Development of the VR-CAD System for Landscape and Town Planning

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ABSTRACT

A virtual reality computer-aided design (VR-CAD) system that provides a virtual space was developed. The system uses a head mount display (HMD) to create a virtual space and reproduces topographic features from digital terrain information. A 3D positioning system is used to model highways, buildings, and trees in the VR environment. The modeling experiment by architects suggests only usefulness of 3D modeling, but also problems about the sense of scale, recognition of the cursor, and difficulty of highway modeling.

KEYWORDS

Virtual Reality, Head Mount Display, Town Planning, Landscape Design

INTRODUCTION

Civil engineering structures are three dimensional (3D), although two dimensional (2D) approaches based on drawings are conventionally used in the design of such structures. The knowledge of 3D geometries of topographic features is indispensable because they function as structural foundations. The designers are required to have the ability to convert 2D terrain data to 3D data in their mind. This ability, which greatly depends on the experience and the skill of each designer, affects the quality and the efficiency of designing structures of complicated shape or structures built on complicated terrains.

To address this problem, virtual reality technology is used in this study to develop a virtual reality computer-aided design (VR-CAD) system for landscape and town planning. A head mount display (HMD) is used in the system to reproduce a 3D digital terrain model (DTM), on which design work can be carried out.

Concept of the VR-CAD system

Virtual reality is a technology to create simulated worlds by use of computers. Virtual reality can be applied to many areas including design, simulation studies, games, and education to add realism.

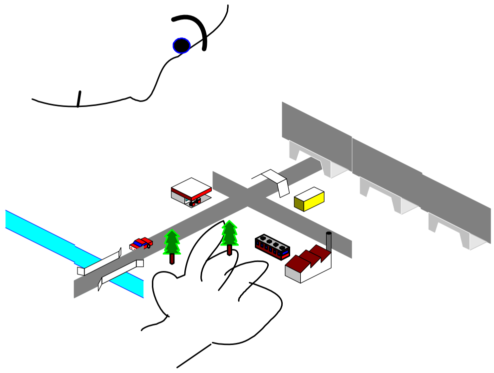

Fig.1 The concept of the VR-CAD

The present virtual reality technology can provides humans with computer-synthesized information associated with not only visual but also auditory and tactile senses to create virtual worlds.

Tools typically used to create virtual spaces include HMDs, data gloves, motion capture systems, CAVE systems (Cruz-Neira et al., 1993), and 3D positioning systems. As an example of 3D modeling system, "3DM" developed by Butterworth et al.,(1992) is a 3D modeler utilizing a HMD. Kwaw and Gorny(1999) developed the Virtual-CAD(VCAD) that supports design of virtual technical object in a three-dimensional stereoscopic environment using pre-defined virtual construction elements. Tanaka et al.(2000) presented a cutting-operation simulation system, which employs a stereoscopic system and a force-feedback pointing system (PHANToM) to simulate the cutting operations of 3D polygon models. Hashimoto and Nakajima (1999) are developing a modeling system that works in an immersive display system CAVE. Also, a modeling system called Illuminating Clay, which allows synthesis of flexible clay models and 3D computer images, is being developed at the Department of Urban Studies and Planning of Massachusetts Institute of Technology (Piper, et al., 2002).

Against these works, this paper aims to develop the VR system for infrastructure and landscape design with the terrain model. Conventionally, civil engineering structures are planned and designed on drawings, which are drawn by designers who construct 3D geometries in their mind. By using virtual reality technology, 3D virtual spaces can be defined arbitrarily on a computer. The authors have developed a highway design system that is based on the stereoscopy of aerial photographs (Makanae and Fukuda, 1998; Makanae, 2002). This is a type of VR-CAD that allows 3D highway route planning using parametric curves in the stereoscopic environment given by a pair of aerial photographs. When aerial photographs are used, however, the designer's view is restricted by the photographing point in the air, and it is difficult to relate the processing of design structures directly with topography.

This study provides a system in which highways and other facilities are designed based on a 3D terrain model constructed from digital terrain data for landscape and town-planning. As schematically shown in Fig.1, the VR-CAD system developed in this study allows a designer as a giant to get into a virtual space created on the computer and move freely over the space for design operations.

The system requirements for the VR-CAD are below;

- Build the VR environment in which a designer can move freely as a giant.
- Represent the terrain model in the VR environment.
- Model and place the objects such as building, trees, and highway.

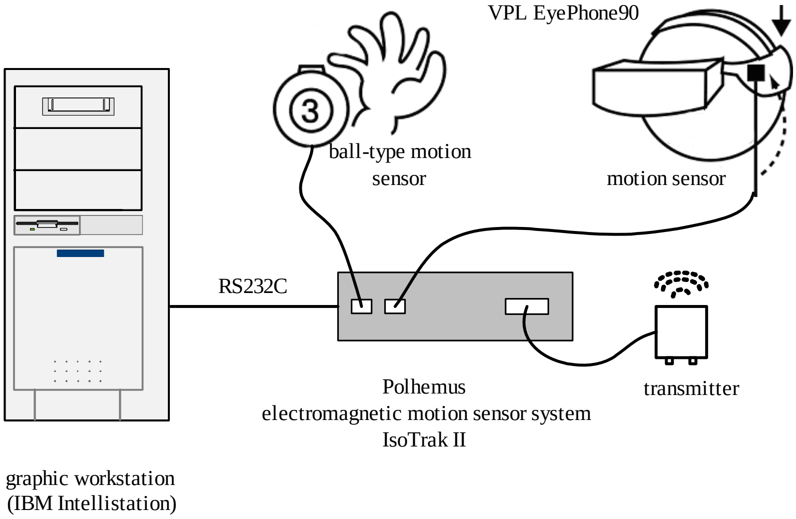

Fig.2 Hardware components of the VR-CAD

Hardware configuration

The hardware configuration of the VR-CAD system developed in this study is shown in Fig.2.

Image processing system

The image processing system is built around an IBM Intellistation ZPro with an Intel's 550-MHz Pentium III Xeon CPU, 256-MB RAM, and 9-GB disc space. A dual-monitor graphics board (Millennium G400) is used for the simultaneous output of two images on a HMD.

3D positioning system

As a virtual reality input device, a 3D magnetic positioning system (Polhemus 3SPACE ISOTRAK II) is used to track user's movement. This system acquires positional data without contact by use of magnetic transducing technology.

Two magnetic sensors are used in the system.

(a) Head tracking sensor

A magnetic sensor is attached to and interlocked with the HMD. The sensor detects the position and the direction of the user's head and outputs X, Y, and Z, coordinates and Euler angles (pitch, yaw, roll). The standard sensor is attached to the head to control the view point of the user in the virtual space.

(b) 3D mouse sensor (ball type)

A ball-type magnetic sensor is used as a 3D mouse. The on/off data of the switches on the sensor can be acquired.

HMD (VPL Research Eyephone90)

The HMD has two liquid crystal displays (LCDs) with a resolution of 640 x 480 pixels to cover the views of the user's right and left eyes. Different images can be shown for the right and left eyes. Stereoscopic vision is given to the user by displaying images of different view points on the two LCDs in consideration of the parallax of both eyes.

With the combination of the HMD and the magnetic sensors, the position and the direction of the head are measured and corresponding images are displayed so that the user can view all angles in both horizontal and vertical planes.

Development of the VR-CAD system

The VR-CAD system was developed by using Microsoft Visual C++ 6.0 and the OpenGL graphics library. The basic flow of the system is shown in Fig.3.

Build the VR environment

The sensor part of the 3D positioning system is attached to the HMD so as to track positional data according to head movement. The positional data is analyzed by the computer, and appropriate images for both eyes are created according to the view point and the viewing direction. Images are renewed at 0.15-s intervals. Images are output on the HMD to provide stereoscopic vision to the user based on the parallax of both eyes.

Represent the terrain model in the VR environment

During the system startup, 50-m-mesh altitude data issued by the Geographical Survey Institute of the Ministry of Land, Infrastructure and Transport (JAPAN) is read

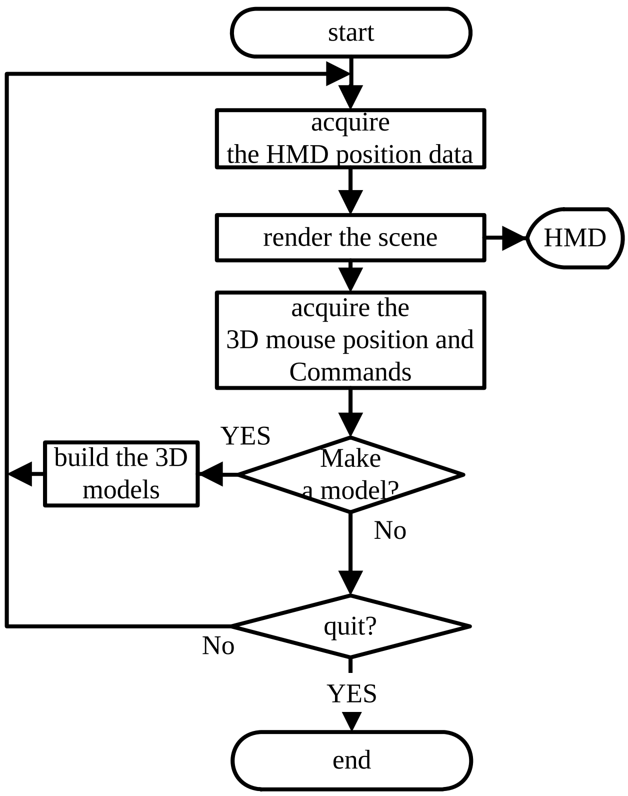

Fig.3 A flowchart of the modeling system

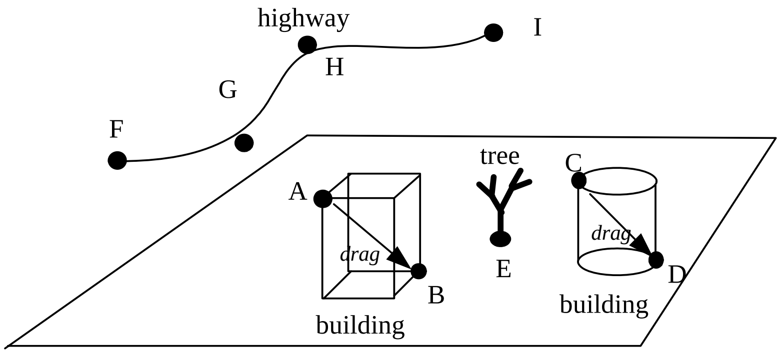

Fig.4 Modeling objects

to construct a 3D terrain model. The user conducts modeling operations based on this model.

Model and place the objects

The system allows creation of simple 3D models such as buildings, trees, and highways (viaducts) on the terrain model. through the numeric keyboard and the 3D mouse.

(1) Buildings

Buildings are simply shaped, either rectangular solids or cylinders. A rectangular building can be given by two diagonally opposite points, and a cylindrical building is created by calculating a center point, radius, and height from two given points.

(2) Trees

Trees in the system are created as joint models, which are used for expressing humans, animals, plants, and other objects in computer graphics. A simple 3D tree model can be created by defining a tree structure.

(3) Highways

With regard to the creation of highway models in 3D spaces, Makanae(2000) discussed the applicability of spline, Bezier, and B-spline curves, and the cubic B-spline curve which makes for the smoothest transition for roads is most applicative for highway alignment. In this study, cubic B-spline curves are adopted in this study to create 3D highway models.

In the present system, control points can be defined in a virtual space by using the 3D mouse, and the center line of a highway is defined by a B-spline curve given by the control points(ex. Fig.4, F, G, H, I). A 3D highway model is created based on the highway line and predetermined cross-sectional data. The system does not take the cross-fall of the highway into account.

Modeling operation

A view of modeling operation using the VR-CAD system is presented in Fig. 5.

Topographic data is delivered as 3D information to the designer through the HMD. To generate images, the location and the direction of the designer's head are detected by the sensor attached to the HMD. After selecting a kind of object type through a numeric keyboard, then a user models an object by moving a 3D cursor(grey-colored ball) in the VR environment.

-building: drag the cursor between two diagonally opposite points(Fig.4 A-B, C-D)

-tree: click on the point to plant a tree(Fig4 E)

Fig.5　A scene of modeling

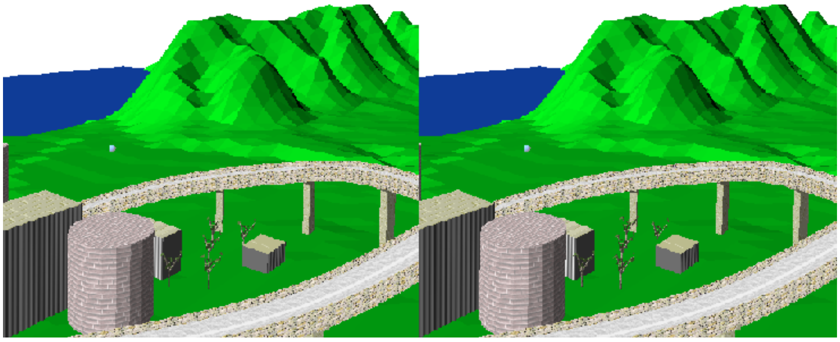

Fig.6　Stereoscopic images by the VR-CAD

-highway: set the control points.(Fig4, F,G,H,I), then command to make 3D models through a numeric keyboard

These objects are attached to the ground automatically.

An example of modeling is shown in Fig.6. The two images are for the right and left eyes.

Evaluation of the VR-CAD

To make clear the effectiveness of the VR-CAD in this study, an experiment is carried out. The experiment is to model the objects (buildings, highways, trees) freely in the virtual environment. Subjects for the experiment are 5 architects who have experiment using the 3D-CAD. After modeling the objects, subjects evaluate spatial recognition and usability in 5 grades. Average values of the each item of evaluation are shown in Table.1.

According the result, stereognostic sense and recognition of the terrain feature have better grades, but sense of scale, the recognition of position of a cursor and positional relations between the terrain and objects are problems about spatial recognition. Regarding modeling usability, building and tree modeling have better grades, but highway modeling is evaluated as difficult. As other problems, some subjects point out a need for much time to training to use the system, tiresomeness to walk around in the VR environment while designing. As merits of the VR-CAD, ease of 3D modeling and acquisition of 3D view, usefulness for landscape design are pointed out by some subjects.

Table 1. Evaluation of VR-CAD

Category	Item	Average (1-5)
Sense and Recognition	Scale	2.4
	Stereognostic sense	3.8
	Terrain feature	3.4
	Position of cursor	1.8
	Positional relation between the terrain and objects	2.6
Modeling Usability	Building	3.6
	Tree	3.6
	Highway	2.8

Conclusion

A VR-CAD system using a HMD was developed and its effectiveness for landscape and town planning was discussed in this study. Civil engineering structures such as highways can be designed in a virtual space define on a computer. The modeling experiment by architects suggests only usefulness of 3D modeling, but also some problems about the sense of scale, recognition of the cursor, and difficulty of highway modeling. To solve these problems, improvements of user interface are required.

The capability of the developed system is limited to constructing terrain models and modeling and placing simple buildings, trees, and highways. To put the system to practical use, the software needs to have advanced functions such as processing in relation to topography. In the conventional method, 2D drawings are used for 3D design. However, the concept of drawing does not exist in the 3D virtual space created by the VR-CAD system. 3D design methods need to be established regarding how to carry out design work and how to define information in the 3D virtual environment.

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