees, parking lots, etc. The customization required for the virtual objects is dictated by the level of interaction required in a scene. This involves deciding what scene objects need to be programmed to receive (or recognize events) and respond. This is based on the very familiar event-response logic, wherein a software object receives input and produces corresponding output.

Ultimately, any object is modeled by specifying the geometric and appearance attributes. Next, the paper discusses the use of the other mode of VR mentioned earlier. The iSpace is a CAVE system that allows high fidelity and facilitates interaction, navigation, and immersion. Game-based scenarios are developed to promote the fun-learning process. The so-called game can provide a learning situation different to the traditional one. The fundamental value of games provides the player a sense of ownership, stimulating lateral thinking, problem solving, and teamwork. The players also need to overcome the frustration and stay on the targets [10]. Gee (2003) [10] also indicated that a game can help people learn complex GIS concepts by an interactive participation mode. The recent US National Education Technology Plan's research indicated that games can be used as an assessment tool to evaluate the students' understanding about the course content. Because gaming can provide immediate feedback, and the players can correct accordingly and move forward, while providing the opportunity to experiment and explore [21]. These GIS-based games can be used in GIS education, business, GIS applications in health and medical care, military, and government [1].

Results and Discussion: Study outcomes of the GIS-related Games in iSpace lab

The authors developed a kinesthetic guide system with a cave automatic virtual environment (CAVE), which can also be the assistance of the aforementioned ideas. The virtual CAVE system uses the image detection technology to encoding the location of a user, then decode the coordinate to generate 3D image. The CAVE system includes 1. Image processing modules, which receive and analyze images and create motion database, 2. Storage modules, which store the motion data, including database of library, building models, and statistics, 3. Analyzing module, which operates according to the instruction of users and motion data, 4. Instruction interface module, which determines the navigation mode based on user's instruction, and collect the votes in the database of a specific building model. For this study, the steps in the game creation include 1. Aerial Photo Collection, Google Earth maps, and GIS data of campus, and create building models by Sketch up, 2. Discussion about the information to be shown in the campus navigation system, with the SA inputs (analysis and architecture), 3. Importing the information and data into the Unity module to complete the interactive navigation system. The system contains three modes: fly-through, drive, and vote modes. In the fly-through mode, the system automatically exhibits the 3D scenes with bird's-eye view and return an overview information (Figure.10). In the drive mode (Figure.11), users can explore the 3D scenes with their hands in a kinesthetic way.

Particularly in the field of Geoinformatics, a specialization dealing with the objects in 3D/4D spatial domain and their interaction with the neighboring objects, it is imperative to have interactive VR based tools for educating the students the concepts and applications of the

technology. The perception of 3D/4D geographic space will facilitate better understanding of spatial concepts and phenomena. This leads to more confidence and innovative thinking of students for application of technology in new domains overcoming the limitations. From an academic standpoint, this framework signifies a paradigm shift in the instructional approach to GIS instruction. As knowledge and skills within the geospatial domain form an essential component of GIS curriculum, the inability to successfully understand such concepts and complete courses may indeed lead to increased course dropout rates. The 3D visual approach enables students to overcome any inhibitions they may have and the interactive framework stimulates them to explore and understand GIS using practical examples and a game-oriented instruction. Finally, in the Table 1, we present the summary of the various important features with respect to the 3 modes discussed in the study within the GIS context.

Limitations

As this is a prototype study, this paper focuses on the design and implementation in detail. This framework has been designed after careful literature study and considering the limitations (graphical, geospatial, etc.). The paper explains the various steps and also how the framework for different applications within the geospatial domain, however, the assessment could not be included as this is a work in progress. However, currently, we are working on demonstrating the Desktop VR part (using a test site – Figure 12) that can be accessed via an OpenSource plugin for viewing 3D worlds on the internet. This will facilitate testing the interface and compare the results with the ones obtained from the iSpace. Figure 13 shows the demonstration of the 'layer-based approach' used in GIS. These can be interacted with by the user upon completion, wherein the user can enable or disable the different layers (landuse, road network, 3D buildings, etc.) and view them with different Levels of Detail (LOD) and Points of View (PoV).
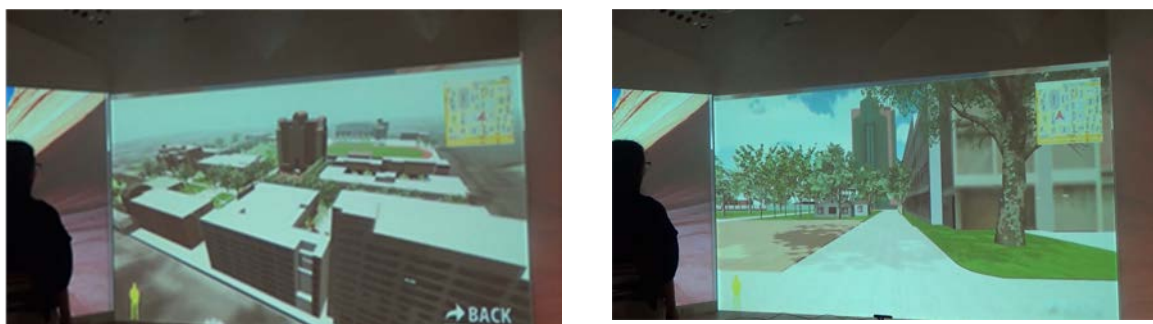

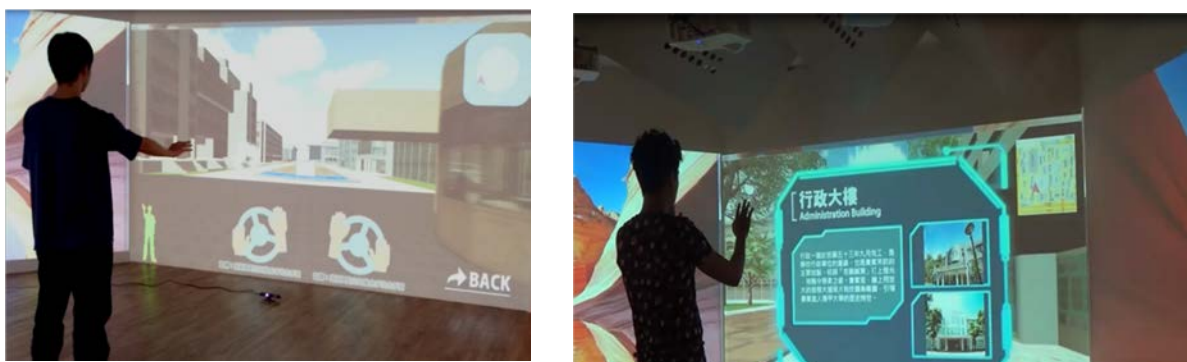Figure.10. Fly-through in the iSpace CAVE (Left: bird's-eye view; Right: human-eye View).

Figure.11. Drive mode guide in iSpace.

Table.1: Comparative Results Among the 3 Modes for GIS Applications [6].

	Desktop VR for GIS	Augmented dVR With HMD system for GIS Visualization	iSpace for Geospatial Applications
Display	Standard LCD Monitor + GIS Software for Viewing GIS Files	LCD Monitor + Oculus Rift: 1200x800 + Interactive GIS Modules for Augmented VR	- Rear Projected Optically Blended MP system (> 2 million, minimum)
Horizontal Field Of View	At a distance of 20" from screen, approx.. 60 deg for a 20" Screen	< 110 degrees	360 degrees
Tracking	NO	YES Display & rotational tracking	Yes. Wide Range Possible Magnetic Tracking / Optical Tracking (OT)
Real-time Interaction	YES	YES	YES
Immersion	Low	Medium High	Very High
Equipment + Installation Cost	2k	2500 $	2,100,000 (Approx.)
Op/Maintenance Cost	Negligible	Negligible	(Op)50 k /annum (Maint.) 100 k /annum

Conclusion

By helping students to understand the basic concepts of GIS, the proposed approach enhances their performance in the coursework and hence increases graduation success rates in the long run. Besides, improving the geospatial competency of students increases their career prospects. More importantly, the proposed framework can be implemented easily in desktop Virtual Reality (dVR) systems, hence making it affordable for higher education institutions. Upon successful design and implementation, this proposed framework can contribute to significantly improving the infrastructure for education due to its cost-effective approach and easy implementation capabilities. This kind of VR setup greatly helps the demonstration of geospatial concepts involving spatial coordination such as transformation and projection. All features can be modeled as shapes which can be grouped together and transformed (translated or rotated) within the coordinate system within which they are built. The geometry field is used to describe the geometric properties of the object and the appearance field is used to describe how the object looks. The 'intelligent' objects that can

'sense' user actions are programmed along the notion of 'Event Driven Programing.' Figure.14 shows the use of the framework that allows viewing the results in multiple formats. Similarly, a 4D visualization of three dimensional objects in time domain can be visualized in case of simulating the geographic events like urban flooding. The progression wave front in 3D dimension space over a city can be depicted efficiently to demonstrate the impact of friction offered by various landuse/land cover classes on wave progression.

Figure 14. Interacting with 2D/3D geospatial objects: Multiple points of view/Levels of detail.

Figure 12. Test-Site in Development for Evaluation of Framework.
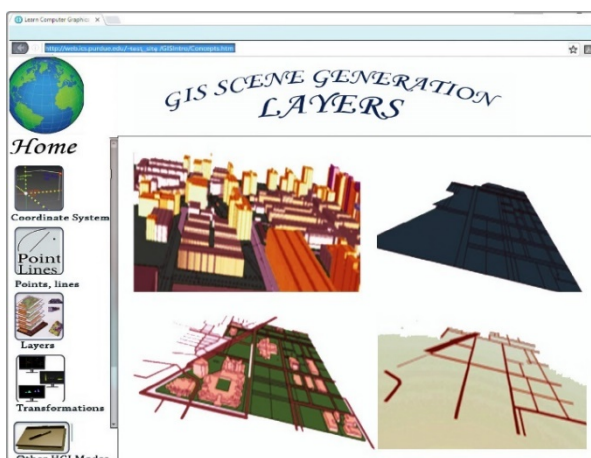
Figure 13. Illustration of Layer-Based Approach: Test-Site in Development.

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