DEVELOPMENT OF A 3D HIGHWAY MODELER USING A DRIVING GAME INTERFACE

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ABSTRACT:

This paper outlines a 3D highway geometric modeling method based on a parametric model involving curvature and gradient functions. Using this method, conditions concerning design standards are input to a computer as numerical functions, with the design velocity, curvature and gradient as variables. We also developed a 3D highway modeler using a driving game interface. To evaluate the interface of the modeler, we conducted experiments and compared the results with those using the mouse-based system in the previous study. As a result, we showed that the system using the driving game interface outperformed the mouse-based system in most categories.

KEYWORDS: highway geometry, product model, driving game interface, CAD, 3D modeling

1. INTRODUCTION

Highway geometrics can be defined using highway alignments (horizontal and vertical alignments) and cross section as parameters. The shapes of respective classes are determined by various parameters, so uniform handling is not possible and this makes it difficult to create an efficient design system. To solve the problem, the author presented a parametric modeling method for handling horizontal and vertical alignments uniformly using length as a parameter (Makanae, 2004, 2005). In the previous study, a prototype of the modeling system was developed, but the highway alignment could not be drawn intuitively. To build a more intuitive modeling method, in this study we used a driving game interface. This paper outlines the parametric highway design method and the 3D highway modeler using the game interface.

2. BUILDING OF HIGHWAY GEOMETRIC DESIGN MODEL

2.1 PARAMETRIC PATH MODEL

When building a highway model, the handling of highway geometrics is important because it governs not only the definition of highway geometrics but also the method for determining the positions of appurtenant objects (appurtenances on highways). Therefore, this study examines methods for defining highway geometrics.

Highway geometrics can be defined using highway alignments (horizontal and vertical alignments) and cross sections as parameters (AASHTO, 1994). Vertical alignments are subordinated to horizontal alignments, and they cannot be independently of each other. Cross sections are subordinated to alignments. These classes of highway have associations with one another; modifications to part of the alignment have an impact throughout the highway. In conventional design methods, horizontal alignments are composed of three classes: tangents, arcs and clothoids, while vertical alignments are composed of tangents and transition curves such as quadratic curves. The shapes of respective classes are determined by various parameters, so uniform handling is not possible, and this makes it difficult to create efficient design systems. To solve the problem, the author presented a method for handling horizontal and vertical alignments uniformly using length as a parameter, and also for handling them independently of each other (Makanae, 2002a, b, 2004). To do this, the author defined the horizontal and vertical alignments as curvature and gradient functions without considering respective alignments; the method was shown to allow

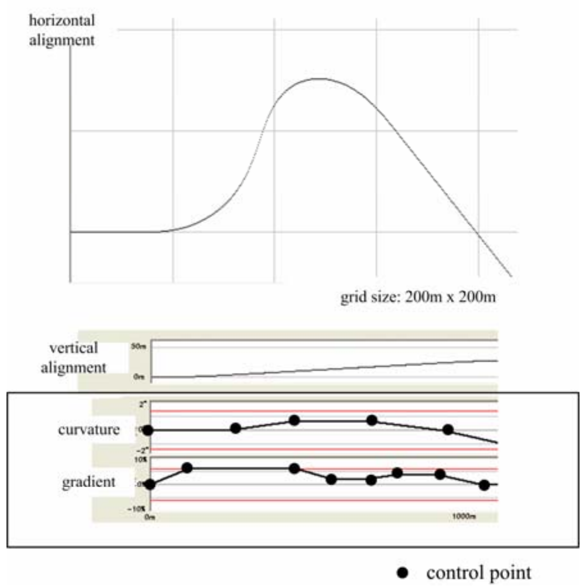

Figure 1: Functional representation of highway alignment

superelevation and widening to be designed automatically and so is efficient. This study used a similar method. This paper outlines highway geometric design modeling (Parametric Path Model; Makanae, 2005) using the method.

2.2 CURVATURE FUNCTION

The trajectory of an automobile traveling on a plane at a constant velocity with the steering wheel set at a fixed angle has a constant curvature regardless of the trajectory length, and draws a straight line or a circular curve. In the case where the driver turns the steering wheel at a constant angular velocity, the trajectory draws a curve with the curvature either increasing or decreasing in proportion to the trajectory length traveled; such a curve is known as a clothoid. A horizontal alignment, which is a series of the above elements of an alignment, can therefore be represented by a function of curvature varying with time or trajectory length. Here, a function representing variations of curvature based on trajectory length l is expressed by curvature function C(*l*).

A clothoid used for a transition curve assumes that the steering wheel is turned at a constant speed, in which case the rate of change in curvature remains unchanged. If the rate of change in curvature is represented by k_c, C(*l*) for trajectory length l can be represented by the linear expression:

$$C(l)= k_c\, l + c_s \qquad (1)$$

where, c_s is the initial curvature.

Equation (1) can also represent a straight line or a circular curve. A driver traveling along a continuous highway alignment turns the steering wheel continuously, so curvature function C(*l*) also becomes continuous. C(*l*) may thus be regarded as a continuous piecewise linear function.

2.3 GRADIENT FUNCTION

For existing design methods, elements of a vertical alignment consist of straight lines and vertical curves. For vertical curves, parabolic curves are generally used. Gradient, which is the differential of vertical alignment, is therefore represented by a linear expression. Gradient function *I*(*l*) can be represented by:

$$I(l) = k_i\, l + i_s \quad (2)$$

where, k_i is the rate of change in gradient, i_s is the initial gradient and l at the origin is assumed to be 0. Since vertical gradient is continuous as well as horizontal alignment, gradient function I(l) is continuous and so can be handled as a piecewise linear function.

Figure 2 presents horizontal and vertical alignments in plan view where the boundary conditions of centerline curvature and gradient are defined as shown in the bottom half.

By definition of control points for curvature and gradient functions, 3-D coordinates of the highway alignment can be defined.

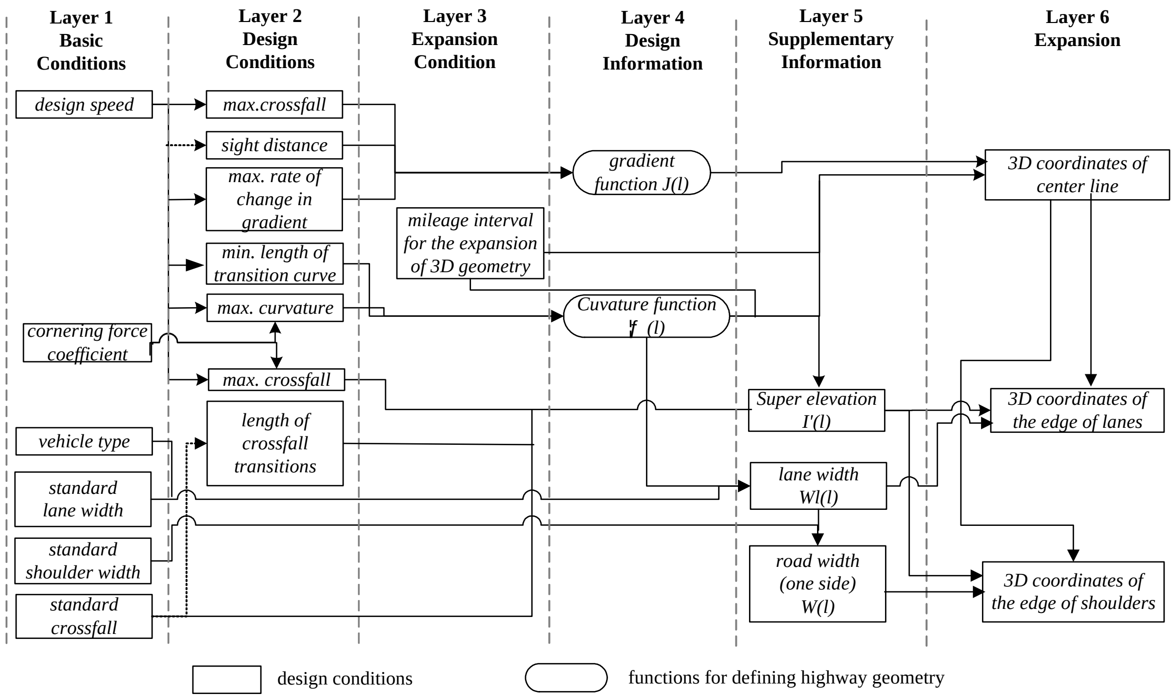

Figure 2: Schema of geometric design model

3. SCHEMA OF GEOMETRIC DESIGN MODEL

This study used an undivided two-lane highway without a sidewalk as the basic model. Here, design speed, width of the traffic lane and shoulder, and standard value of crossfall are defined as the initial values.

Based on the boundary conditions for curvature and gradient function, 3D coordinates of the highway alignment can be defined. Crossfall and widths of the lane can be determined automatically by the curvature functions. Thus, a 3D highway geometric design model can be built in the design space.

The following restrictions are placed on the curvature and gradient functions for the comfort and safety of the vehicle occupants:

- Maximum curvature
- Minimum length of transition curve
- Vertical gradient
- Length of vertical circular curve

The modeling process of the 3D highway geometry can be schematically classified into six layers (Figure 2).

Layer 1 provides the most basic information on the highway to be designed, and defines such elements as the design velocity, design vehicle, lane width, shoulder width, and cross slope.

Layer 2 provides conditions for defining the curvature and gradient functions that define the alignment.

Layer 3 shows conditions that define the conditions for expanding the curvature and gradient functions.

Layer 4 provides data that define curvature and gradient functions, which are the backbone of the geometric design defined by the design engineer and which are the boundary conditions of the functions.

Layer 5 provides preliminary data for defining a geometric design based on the highway alignment defined in Layer 4. The data are obtained automatically.

Layer 6 shows the results of expansion to the design space of the highway geometric design built based on the data defined in Layers 4 and 5.

Crossfall and width of the lane can be determined automatically by curvature functions. Thus, a 3-D highway geometric model can be built in the design space.

4. DEFINITION OF CLASSES OF HIGHWAY

Highways are composed of various objects, and so when designing a highway, the association of these objects with alignments must be defined. Only the following classes of objects are considered when assessing definition methods:

•Lanes

•Shoulders

•Center strips

•Sidewalks

•Appurtenances (e.g. barriers, trees and signs)

When building the highway model, the attributes (e.g. width) of these classes should be defined and their association with alignment length data, which are the basis of the model, should be presented. Figure 3 shows a detailed highway model with necessary attribute data provided for the selected classes.

5. DEVELOPMENT OF A HIGHWAY MODELER USING A DRIVING GAME INTERFACE

5.1 CONCEPT OF THE 3D HIGHWAY MODELER

The model described in Figure 3 is a data model based on the length of highway centerline. The alignments and cross sections are subordinated to length data. Highway design support systems based on the model are also designed to be capable of studying the curvature, gradient, cross section and appurtenances to be installed, based on the length data. An image of such a system is shown in Figure 4.

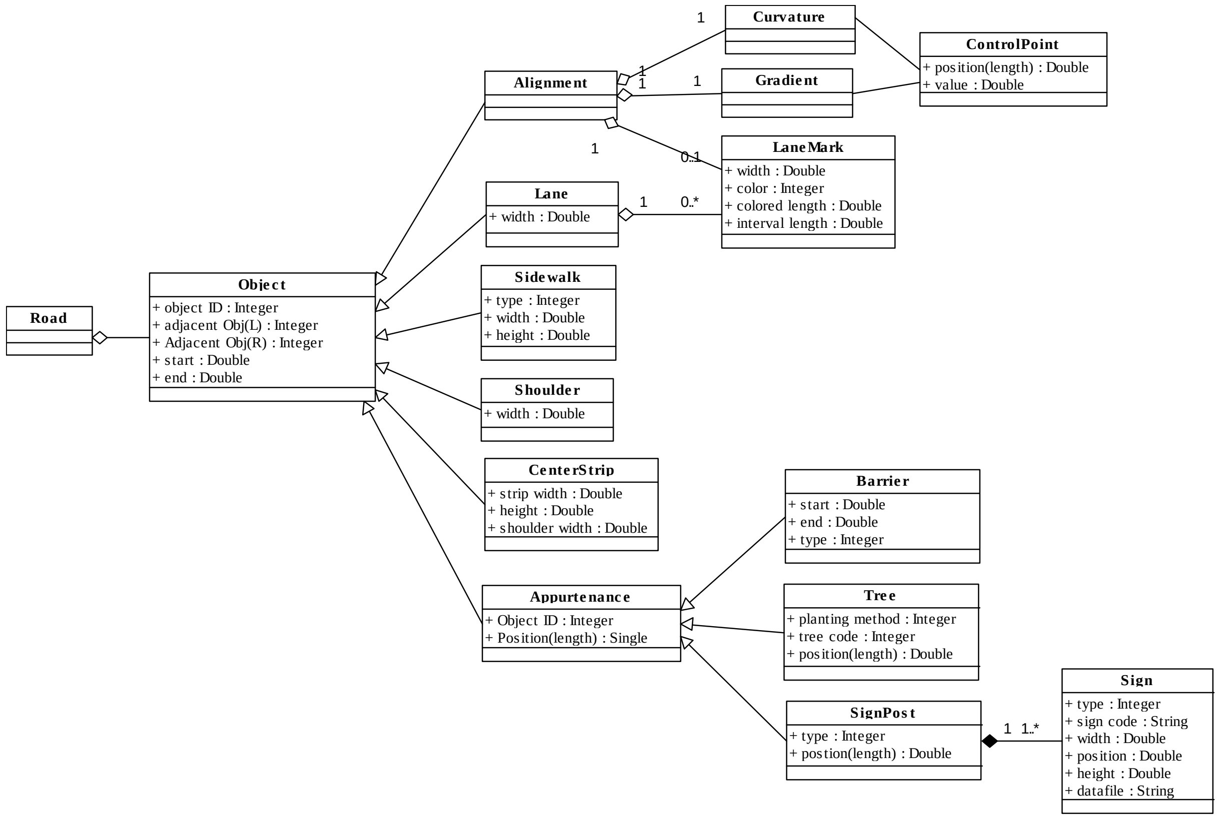

Figure 3: Highway model in UML

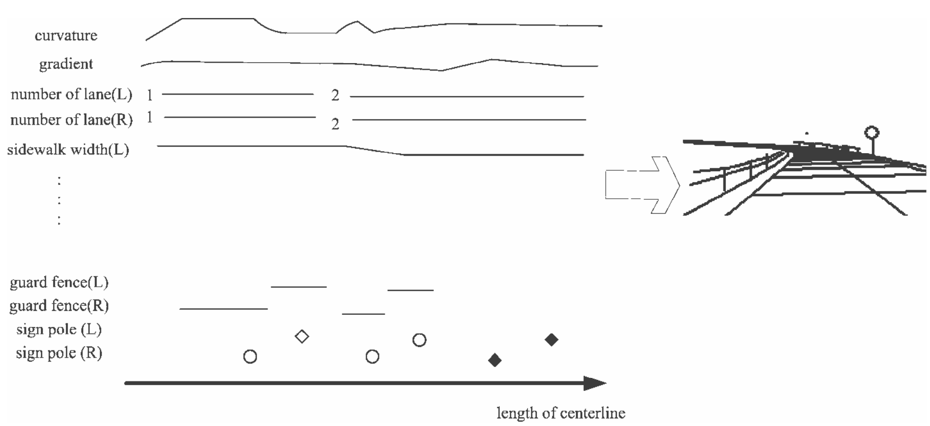

Figure 4: Concept of the 3D highway modeler

A series of one-dimensional data like the length in the system may be provided with various additional data by MIDI (Musical Instrument Digital Interface) sequencing software, which is used to produce music. The software expresses music by adding MIDI data over a continuous period of time. The editor used in this study is based on a similar concept and is called a “3D highway modeler”.

The 3D highway modeler was developed under the following environment. XML (Extensible Markup Language) was used to equip HSE with the highway model.

Operating system: Microsoft Windows 2000/XP Professional

Programming language and library: Microsoft VisualBasic 6.0, OpenGL, Microsoft XML(DOM)

Highway geometrics can be presented in 3D space according to the attributes of the classes of the highway and the parametric alignments expressed by functions, based on the basic design conditions such as the design speed and cross slope. The highway geometrics so presented take superelevation, surface drainage and widening into consideration.

Makanae (2002a, b) referred to two-lane undivided highways. In the modeling in this study, multilane divided highways were also modeled. On divided highways, the axis of rotation was positioned at the roadway centerline on either side of the center strip.

Figure 6 shows the interface of the 3D highway modeler in the previous study. The bottom window with the black background serves as the input window. In the window, the curvature function, gradient function, number of lanes on the left and right sides, whether barriers are installed or not on both sides, sidewalk widths on both sides, width of the median strip, trees on both sides and signs on both sides can be specified by scrolling the screen. Plans, profiles or results of the calculated superelevation or roadway width can be displayed graphically according to the specifications, and a 3D perspective is displayed in real-time accordingly. The perspective viewpoint can be freely determined. Basic design conditions such as design speed and standard cross slope are specified on another screen. However, with this prototype system it is not intuitive to draw a 3D highway route in the 3D space.

5.2 APPLICATION OF DRIVING GAME INTERFACES

In order to build a more intuitive interface to draw the highway route, we used a driving game interface with a steering wheel and pedals, because the elements of highway design, such as clothoids and circular curves, are designed to match drivers' steering under the assumption that the vehicle travels at a constant velocity. Applying this concept, the highway drawing pointer moves at a constant speed in this system. The steering-wheel-type device can determine curvature changes, and the pedal-type device can determine gradient changes. The value of the left pedal means negative gradient, and the right one means positive gradient. Figure 5 shows the configuration of this system. Microsoft Direct Input in DirectX is used as the application interface to control the driving game interface.

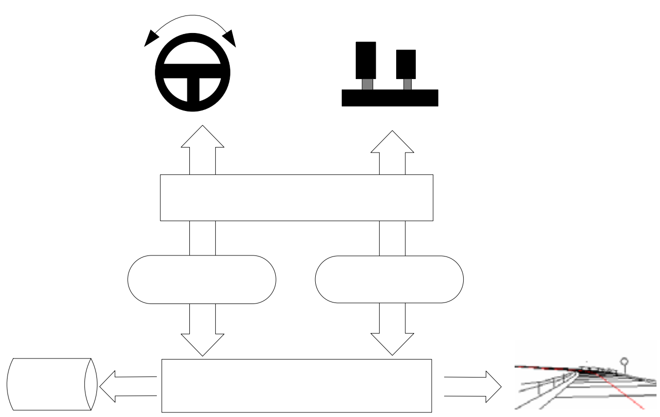

Figure 5: Configuration of the 3D highway modeler

5.3 EVALUATION OF THE 3D HIGHWAY MODELER AS A DESIGN INTERFACE

To clarify the advantages of these interfaces, an experiment was carried out, and the previous interface using a mouse (in 5.1) and the developed interface using the driving game interface were compared. The procedure of the experiments was as follows:

1) Practice to draw the highway route on each system (3 minutes for each).

2) Five points on the plane are displayed on the screen. The subject must draw the highway route within 3 minutes on each system (only in horizontal).

3) Fill out a questionnaire about ease, accuracy, fun, motivation, etc.

Seven subjects were used (4th grade students of Miyagi university, 6 males and 1 female). The experiment compared the previous interface using a mouse (in 5.1) with the interface using the driving game interface.

Figure 6: A scene of the experiment

The results are shown in Table 1. Using the driving game interface, 6 of the 7 subjects could draw the highway route within the time, but 6 of the 7 gave up using the mouse system. According to the results of the questionnaire, the system using the driving game interface outperformed the mouse system in all items.

Table 1: Evaluation of 3D highway modeler interfaces

		MOUSE						DRIVING GAME INTERFACE					
	M/F	TIME	Ease	Accuracy	Learnability	Fun	Motivation	TIME	Ease	Accuracy	Learnability	Fun	Motivation
A	M	give up	1	1	2	2	2	1:41	5	5	5	5	5
B	M	give up	2	1	3	3	3	1:57	4	4	4	5	5
C	M	give up	3	3	3	4	4	1:59	4	4	5	4	4
D	M	give up	1	1	1	2	2	2:13	3	2	5	4	3
E	M	2:52	3	4	2	2	1	2:11	4	4	5	5	5
F	F	give up	1	1	2	1	1	give up	2	2	3	4	4
G	M	give up	1	1	2	4	2	2:55	3	3	4	5	4
Average			1.7	1.7	2.1	2.6	2.1		3.6	3.4	4.4	4.6	4.3

This result shows that the driving game interface is superior to the previous mouse system and will motivate the designing of highway routes. However, the routes drawn by the game interface have vibration due to the subjects' erratic steering. In order to apply this method to the actual highway design process, it is required to optimize the highway alignment acquired from the routes drawn by users using the game interface.

6. CONCLUSION

This paper outlined a 3D highway geometric modeling method based on a parametric model by curvature and gradient functions. In this method, conditions concerning design standards are provided to a computer as numerical functions with the design velocity, and curvature and gradient as variables. The design method is totally different from existing methods based on drawing (Beilfuss and Guess, 1990). The design engineer can now obtain an alignment that meets the design standards without considering the alignment parameters. Wasteful drawing work is thus reduced, and design efficiency is increased. Since alignment design becomes possible while monitoring a three-dimensional highway alignment, visual evaluation, or verification of how the alignment looks to the driver's eyes, is now possible. Thus, the quality of design is expected to increase.

A 3D highway modeler using the driving game interface was also developed in this study. In order to evaluate this system, experiments to compare with the mouse-based system in the previous study were carried out. As a result, it was shown that the system using the driving game interface was superior to the mouse-based system in ease, fun, etc. The major problem remaining to be solved is how to optimize the highway alignments acquired by this system.

This paper showed that the game interface is very useful and fun as a design tool and may encourage a designer to design. As game interface technology is evolving very rapidly, smarter applications using these interfaces for design must be considered and developed in future research.

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