DEVELOPMENT AND EVALUATION OF A TERRAIN REPRESENTATION SYSTEM FOR HIGHWAY ROUTE PLANNING

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Abstract

In recent years, mixed or/and augmented reality,which aims to integrate virtual space with real space have be received a significant amount of attention in research and development. In particular, tangible interface is one of the interesting research growth areas. The hypothesis of this research project is that the introduction of a tangible interface should assist designers and planners to recognise the 3-D feature of the terrain and therefore a more efficient highway route planning and construction can be developed. In this context, the objective is to develop and evaluate a tangible terrain representation system (TTRS). The TTRS can represent a terrain surface by controlling the shape of a stretchable screen used to represent the terrain surface by means of a total of 64 actuators (8×8) and projecting an aerial photograph onto the screen. Applying the TTRS to highway planning, a highway alignment is determined by control points which are positioned by a magnetic position device. As a highway planner set the control point of a highway alignment on the TTRS, the image of a highway alignment is projected on the TTRS. The TTRS was evaluated against VR-based visual 3D representation using a group of 9 final year graduate students. A well defined evaluation measures of usability was developed and used in the process. The paper concluded that TTRS is very effective tools for design and construction of highway projects.

Keywords

Virtual reality, Tangible display, Highway Design and construction, Digital Terrain Model, Evaluation of usability.

1. INTRODUCTION

Current methods of highway alignment planning and construction, in which 2D topographic maps and planners 'imagination' and experience of interpreting images and other information are used. A planner of the highway should reconstruct a 3D topographic image from 2D maps in his/her mind using their experiences and intuition. Accuracy of such images is therefore depends on planner's ability and experience. Recent advances in the development and dissemination of spatial information have made it possible to obtain and use various type of spatial information easily. It is also becoming possible to obtain and use topographic information in many cases which can be provided in the form of mesh data such as USGS Digital Elevation Models (DEM). Such information may be provided bird's eye view prepared by projection translation in two dimensions on a computer display, however, this representation methods make it difficult to intuitively understand topographic information.

To solve this problem, the Makanae et al (2005) have been developing methods for representing virtual terrain surfaces defined on the computer by applying virtual reality (VR) technology and of highway design systems that can be realized by applying those methods, such as the highway route planning system using ‘stereoscopic’ visualization of aerial photographs, or VR-CAD for landscape design using a head-mounted display. However these systems have some problems, for example, the planner must wear special stereoscopic visualization devices and the accuracy of the alignment of new route is not accurate. In recent years, research and development efforts associated with mixed reality, which aims to integrate virtual space and real space have also been developed. One of these efforts is the research and development of tangible interface. Believing that the introduction of a tangible interface helps solve these problems, the authors have been working on the construction of a tangible terrain representation system (TTRS) for highway design. This paper introduces and discusses the mechanism of the TTRS and highway planning method and construction using this system. The paper also evaluate the usability of the TTRS in comparison with ‘stereoscopic’ visualization systems using a well developed usability measures.

2. VR-BASED VISUAL 3D REPRESENTATION METHOD

Virtual reality (VR) is a technology to experience a realistic virtual world defined on the computer. The technology uses an interface which makes an effective use of stereoscopic visualization and this can be made possible by means of the two human eyes in order to visually enhance the degree of reality.

The mechanism by which a human visually recognizes the three-dimensional configuration of an object involves two types factors: physiological factors and psychological factors. Physiological factors, which are due to the functions of the human eye, include the focus adjustment function of the lens, eye convergence, binocular parallax and monocular motion parallax. Psychological factors, which help reconstruct 3D images from experience, are classified either as geometric or optical. Among these factors, binocular parallax, which is one of the physiological factors, is generally thought to be most important in 3D perception.

The stereoscopic visualization technology used in the field of virtual reality is based mainly on 3D perception caused by binocular parallax. If the locations of the eyes of a human viewer are determined in a virtual space defined on the computer, a pair of perspective images just like images that would be perceived by the two human eyes can be obtained by applying computer graphics (CG) technology. By giving the perspective images thus obtained to the two eyes of a human viewer, the viewer can be made to perceive the images as a 3D object. Devices for giving different images to the left and right human eyes have been developed during the evolution of virtual reality technology. Representative examples of such devices are stereoscopic eyeglasses with liquid crystal shutters, 3D displays, head-mounted displays (HMD) and immersive displays such as CAVE (e.g., Cruz-Neira, 1993).

In recent years, research efforts associated with mixed reality, which aims to integrate virtual space and real space have also been developed. One of these efforts is the research and development of tangible interface. The MIT Media Laboratory, for example, has developed a system called "Illuminated Clay," which projects information onto a terrain surface created with clay (Piper et.al., 2002).

3. VR-BASED HIGHWAY DESIGN SYSTEM DEVELOPED TO DATE

The authors have been working to develop terrain representation methods making use of VR technology and construct design support systems using these methods. This paper describes: a road design support system that uses stereoscopic visualization of aerial photographs and a terrain representation and urban space modeling system that uses an HMD, both of which have been developed by the authors, along with problems of these systems.

4. HIGHWAY ROUTE PLANNING SYSTEM USING AERIAL PHOTOGRAPHS

Makanae(2002) has developed a system (HRPS; Highway Route Planning System) that acquires terrain images through the stereoscopic visualization of aerial photographs and enables road design. Aerial photograph images taken into the computer in the form of digital information are shown on the display of a stereoscopic viewer (CrystalEyes2 manufactured by Stereo Graphics, Inc.) as information that can be visualized stereoscopically. A coordinate system identical to the stereoscopic visualization space obtained by aerial photograph orientation is defined on the computer, and road design is conducted in this 3D virtual space. Parametric curves (B-spline) are used to define road alignments, and control points are located within the space so that their alignments can be defined easily. A 3D model of each road structure is automatically generated according to the alignment defined on the aerial photograph, and plans, longitudinal profiles and perspectives can be displayed.

The main advantage of this system is that it allows an engineer who is might be good at interpreting topographic characteristics (e.g., landslides) from aerial photographs to directly determine road alignments with the assistance of a road de-sign module that uses parametric curves. This is particularly advantageous in, for example, designing mountain roads under poor topographic conditions. By making direct use of aerial photographs, unnecessary mapping processes can be eliminated. A problem with this system is the applicability of road alignments determined by using parametric curves to the current design standard. An-other problem is that the relationship between constructed road structures and the terrain surface represented in a virtual 3D visualization space cannot be computed.

5. TERRAIN REPRESENTATION METHOD USING HMD: VR-CAD SYSTEM

In the conventional drawing-based space design method, the designer constructs 3D configurations in his or her mind while preparing drawings. VR technology, however, makes it possible to define any 3D virtual space on the computer. The VR-CAD system developed by Makanae (2003) enables the designer to immerse himself or herself into a virtual space constructed on the computer. In the virtual space, the designer can exist on any scale: the designer can enter the space either as a correctly scaled human figure or as a giant. The system also enables the designer to conduct 3D design without relying on the 2D/3D conversion capability of the designer.

The system consists of a head-mounted display (HMD) and 3D position sensors. By combining the HMD and a position sensor, the position and orientation of the head can be measured and appropriate images can be displayed so that the design has a 360-degree field of view both in the horizontal direction and in the vertical direction.

Since the system is intended for use in constructing large structures such as roads, terrain information is essential. Elevation data (50 m mesh) in Digital National Land In-formation are used as 3D terrain models for terrain representation in the virtual space. The modeling input inter-face of the VR-CAD system has a 3D mouse and key-board equipped with a position sensor. These devices enable 3D modeling of such features as buildings (rectangular prisms, cylinders), roads and trees by simple operations. Known problems of the design interface of this system include the difficulty in perceiving the position of the 3D cursor and the difficulty in comprehending the relative positions of the terrain surface and the object of interest.

6. DEVELOPMENT OF TANGIBLE TERRAIN REPRESENTATION SYSTEM

From the above discussion, problems of the terrain and design support systems the authors had developed include the following:

- Difficulty in comprehending the relative positions of the terrain surface and the object of interest
- Need for a special stereoscopic visualization device
- Limited field of view
- Not usable for group work

Some of these problems can be solved by using large scale display systems such as a CAVE system. They have no filed of view limitation and can support more intuitive positioning and group working. However, they require wearing the stereoscopic device and the cost is expensive. Believing that the introduction of a tangible interface helps solve these problems, the authors have been working on the construction of a tangible terrain representation system.

Figure 1 shows the configuration of the terrain representation system. As shown, the system represents a terrain surface by controlling the shape of a stretchable screen used to represent the terrain surface by means of a total of 64 actuators (8 by 8) and projecting an aerial photograph onto the screen.

The size of screen is 60cm by 60cm square, and the moving range of each actuator is about 250 mm.

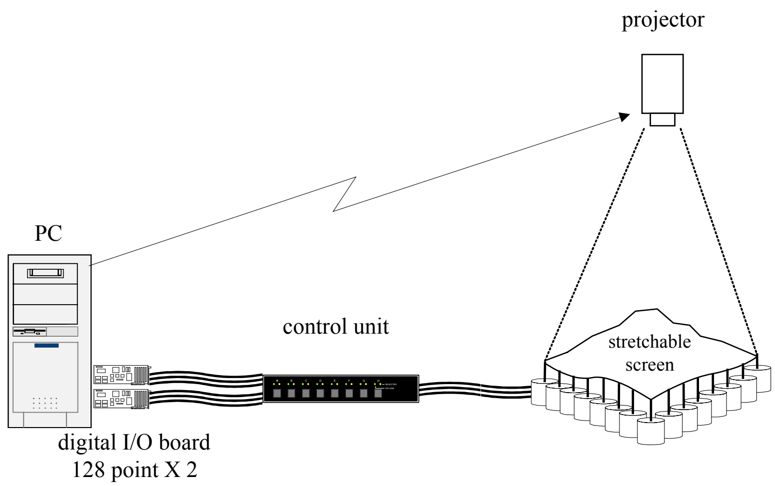

Figure 1: The configuration of the terrain representation system.

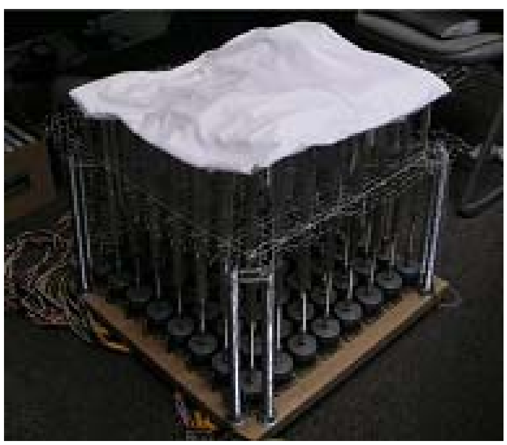

Figure 2: An Overview of the TTRS

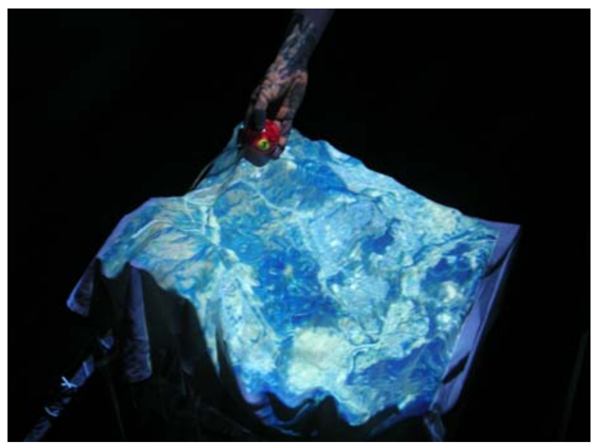

Figure 3: Highway Route Planning Using the TTRS

Mesh data of Digital National Land Information (Japan) are used as terrain data, and the height of each actuator is determined according to the mesh data values. The scale of the terrain relies on resolution and grid interval. Where the grid interval is 50m, the system can represent the area of 350m x 350m horizontally, 209 m vertically. Where the grid interval is 1km, it is 7000m x 7000 m horizontally, 4172 m vertically. The resolution of this system is limited to 8 x 8, however, the effective resolution for each purpose of terrain representation must be considered in future.

Figure 2 shows an overview of a terrain represented by using the system. An aerial photograph is projected onto the stretchable screen. The cost for this development is less than US$10,000. Its low cost gives an advantage on the TTRS as compared as large scale display systems.

7. USABILITY MEASURES

In order to evaluate the usability and facilities provided by the TTRS compared with the 'stereoscopic' visualization systems, a well defined methodology has been developed. It includes the following:

- Review of recent literature of usability measures.
- Development of scenarios of designing of a highway in Japan using both TTRS and 'stereoscopic' visualization systems.

- Development of questionnaire for usability measures based on the literature review and the scenarios design
- Run experiments using 9 final students in the project design at Miyagi University, Japan.
- Analysis of the results and suggestions for future research activities.

The following discuss the above points in details.

7.1 Review of literature in usability measures: Usability is a core term in human-computer interaction (HCI). Usability has been defined as 'the capability to be used by humans easily and effectively' (Shackel, 1991) and 'the effectiveness, efficiency, and satisfaction with which specified users can achieve goals in particular environment', (ISO 1998). A key research question in HCI is how to work with and improve the usability of interactive systems. Hornbaek, K 2005, researched a wide range of papers in the area of usability and identified strength and weakness of current practices of using usability measures. He argued that there are several challenges with respect of measuring usability, these are: understand better the relationship between objective and subjective measures of usability, understand better about how to measure learnability and retention, study correlation between measures and to push the boundaries beyond current measures to include micro measures such as those related to cognitively and social complex tasks. Dawood et al (2005) developed user evaluation methodologies to measure the usefulness and operations of the VIRCON tools. They used real live case studies and 10 industrial personnel to experiment with the VIRCON tools. The methodology includes three steps approach: briefing of participants of the tools and the case studies, participants apply the tools in a well defined steps and detailed instruction and finally participants fill questionnaire to evaluate the system. The questionnaire was then followed up by semi-structured interviews to identify issues with the tools and the case study.
Using pervious literature, the authors classified measures under the following headings:
Measure of effectiveness, Measure of efficiency, Measure of satisfaction and Attitude towards interface. More elaboration of these measures will be presented in questionnaire form. Details of these measures will be demonstrated in the questionnaire section.

7.1 Development of scenarios: The scenarios are composed of series of tasks to develop a highway alignment using TTRS and '3D stereoscopic' tools. Topographic information of a location in Japan has been obtained in the form of mesh data such as USGS Digital Elevation Models (DEM). Aerial photograph images taken into the computer in the form of digital information and used in the stereoscopic viewer and TTRS. The tasks are to recognise the terrain and draw the 3D highway alignment in the 3D virtual space by setting some control points for a parametric curve. In the TTRS system the magnetic tracking system POLHEMUS FASTRAK, is used as a pointing device. As the planner set the control point on the TTRS, the parametric alignment can be calculated automatically, and then it is overlaid on the aerial photograph and projected on the TTRS (Figure 3). By using this system, the planner can obtain images of terrain and highways intuitively without wearing any equipment.
Each participant runs the design scenarios on TTRS first and then on the stereoscopic viewer or vice versa.

7.2 Development of questionnaire: In order to measure usability and questionnaire list has been developed and incorporates the measures identified above. Once participants develop the scenarios identified above for each system, they are asked to fill the questionnaire. The measures covered various aspects as can be seen in table 1. Participants are asked to rate each measure using 5-scale rating method: '2' being very effective or highly satisfied, '1' being satisfied, '0' average, '-1' not quite satisfied and '-2' not satisfied.

7.3 Running experiments: Nine final year students from Project Design at Miyagi University participated in the evaluation process.
Each student followed the scenarios identified above and developed a route for a highway design using TTRS first and then the Stereoscopic system or vice versa. Each experiment lasted about 1 hour. Five students experimented with HMD stereoscopic view first and then moved to the TTRS and the other four experimented with TTRS first and then moved to HMD stereoscopic view. Although the experiments were conducted using final year students, the results of the experiments can be related back to professional highway planners as all students have some from of

practical experiences and academic courses at Miyagi University are highly relevant to industry.

7.4 Analysis of the results: The results of the questionnaire are given in Table 1. Respondents were asked to allocate a score to each measure after completing the tasks that were assigned to them. Table 1 shows the score for each respondent for 13 measures. Averages and standard deviation was calculated in order that the results of HMD and TTRS can be compared. As can be seen in table 1, the tangible display produced better scores than HMD in all measures except for 'satisfaction with the ease-of-use' and 'fun'. The TTRS scored very high in measures like 'easy to manipulate', 'easy to understand the features of the terrain', 'realism', 'learnability' and 'easy to understand the 3D position of the pointer'. These are very important measures which validate the use and deployment of the TTRS.

On the other hand, the TTRS scored low in three measures, 'accuracy to drawing a highway alignment', 'satisfaction with ease of use' and 'anxiety'. The research team is taking these issues on board and plans are underway to design and implement the next generation TTRS. A total of a total of 256 actuators (16 by 16) TTRS is being design compared with the current TTRS (8 by 8) and this should improve the accuracy and satisfaction with ease of use. Figures 4 and 5 shows the analysis of the experiment results in '100% stacked bars' presenting the score in percentage format for each measure. For example, in figure 4, 65% of respondents were 'highly satisfied, score 2' with measure code 1 'easy to understand the features of the terrain'. What is apparent from figure 4 and 5 is that the TTRS shows higher percentage of satisfaction (scores 2 and 1) for most of the measures.

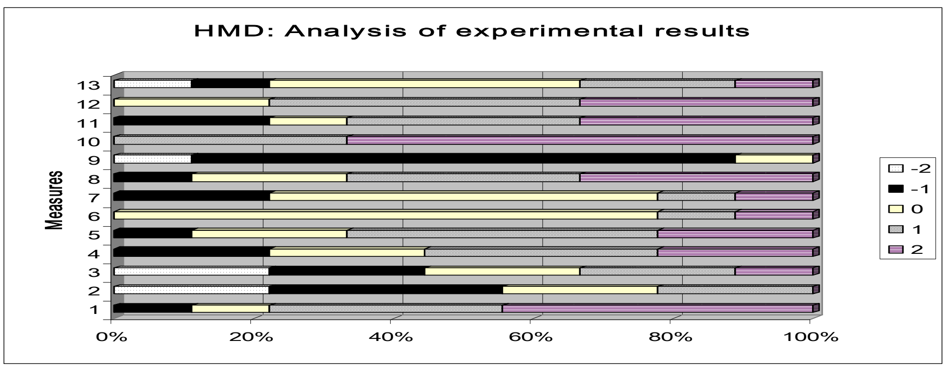

Figure 4: Analysis of experimental results fro the HMD

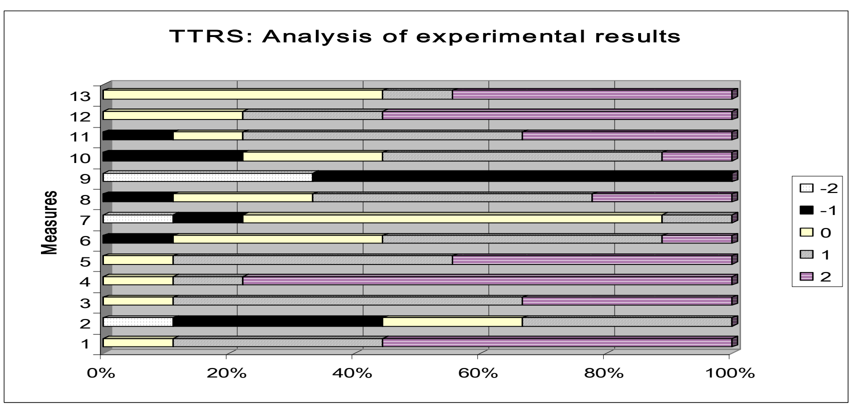

Figure 5: Analysis of experimental results fro the TTRS

Table 1: Results of measures analysis

	HMD	A	B	C	D	E	F	G	H	I							
		22	21	25	20	21	21	21	22	21							
Measure Code	Measures	F	M	M	M	F	M	F	F	M	**Average**	**STD**	-2	-1	0	1	2
10	Fun	1	2	2	1	2	1	2	2	2	**1.667**	**0.500**	0	0	0	3	6
1	Easy to understand the feature of terrain	1	2	2	1	1	0	-1	2	2	**1.111**	**1.054**	0	1	1	3	4
12	Leanability	1	1	1	0	2	2	0	1	2	**1.111**	**0.782**	0	0	2	4	3
8	Annoyance	1	1	0	-1	2	0	1	2	2	**0.889**	**1.054**	0	1	2	3	3
5	Realism	1	1	1	2	2	0	0	1	-1	**0.778**	**0.972**	0	1	2	4	2
11	Intuitive	-1	-1	1	2	0	1	2	1	2	**0.778**	**1.202**	0	2	1	3	3
4	Easy to manipulate	-1	0	1	1	2	0	2	-1	1	**0.556**	**1.130**	0	2	2	3	2
6	Satisfaction with interface	0	0	2	0	1	0	0	0	0	**0.333**	**0.707**	0	0	7	1	1
7	Satisfaction with the ease-of-use	1	-1	0	0	0	0	-1	2	0	**0.111**	**0.928**	0	2	5	1	1
13	Physical comfort	-2	2	1	1	-1	0	0	0	0	**0.111**	**1.167**	1	1	4	2	1
3	Easy to understand the 3D position of the pointer	1	-1	2	-1	-2	-2	1	0	0	**-0.222**	**1.394**	2	2	2	2	1
2	Accracy to draw a highway alignment	0	1	1	-2	-2	-1	0	-1	-1	**-0.556**	**1.130**	2	3	2	2	0
9	Anxiety	-1	-1	-1	-1	-2	-1	-1	0	-1	**-1.000**	**0.500**	1	7	1	0	0

	Tangible Display	A	B	C	D	E	F	G	H	I							
		22	21	25	20	21	21	21	22	21							
Measure Code	Measures	F	M	M	M	F	M	F	F	M	**Average**	**STD**	-2	-1	0	1	2
4	Easy to manipulate	2	2	2	1	2	2	2	0	2	**1.667**	**0.707**	0	0	1	1	7
1	Easy to understand the feature of terrain	2	2	1	1	2	0	1	2	2	**1.444**	**0.726**	0	0	1	3	5
5	Realism	2	2	1	1	2	1	0	1	2	**1.333**	**0.707**	0	0	1	4	4
12	Leanability	2	2	1	1	2	2	0	0	2	**1.333**	**0.866**	0	0	2	2	5
3	Easy to understand the 3D position of the pointer	0	1	1	2	2	1	2	1	1	**1.222**	**0.667**	0	0	1	5	3
11	Intuitive	2	-1	1	2	1	1	1	0	2	**1.000**	**1.000**	0	1	1	4	3
13	Physical comfort	2	2	2	0	2	0	0	1	0	**1.000**	**1.000**	0	0	4	1	4
8	Annoyance	1	1	0	-1	2	0	2	1	1	**0.778**	**0.972**	0	1	2	4	2
6	Satisfaction with interface	1	2	1	1	0	1	0	-1	0	**0.556**	**0.882**	0	1	3	4	1
10	Fun	-1	1	0	-1	2	1	0	1	1	**0.444**	**1.014**	0	2	2	4	1
2	Accracy to draw a highway alignment	-1	0	1	1	-2	1	-1	-1	0	**-0.222**	**1.093**	1	3	2	3	0
7	Satisfaction with the ease-of-use	1	-1	0	0	0	0	-2	0	0	**-0.222**	**0.833**	1	1	6	1	0
9	Anxiety	-1	-2	-1	-1	-2	-2	-1	-1	-1	**-1.333**	**0.500**	3	6	0	0	0

8. CONCLUSIONS

Planning highway routes is time consuming and demand highly experience planners. For the purpose of accuracy and realism, planners have to imagine the terrain features and possibly assemble a 'mental' 3D model of the terrain. This paper describes the terrain representation methods and their application which should assist planners to imagine the terrain feature and therefore can plan highway routes more effectively and efficiently. The method dubbed TTRS 'Tangible Terrain Representation System' which can represent a terrain surface by controlling the shape of a stretchable screen used to represent the terrain surface by means of a total of 64 actuators (8×8) and projecting an aerial photograph onto the screen.

The paper discussed the development of the TTRS and developed an evaluation strategy for usability measures. The paper concluded that TTRS is very effective tools for design of highway projects.

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