3D highway route-planning system on the virtual terrain by aerial photographs

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Abstract: In this study, a virtual reality highway route-planning system (VR-HRPS) was developed. VR-HRPS enables the planner to plan the route of highways on the 3D virtual terrain reproduced by the stereoscopic vision of the aerial photographs. To design the highway in the 3D space, a highway alignment is defined as a quadratic B-spline curve. In order to provide the stereoscopic image and manipulate the 3D cursor easily, a stereoscopic viewer and a 3D mouse system for virtual reality are used. Utilizing VR-HRPS, it is possible to get more accurate topographic information with a smaller load on the computer and evaluate the highway alignment simultaneously with the route planning.

Key words: Highway alignment, Virtual Reality, Stereoscopy, Aerial photographs

1 Introduction

Stereoscopic vision of aerial photographs is very useful technology for accurate communication of the 3D topographic image. Though it is known that much geology and geomorphologic information for the construction can be obtained through aerial photographs (BL 82), it is rare to use them for the highway design directly.

To design the highway on the 3D virtual terrain by the stereoscopy of the aerial photographs, a stereoscopic viewer with a drawing system is required. Stereoplotters for photogrammetry can draw curves on the 3D virtual terrain, but it is not adequate for highway design because it is not possible to use the rulers for highway design.

This paper proposes the Virtual Reality Highway-Route Planning System (VR-HRPS) on the virtual terrain by the stereoscopy of the aerial photographs. It uses the stereoscopic viewer and the 3D mouse system for virtual reality to improve the interface of previous system (MF 98; MAK 00).

2 Concept of VR-HRPS

Virtual reality(VR) is the computer-generated simulation of a real or imagined environment. Stereoscopy is the one of the most important technology to represent the virtual environment realistically, and a HMD (head mounted display) or a stereoscopic viewer is used.

VR-HRPS uses the stereoscopic technology for virtual reality. The conceptual diagram of VR-HRPS is shown in Figure 1. Through the stereoscopic vision of the aerial photographs, a highway planner can build the 3D virtual terrain in his brain.

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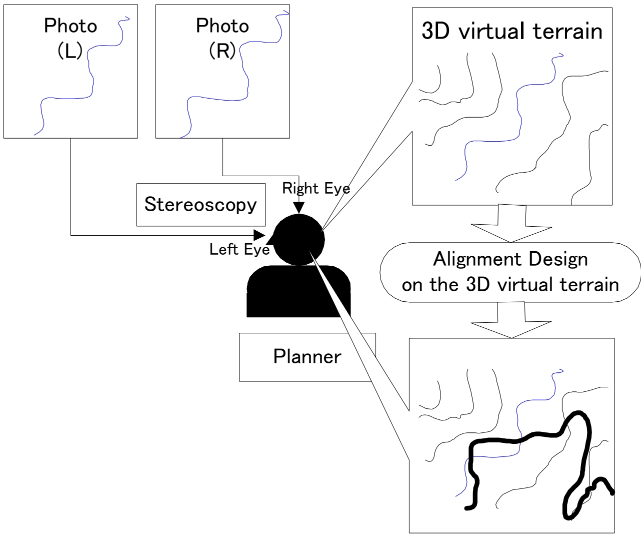


Figure 1 Concept of VR-HRPS

To plan the route of the highway in his 3D virtual images, VR-HRPS must build the numerical 3D virtual space equal to the aerial photographs and provide the function to design the 3D highway geometry in it.

Some studies have been developed the highway design systems using aerial photographs (NAK 72). They have used stereoplotters and not fully used the information on the planned alignments obtained from aerial photographs. In recent years, CAD systems using digital terrain model (DTM) are being used for practical purposes (YB 00). They have, however, several restrictions such as the need of a large amount of digital data for precise re-creation of the surface of the terrain and of high-speed computers for the processing of such data.

In comparison with the above systems, the VR-HRPS based on aerial photographs that is proposed in this study has the following advantages.

- Aerial photographs, as a means of dissemination of topographic information, can be transmitted as three-dimensional information through stereoscopy, and suffer less data deterioration than topographic maps.
- The proposed system places a much smaller load on computers than the highway alignment development systems using digital topographic information. It needs no special equipment like stereoplotters and facilitates the addition of features and the creation of interfaces specializing in highway alignment development.
- Definition of a highway alignment as a three-dimensional alignment based on a B-spline curve enables the direct acquisition of development information as three-dimensional digital information and the real-time assessment of the development plan.

3. Building of a three-dimensional alignment development system

VR-HRPS is a simulator of designing using a spatial spline (LOR 71) in the 3D virtual space reproduced by aerial photographs. The points to build VR-HRPS are shown below:

- How to define the numerical 3D virtual space
- How to define the 3D highway alignment on the 3D virtual terrain
- How to build the 3D interface of VR-HRPS

Figure 2 shows the flowchart of VR-HRPS.

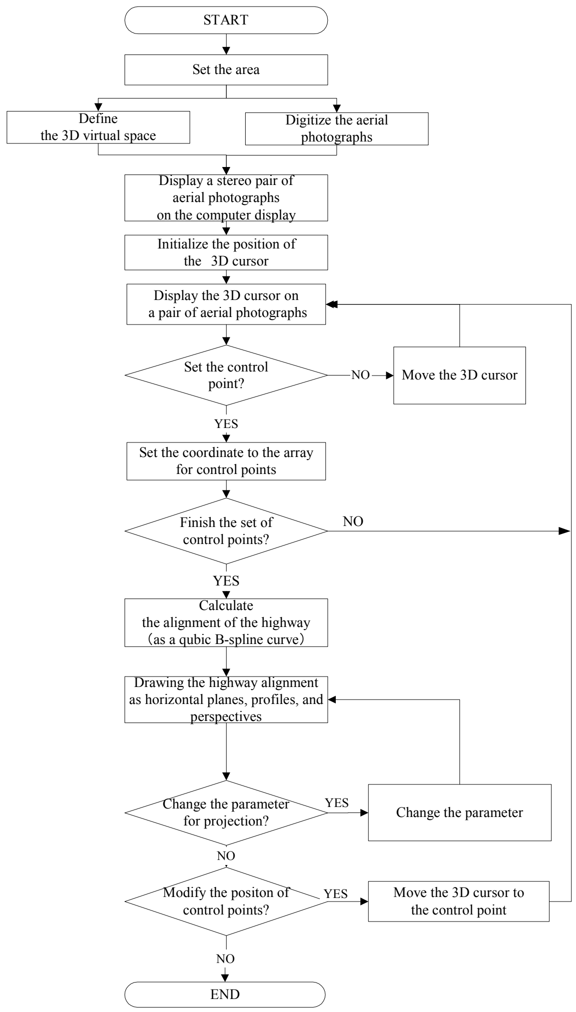


Figure 2 Basic flow of VR-HRPS

3.1 Definition of the 3D virtual space

In order for aerial photographs to be used on a computer, they are transformed into digital information via an image scanner. The resolution of the aerial photographs displayed on the computer screen is determined by the resolution of the computer screen.

Two adjacent aerial photographs along the flight line have almost 60% forward overlap (Figure 3). Applying each photograph to each eye, the 3D virtual terrain can be reconstructed in the viewer's brain stereoscopically.

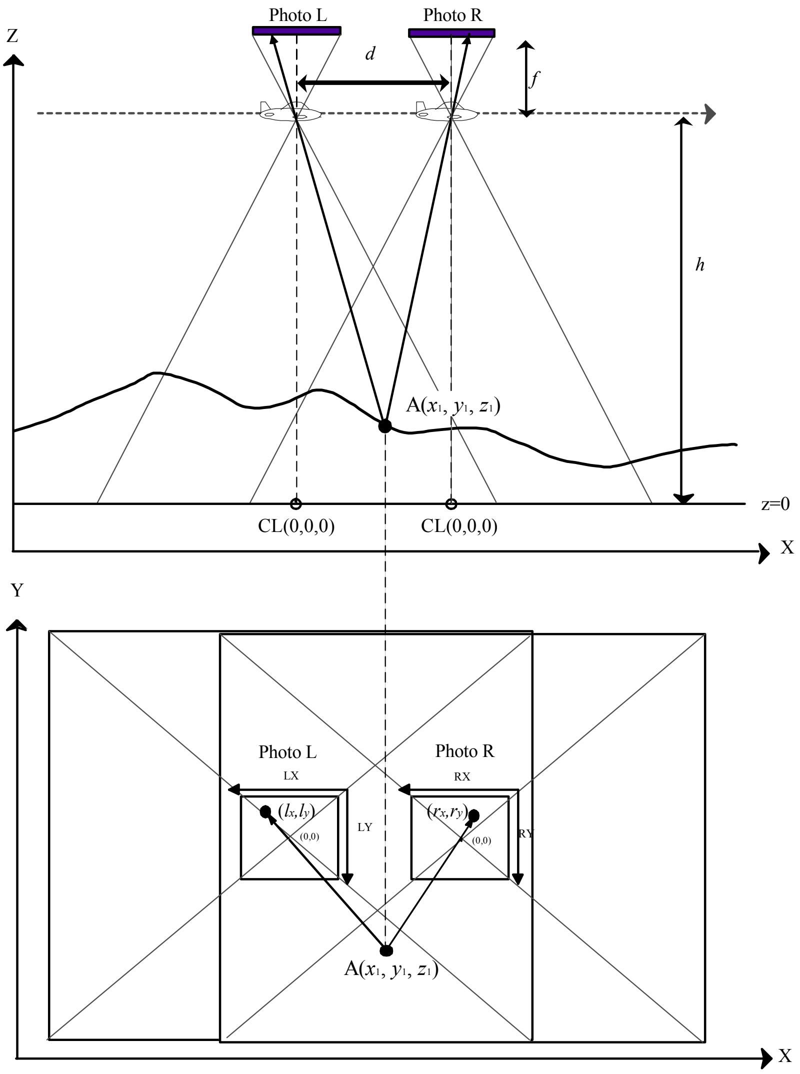


Figure 3 Definition of the virtual space

The principle of establishing a virtual space on a computer is similar to that used by stereoplotters. First, the dimensions of the camera during filming, horizontal coordinates X and Y, height *h*, focal distance *f*, angle of view and angular orientation of camera, are required to build the virtual space.
Here a 3D coordinate system is defined as figure 3. The origin is set at a height of 0 m from the projection centre of photograph L *CL,* and the distance in direction X between the two camera's position is defined as *d*. Coordinate system for the screen where photographs L and R are projected, are defined as LX-LY and RX-RY. Each centre of them is assumed as the origin of each coordinate system.
For a point A(x_1, y_1, z_1) in the virtual space, its position on photographs L(l_x, l_y)and R(r_x, r_y) are obtained by equation [1].

$$\begin{cases} l_x = \dfrac{x_1 \cdot f}{h - z_1} \\ l_y = \dfrac{y_1 \cdot f}{h - z_1} \\ r_x = \dfrac{(x_1 - d) \cdot f}{h - z_1} \\ r_y = \dfrac{y_1 \cdot f}{h - z_1} \end{cases} \qquad [1]$$

3.2 Definition of the 3D highway alignment

A highway alignment is designed as a combination of 2D alignments such as a horizontal alignment or a vertical alignment on paper. But it is not easy to define the alignment in the 3D virtual space by this method. In this study a parametric curve has been regarded as an effective means of definition of free-form curves under CAD systems(RA 90). The quadratic B-spline function is applied here in view of the smoothness, freedom of distortion of curves and ease of calculation.
The B-spline curve is an application of the B-spline function proposed by Schoenberg(SCH 46). The coordinate of interpolation point (X, Y, Z) of a quadratic B-spline curve for three control point $P_1(x_1, y_1, z_1)$, $P_2(x_2, y_2, z_2)$ and $P_3(x_3, y_3, z_3)$ can be obtained by equations [2] and [3] (RA 90).

$$\begin{cases} X = N_1(t) \cdot x_1 + N_2(t) \cdot x_2 + N_3(t) \cdot x_3 \\ Y = N_1(t) \cdot y_1 + N_2(t) \cdot y_2 + N_3(t) \cdot y_3 \\ Z = N_1(t) \cdot z_1 + N_2(t) \cdot z_2 + N_3(t) \cdot z_3 \end{cases} \qquad [2]$$

with

$$\begin{cases} N_1(t) = \dfrac{(1-t)^2}{2} \\ N_2(t) = t(1-t) + 0.5 \\ N_3(t) = \dfrac{t^2}{2} \end{cases} \quad [3]$$

By varying the value of t from 0 to 1, a curve can be drawn that starts at P_1 and end at P_3. To draw the 3D highway alignment in the 3D virtual space, a planner must set some control points for a parametric curve (Figure 4).

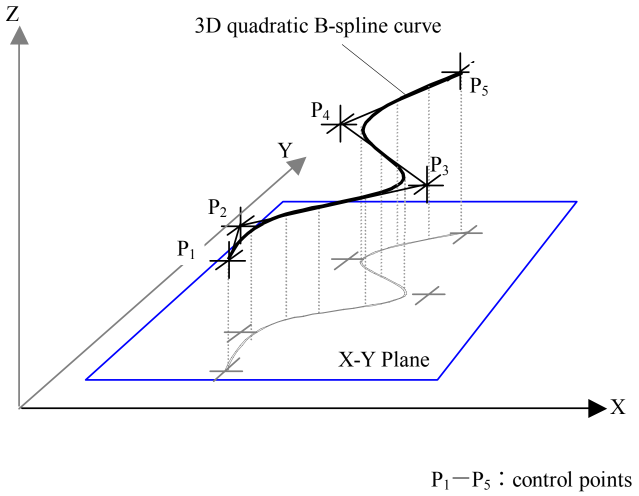


Figure 4 The model of a 3D highway alignment

3.3 Interface of VR-HRPS

VR-HRPS is a personal-computer-based system with some specific devices. The block diagram of VR-HRPS is shown in Figure 5.

3.3.1 Device for stereoscopic vision

The 3D virtual space can be constructed by the stereoscopic vision of aerial photographs. In order to provide the stereoscopic vision to the viewer, Stereographics CrystalEyesPC is used. CrystalEyesPC is a wireless eyewear system that delivers stereoscopic 3D images on standard computer displays. To make the stereoscopic image, the image for the left eye is displayed on an upper half of screen, and one for the right eye is shown on a lower half. Each image must be compress 1/2 in vertical. If turning on CrystalEyes, an image for each eye will be displayed alternatively synchronized with the LCD shuttering of eyewear above 120Hz.

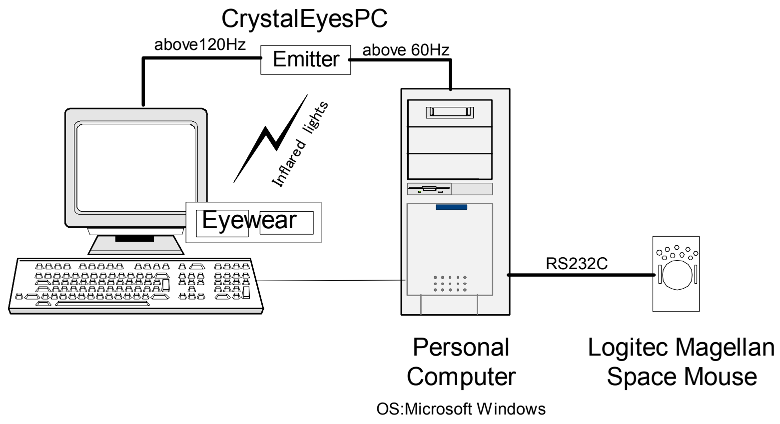


Figure 5 Block Diagram of VR-HRPS

3.3.2 Device for the manipulation of the 3D cursor

In order to set 3D control points for a highway alignment in the virtual space, a 3D cursor is required. A planner needs to move the cursor in every direction to set the control points of the highway.

VR-HRPS applies Logitec Magellan/Space Mouse to improve the performance of manipulation (Figure 5). Magellan is a 3D mouse system, which can capture translation and rotation about 3 axes.

4 Route planning and evaluation system

4.1 Route planning system

To plan the route on the virtual terrain through the CrystalEyes, a planner settle the control points of a highway alignment by a manipulation of the 3D cursor. By repeating the positioning of the control points, one route of the highway can be settled on the virtual terrain.

In order to represent the 3D highway alignment defined by a parametric curve, the alignment must be translated to the coordinate system on each screen of aerial photographs and is overlaid on them.

An example of the route planning by VR-HRPS shows in Figure 6. This is a case of road relocation required by the dam construction. The route is planned avoiding some areas landslides predicted through the stereoscopic vision of aerial photographs.

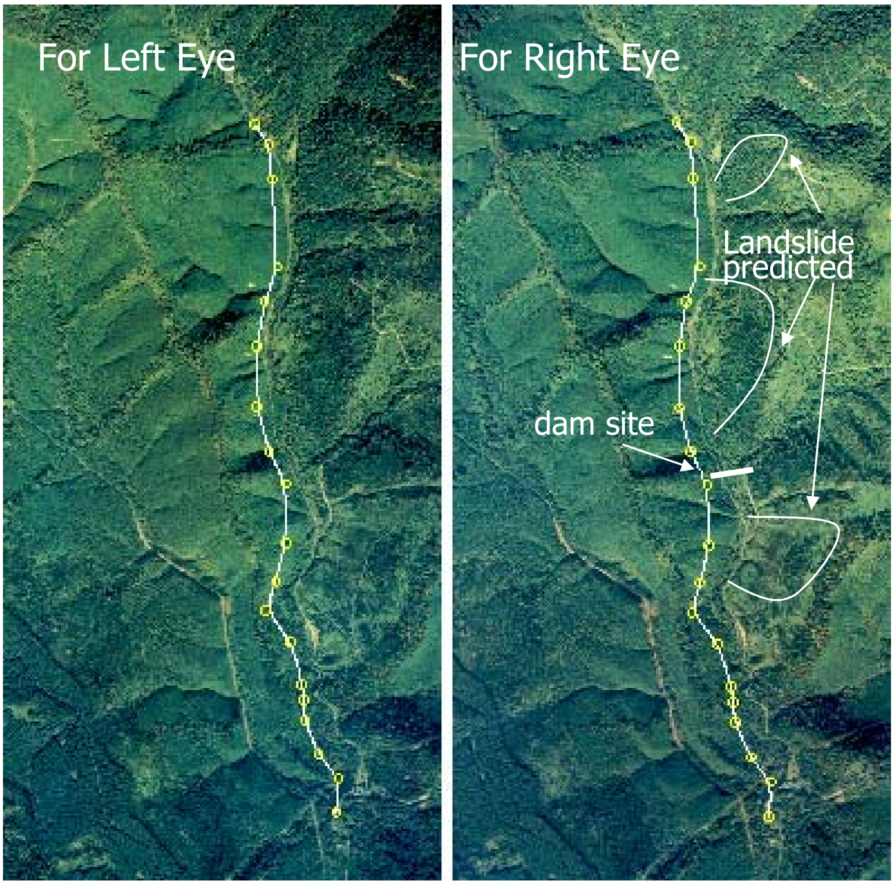
4.2 Route evaluation system

The 3D highway alignment must be evaluated about the compatibility with the existing design criteria for 2D alignments. For evaluation of the 3D highway alignment, VR-HRPS shows information about the 3D alignment(Figure 7).

4.2.1 Projection on two-dimensional plane

A study of the compatibility with the existing design criteria for highway alignment requires the representation of the 2D plane in a plan and a profile. As shown in Figure 4, a horizontal plan is a parallel projection of a 3D highway alignment on the X-Y plane. a profile is a graph representing a side view of the alignment with elevations. In addition, calculation of vertical grades leads to the creation of a vertical grade diagram.

Implementation of the above calculation at the same time as the positioning of control points enables simultaneous assessment of the highway alignment with the design criteria. VR-HRPS is programmed not to set the alignment over the designated vertical gradient.



Aerial Photographs: CHO-77-39 C5A-16-17, GSI, 1977.

Figure 6 An example of route-planning by VR-HRPS

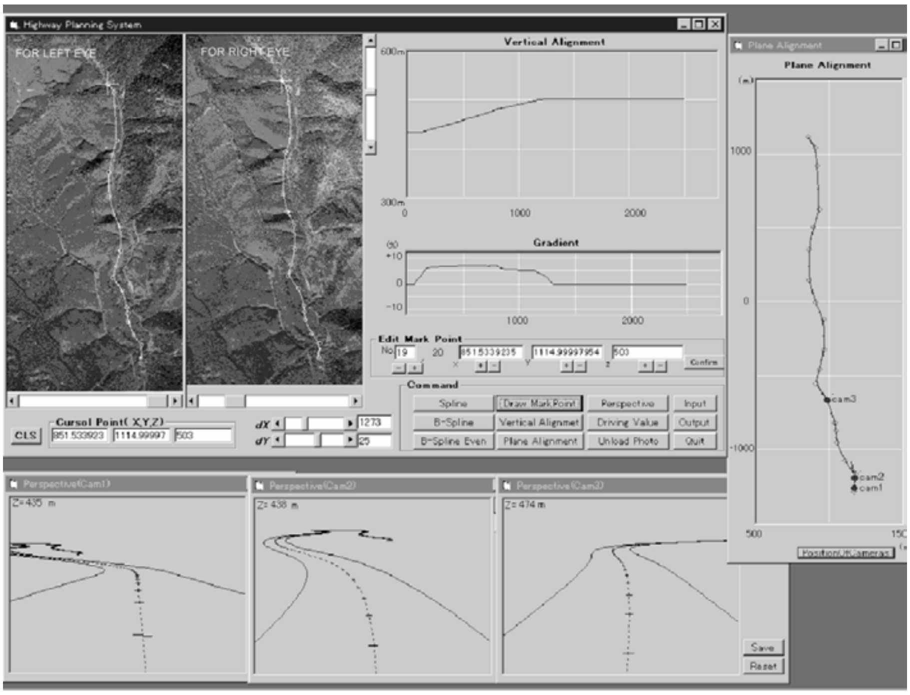


Figure 7 The interface of VR-HRPS (Evaluation mode)

4.2.2 Perspectives drawing of highways

Three-dimensional definition of a highway alignment facilitates the drawing of a perspective of the highway through calculations for perspective projection for a given viewpoint. To render the perspectives, it is required to make the 3D model of the planned highway. In order to make the model, coordinates for the sideline are calculated based on the highway width given as an initial condition for the plan. The perspective can be no more than an outline at this stage because no superelevation has been determined. Visual evaluation is, however, possible or how the highway alignment that has actually been drawn looks to the driver's eyes can be evaluated.

5 Conclusions

In this study, a virtual reality highway route-planning system (VR-HRPS) was developed. VR-HRPS enables the planner to plan the route of highway on the 3D virtual terrain reconstructed by the stereoscopic vision of the aerial photographs. Benefit of VR-HRPS is show as below:

- A planner can obtain much topographic information through the stereoscopic vision of aerial photographs. And direct use of aerial photographs can suffer no data deterioration through the process of mapping and reading maps.
- Much smaller load on computers than the other system based on digital terrain models (DTM).
- Utilizing the stereoscopic device and the 3D mouse system, it become easier to set

the control points of the highway alignment on the 3D virtual terrain than the previous systems.
- VR-HRPS can provide the digital 3D models of the planning highway simultaneously with the definition of the highway alignment. It enables the real-time evaluation of the highway alignment through the horizontal plan, the profile, gradient, and perspectives.
The Design of the highway alignment is performed by a highway engineers generally. VR-HRPS enables the geologic or geomorphologic surveyors, who are good at reading the aerial photographs, to design the highway
The next issue of the development of VR-HRPS is to link the 3D virtual terrain to the digital terrain model (DTM). It will enable to calculate the area and earth volume for the construction of the highway, and the design-evaluation system will be more advanced.

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