Application of 3D Terrain Representation System for Highway Landscape Design

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Abstract

In recent years, mixed or/and augmented reality, which aims to integrate virtual space with real space, has received considerable attention. In particular, the development of a tangible interface is an interesting research area. In this study, the objective is to develop and evaluate a tangible terrain representation system (TTRS). The TTRS can be used to represent a terrain surface on a stretchable screen by controlling its shape using 64 actuators (8 × 8) and projecting an aerial photograph onto the screen. The TTRS can be used to determine a highway alignment by defining control points using a magnetic positioning device. When a highway planner sets the control point of a highway alignment on the TTRS, the image of the highway alignment is projected onto the TTRS. A group of nine final-year graduate students was selected to evaluate the TTRS against a virtual reality (VR)-based visual 3D representation. A well-defined evaluation measure of usability was developed and used. Further, the paper introduces a highway and landscape design system developed by using a desktop TTRS system.

Keywords: virtual reality, tangible display, highway design and construction, landscape design, digital terrain model, evaluation of usability

1 Introduction

The current methods of highway alignment planning and construction include the use of 2D topographic maps and the planners' creativity and experience of interpreting images and other information. A highway planner has to mentally reconstruct a 3D topographic image from 2D maps using his/her experiences and intuition. Therefore, the accuracy of such images depends on the planner's ability and experience. Recent advances in the development and dissemination of spatial information have made it possible to obtain and use various types of spatial information easily. It is also becoming possible to obtain and use topographic information in many cases; this information can be obtained in the form of mesh data such as USGS digital elevation models (DEM). Such information can be projected two-dimensionally on a computer display to provide a bird's eye view of the terrain; however, this representation method makes it difficult to intuitively understand the topographic information.

To solve this problem, Makanae et al. (2005) have developed methods for representing virtual terrain surfaces defined on a computer by applying virtual reality (VR) technology. These methods can be used to realize highway design systems such as the highway route planning system using stereoscopic visualization of aerial photographs and VR-CAD system 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 alignment of the new route is not accurate. In recent years, research and development efforts have been focused on mixed reality, which aims to integrate virtual space and real space. One of these efforts is the research and development of a tangible interface. Believing that a tangible interface will help solve the above-mentioned problems, the authors have been working on the construction of a tangible terrain representation system (TTRS) for highway design.

In the previous study, an evaluation of the TTRS was carried out. This evaluation clarified that the TTRS is an effective tool in terrain recognition. This paper introduces the mechanism of the TTRS, its application to highway design, and the construction of an improved version of the TTRS for landscape design.

2 VR-Based Visual 3D Representation Method

Virtual reality (VR) is a technology that enables a person to experience a realistic virtual world defined on the computer. The technology uses an interface that makes an effective use of stereoscopic visualization. This is made possible by the use of two human eyes in order to visually enhance the degree of reality.

The mechanism by which a human visually recognizes the 3D configuration of an object involves two types of 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 as optical factors. Among all these physiological and psychological factors, binocular parallax, which is a physiological factor, 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 the 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 providing 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 a 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 Construction of TTRS

We have been working to develop terrain representation methods making use of VR technology and to construct design support systems using these methods (Makanae, 2002, 2003). From these

researches, we have identified the following problems of terrain representation and design support system:
-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 field of view limitation and can support more intuitive positioning and group working. However, these systems require the users to wear a stereoscopic device and are thus expensive. Believing that the introduction of a tangible interface will help to solve these problems, we have been working on the construction of a tangible terrain representation system (Makanae and Nakahara, 2005; Makanae and Nashwan, 2009).

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 for representing the terrain surface by means of 64 actuators (8 × 8) and projecting an aerial photograph onto the screen. The size of the screen is 60 cm × 60 cm, and the moving range of each actuator is approximately 250 mm. In the TTRS system, the magnetic tracking system POLHEMUS FASTRAK is used as a pointing device. As the planner sets 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. By using this system, the planner can obtain images of the terrain and highways intuitively without wearing any equipment. Each participant runs the design scenarios on the TTRS first and then on the stereoscopic viewer or vice versa.

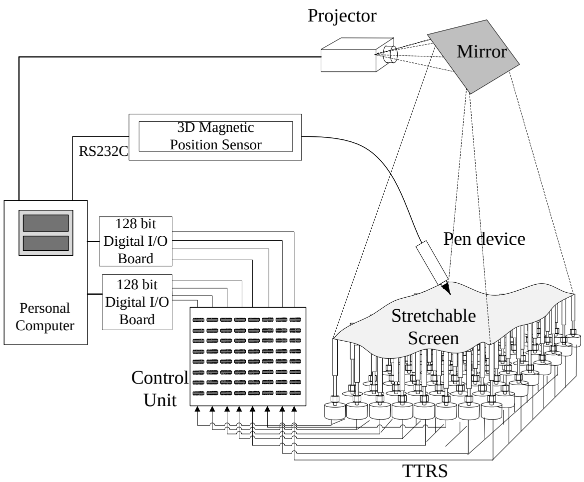


Figure 1: Configuration of terrain representation system

4 Usability Measures

The 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 depends on the resolution and the grid interval. When the grid interval is 50 m, the system can represent a horizontal area of 350 m × 350 m with a height of 209 m. When the grid interval is 1 km, the system can represent a horizontal area of 7000 m × 7000 m and a height of 4172 m. The resolution of this system is limited to 8 × 8; however, the effective resolution for each purpose of terrain representation must be considered in future.

In order to evaluate the usability of the TTRS, an experience is achieved. The scenarios are composed of series of tasks to develop a highway alignment using the 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 are 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. By using the TTRS, the planner can obtain images of the terrain and highways intuitively without wearing any equipment. Each participant runs the design scenarios on the TTRS first and then on the stereoscopic viewer or vice versa.

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 the TTRS first and then the stereoscopic system or vice versa. Each experiment lasted about 1 h. Five students experimented with the HMD stereoscopic view first and then moved to the TTRS, and the other four experimented with the TTRS first and then moved to the HMD stereoscopic view.

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. The average and standard deviation were calculated so that the results of HMD and TTRS could be compared. As a result, the tangible display produced better scores than HMD for all parameters except for “satisfaction with the ease-of-use” and “fun.” The TTRS scored very high on parameters such as “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 parameters that validate the use and deployment of the TTRS. On the other hand, the TTRS scored low on three parameters, “accuracy to drawing a highway alignment,” “satisfaction with ease of use,” and “anxiety.” The research team is taking these issues on board; plans are underway to design and implement the next-generation TTRS. A TTRS having 256 actuators (16 × 16) is being designed as compared to the current TTRS (8 × 8); this should improve the accuracy and satisfaction with ease of use.

Table 1 : The results of the questionnaire (HND and TTRS)

Code	Item	HMD		TTRS	
		Average	STD	Average	STD
1	Easy to understand the feature of terrain	1.111	1.054	1.444	0.726
2	Accuracy to draw a highway alignment	-0.556	1.130	-0.222	1.093
3	Easy to understand the 3D positioning of the pointer	-0.222	1.394	1.222	0.667
4	Easy to manipulate	0.556	1.130	1.667	0.707
5	Realism	0.778	0.972	1.333	0.707
6	Satisfaction with interface	0.333	0.707	0.556	0.882
7	Satisfaction with the ease-of-use	0.111	0.928	-0.222	0.833
8	Annoyance	0.889	1.054	0.778	0.972
9	Anxiety	-1.000	0.500	-1.333	0.500
10	Fun	1.667	0.500	0.444	1.014
11	Intuitive	0.778	1.202	1.000	1.000
12	Learnability	1.111	0.782	1.333	0.866
13	Physical comfort	0.111	1.167	1.000	1.000

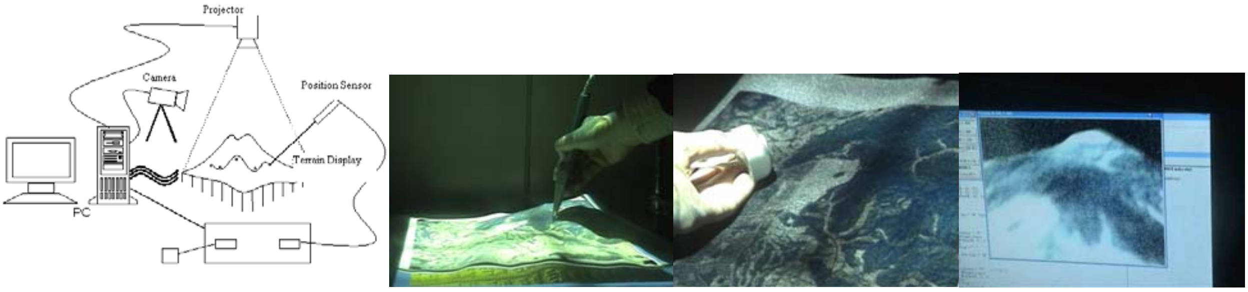
5 Construction of Desktop TTRS

Although the screen size of the TTRS is 60 cm^2, its portability is limited. To improve the portability, we are constructing an improved model of the TTRS that can be used on a desktop. The new TTRS has a 24.5-cm^2 screen that is manipulated by the small type of actuators. The stroke of this actuator is

60 mm, and the weight is 60 g. It is expected that portability will be improved. The configuration of the new TTRS system is shown in Figure 2.

The basic system is the same as the first prototype of the TTRS. The 3D magnetic tracking system Polhemus Fastrak is used as a positioning device. The system has a small CMOS camera device that can output live-view images on the surface. In Figure 2, an example of the image of the live-view system is shown. By using this system, a highway designer can acquire landscape images from the point on the terrain.

To evaluate the prototype of the desktop TTRS, a small experiment is performed. The experiment is to draw a highway on the TTRS and answer the questionnaire. The subjects are six students from Miyagi University.



(a) Configuration (b) Drawing (c) CMOS camera (d) Live-view

Figure 2: Desktop TTRS

The result is shown in Table 2. Each score is an average of a five-grade evaluation. In the experimental evaluation, the ability of drawing a highway is low although a high score is shown for operability and relief recognition. This result implies that the TTRS with a live-view camera is a very useful tool for the recognition of the terrain and the landscape. This is an advantage of the new TTRS as compared to the previous TTRS and the current design method. The subject of this system is to improve the drawing system using a magnetic positioning sensor, which has some problems related to stable positioning, and to improve the projection system to resolve the shadowing problem by hand during the positioning process.

Table 2. Results of the desktop TTRS experiment

Item	Subject						Average Point
	A	B	C	D	E	F	
Ability of drawing	3	3	2	2	2	3	2.5
Relief recognition from TTRS	4	4	4	3	5	4	4.0
Landscape recognition from TTRS	5	4	4	3	3	5	4.0
Relief recognition from live-view camera	5	4	3	4	4	5	4.2
Landscape recognition from live-view camera	4	3	2	4	5	4	3.7
Recognition of matching between relief and highway	4	3	3	5	3	4	3.7
Operability	5	5	4	5	4	5	4.7

6 Conclusions

Planning highway routes is time-consuming and demands highly experienced planners. To ensure accuracy and realism, planners have to imagine the terrain features and possibly assemble a "mental" 3D model of the terrain. This paper describes terrain representation methods and their application that should assist planners with imagining the terrain feature and therefore plan highway routes more effectively and efficiently. Further, the new version of the TTRS, which has a 24.5–cm^2 screen is shown and evaluated in this study. The new system has a CMOS camera using which a planner can acquire landscape images as if he/she were present on the terrain.

Tangible technologies have been developed in the recent several years, and these technologies help the recognition of complicated 3D features such as the terrain considered in this study. Further research and development is required to develop more advanced systems for highway designing using these technologies.

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