A 3-D VR MODEL FOR OPTIMAL ALIGNMENT SEARCH SYSTEM OF HIGHWAY DESIGN (OHPASS) USING ASTER GDEM

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ABSTRACT

This study developed a function in OHPASS, Optimal Highway Path Automatic Search System, to allow it to use ASTER Global Digital Elevation Model (ASTER GDEM) that covers all the topographic data in the world. In addition, we have constructed a system that enables output files from OHPASS to be viewed and evaluated as a three-dimensional (3D) virtual reality (VR) model. The system can be used for landscape evaluation and road structure evaluation in road alignment planning, and for consensus building with concerned parties throughout the world using OHPASS.

KEY WORDS
astergdem, road design, virtual reality, genetic algorithms

1. INTRODUCTION

Construction of ideal highways needs satisfying various demands such as reduction of construction cost, restrictions on the road structure, and conservation of natural environments and good highway landscape. Many studies have been performed on the development of automated models for optimizing highway alignments design.

First development of an automatic model for highway alignment optimization required grasping main costs, developing efficient algorithms, and linking it with the actual Geographic Information System (GIS). "Main costs" usually refer to the expenditures each of which occupies relatively higher percentage of the total cost. The model for highway alignment optimization (Jong, 1998; Jha, 2000) optimized highway alignments by minimizing the total cost.

It is also suggested that the following characteristics are essential for an excellent model for highway alignment optimization (Jong, 1998):[3]
(1) Examines all the main costs and variable costs,
(2) Formulates all the important restrictions,
(3) Generates realistic alignments,
(4) Capable of treating alignments accompanied with backward bending,
(5) Optimizes horizontal and vertical alignments at the same time,

(6) Finds the globally or most globally appropriate solution,
(7) Has efficient solution algorithms,
(8) Has a continuous search space,
(9) Considers the costs for intersections, interchanges, bridges, and tunnels,
(10) Automatically avoids inaccessible areas, and
(11) Compatible with GIS.

For optimizing highway alignments, a number of conventional optimization methods have been used such as the variational method, the dynamic planning method, numerical search, the alignment planning method, and network optimization (Howard et al, 1968; Thomson and Sykes, 1998; Shaw and Howard, 1981, 1982; OECD, 1973; Turner and Miles, 1971; Turner, 1978; Athanassoulis and Calogero, 1973; Parker, 1977; Trietsch and Handler, 1985; Trietsch, 1987a, b; Hogan, 1973; Nicholson et al., 1976).[2][3][4] However, most of these methods lacked one or more characteristics of the highway alignment optimization model indicated above.

Genetic algorithms [3][4] have proven to be effective for optimizing highway alignments, particularly as the optimization of horizontal (planar) and vertical alignments can be performed effectively at the same time. This is performed by searching for a better solution through continuous generation as well as by utilizing the whole search space without stopping at a local solution. This algorithm enables optimization of both horizontal and vertical alignments at the same time. It is possible to generate a flat and continuous alignment (e.g. not a corridor but an accurate linear shape), while directly linking the generated alignments to an actual GIS map.

The Optimal Highway Path Automatic Search System (OHPASS) has been created for the purpose of performing quantitative evaluation on a large number of alignments that are unable to be examined by conventional road design methods for highway alignment plans [3][4][5]. This study reports a new approach that visualizes an optimized alignment by linking ASTER Global Digital Elevation Model (ASTER GDEM) that covers all the topographic data on earth to OHPASS, as well as by linking 3D-CAD to a VR system at the same time (i.e. constructing a system for highway alignment optimization and landscape simulation.)

2. OVERVIEW OF ASTER GDEM

(1) Effectiveness of using ASTER GDEM data

ASTER Global Digital Elevation Model (GDEM) is an easy-to-use, highly accurate DEM that covers all the land on earth, available to all users irrespective of size or location of their target areas. Anyone can use the ASTER GDEM without difficulty to display a bird's-eye-view map or run a flight simulation, realizing visually sophisticated maps. By utilizing the ASTER GDEM as a platform, institutions specialized in disasters, hydrology, energy, environmental monitoring etc. can perform a higher degree of analysis.

(2) Specifications of ASTER GDEM data

Released in 2009, ASTER GDEM is Global DEM for all the land area covered by ASTER. Accuracy is enhanced to 30m per pixel by using multiple ASTER images over the same area. Table 1 shows the specification of data.

Table 1 - Specifications of ASTER GEDM

	ASTER GDEM	SRTM3*	GTOPO30
Data source	ASTER	Space shuttle radar	From organizations the world over in possession of DEM data
Generation and distribution	METI/NASA	NASA/USGS	USGS (US Geological Survey)
Posting interval	30m	90m	1000m
DEM coverage	83 degrees north - 83 degrees south	60 degrees north - 56 degrees south	Global

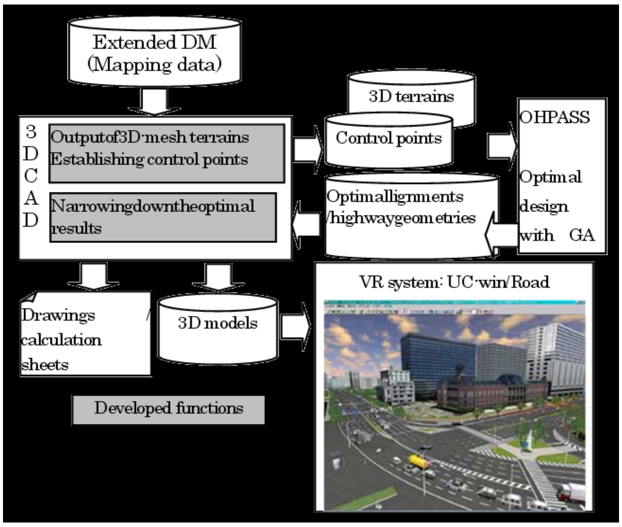

Figure 1 - System configuration

3. LINKING 3D-CAD, ASTER GDEM, AND A VR SYSTEM

(1) System configuration

We have developed a mechanism for creating 3D highway shapes and producing drawings with a data input and creation function in OHPASS. Figure 1 shows the system configuration diagram.

This system has been developed based on AutoCAD Civil 3D (Civil 3D), a civil engineering CAD software. The functions developed include a function to create 3D terrains and control points that are input data using Civil 3D, and a function to incorporate the calculated results into Civil 3D.

Civil 3D has functions that include loading DM, creating 3D representations of terrain, road design (horizontal design, vertical design, and cross-sectional design). In addition, we link the system with UC-win/Road (produced by FORUM8 Co., Ltd.), one of the 3D-model VR systems. UC-win/Road is capable of providing various real-time presentations with CG after generating three-dimensional VR spaces, having been utilized for landscape studies, design consultation, and project briefings. It also has a data exchange function with Civil 3D used in this study, enabling linkage experiments without developing special software.

(2) Terrain data conversion and the establishment of control points (OHPASS Input Interface) :

In order to efficiently create input data for OHPASS, we developed an interface for converting terrain data, setting up control points, and then passing them into OHPASS.

a) Terrain data conversion function
In OHPASS, terrain is mesh datum. A 2m mesh is required for calculations, while a 20m mesh is required for display. For this reason, we have developed a function to create both 2m and 20m mesh files from a 3D surface model created with Civil 3D. While Civil 3D normally provides an API (Application Program Interface) to export the elevation data of points that are specified in the 3D surface, we have increased the speed and efficiency of this process (e.g. by skipping unnecessary elevations when the file size for terrain data is too large.)

b) Control point set-up function
In OHPASS, control points are expressed using lines (for railroads, rivers etc.) or areas (for houses, prohibited planar areas, etc.). We have developed a function to add the information in OHPASS control points to the lines (unclosed polylines) or polygons (closed polylines) created by the standard CAD functions of Civil 3D.

(3) Loading optimal results (OHPASS Output Interface)

We have developed a function that loads the examined results of alignments obtained in OHPASS and displays them as horizontal and vertical drawings. As a feature of OHPASS, it is possible to examine two or more alignments by changing design conditions; this time, a function for selecting and loading an alignment has been added so that loading can be performed with multiple results.

4. DEMONSTRATION EXPERIMENT 1 (USING ASTER GDEM)

(1) Purposes and Procedures of the Experiment

The benefits of using ASTER GDEM are the labor saving effect in creating terrain data and establishing control points. The labor saving effect is evaluated on the assumption that it is compared with a case where a terrain datum is provided simply as a two dimensional CAD data.

a) Labor saving in the process of creating 3D terrain data
Since the contour lines include digital elevation data, time to create a new three-dimensional data is saved. In case height information other than contour lines is required, it is necessary to add the height information separately. However, ASTER GDEM, which is the target of this system, is based on a mesh of 30m/pixel; thus it is assumed that adequate design accuracy can be obtained in three-dimensional representation only by contour line information.

b) Labor saving in the process of establishing control points
We set up control points assuming that ASTER GDEM data are classified into layers by map element type and loaded into the CAD system.

Figure 2 shows the procedure of the experiment.
1. Road design experts list up evaluation items to evaluate control points and design results to consider in designing roads.
2. Optimal design calculation is conducted for the actual object.
3. The results are summarized and evaluated.

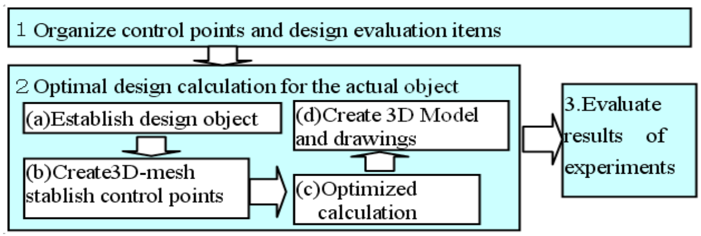

Figure 2 - Procedure for optimal highway design using ASTER GDEM

In 2.(a) in Figure 2, as it was expected to be difficult to select an object for which a topographic map had been organized with ASTER GDEM out of the past design objects, we selected an object for which a topographic map was organized as CAD data, assuming that the ASTER GDEM loading function implemented in this system would be simulated. In (b), we loaded the topographic map for the object selected in (a) into AutoCAD Civil 3D, and edited layers etc. so that it would be in a state of being loaded with ASTER GDEM loading function, in order to simulate the ASTER GDEM loading function. Then, we created 3D terrains and control points using the functions developed in this study. In (c), we specified geometric conditions and earthwork conditions etc., and performed calculation for optimal highway design. In (d), we loaded the result of the optimal design calculation and created a 3D highway model of a road and its drawings.

(2) Subject

The object selected as an experimental subject was a highway outline design of a partial section of an Arterial High-Standard Highway. Its overview is as follows:
(a) Designed daily traffic volume (H32): 16,300-21,800 vehicles/day
(b) Highway standard: 1st class, 2nd grade
(c) Design velocity: V=100km/h
(d) Design length: L=21.8km
(e) Structure width: W=20.5m, Four lanes on completion
(f) Design classification: highway outline design (B)
(g) Design year: 2003
(h) Planned as a completed section
(i) Design work has been performed with a plan of S=1/2500

In this demonstration, using the entire section (total length L=21.8km) of the above design object would cause a large load to be applied to the computer. Therefore, aiming at easiness data handling and saving calculation time, we extracted a section of about 4km as the subject of the experiment.

(3) Creating 3D-mesh terrain and establishing control points

(a) Loading CAD data
Since the CAD data for the subject was in DWG format, which is the same as the standard format for 3D CAD (Civil 3D) used in the experiment, loading was performed in success without any problem.

(b) Editing CAD data to simulate loading of ASTER GDEM
We edited the loaded data in process (a) so that they would be just similar to the loaded ASTER GDEM. ASTER GDEM loading function in Civil 3D classifies the data into layers according to their map element type while loading. This approach is considered common for loading ASTER GDEM data into a CAD system. Since this study simulates the state after loading, the data was divided into layers by map element type after loading CAD data.

In the original CAD data, only the contours had height information. We decided not to provide additional height information because it was assumed that the height information in the ASTER GDEM output data would be contours only, and that the height given by contour lines provides adequate accuracy for the highway design of the subject.

(c) Establishing control points

Control points were established using the control point function explained in the above section "**3. LINKING 3D-CAD, ASTER GDEM, AND A VR SYSTEM**
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(4) Results of the optimal alignment search

The optimal road alignment calculation system searches for the best alignment within a width of 200m from left to right of the initial alignment. In this study, we searched for three routes: Plan A, B, and C.

Plan A - Northern route: This route passes through a northern area and is optimized with the actual design as the original alignment. It is used to compare the actual design (initial alignment) to the optimal calculation results.
Plan B - Central route: This route makes a southern detour around a natural woodland (environmental protection area) that coexists with a nearby population.
Plan C - Southern route: This route passes through the mountainous area in the south, avoids northern areas that are prone to landslides or considered environmental protection areas.

Figure 3 shows the schematic searching ranges for each plan. The upper drawing of Figure 3 shows the schematic searching ranges while the lower one shows the optimal routes searched through genetic algorithm (GA).

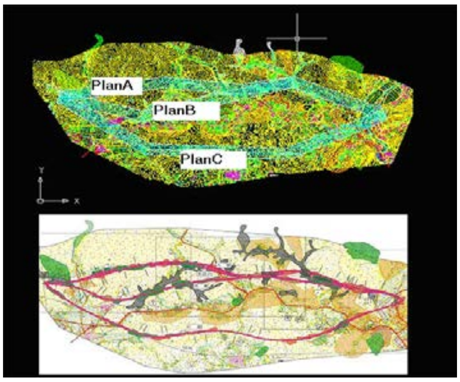

Figure3 - Search range of each route

Table 3 shows a cost comparison. Each of these three plans satisfies the geometric conditions. Plan A is the result of optimization by searching within a range 200m wide on both sides along the initial alignment and combining this with a cost analysis. As expected, when comparing the construction cost of the original plan to that of Plan A, Plan A costs less. However, there are still some problems. One problem is that the alignment of the actual design was partially a cross section of a dual carriageway, which was approximated by a single lane. Also, since a section of 4km was extracted out of the total length of 21.8km for the actual design, the volume of earth was not perfectly calculated.

Table 3 - Comparison of construction costs

Item		Actualdesign	RouteA	RouteB	RouteC
Length (m)	Earthwork	4,150	4,190	4,270	3,500
	Bridge	230+260+240+300	560+400	400+460	640+380
	Tunnel	0	0	0	900
	Total	5,180	5,150	5,130	5,420
Project costs (1,000,000 yen)	Road (earth work)	24,954	20,529	23,277	16,219
	Bridge	53,923	49,224	51,970	46,343
	Tunnel	0	0	0	39,396
	Others	17,263	17,144	17,632	14,274
	Total	96,140	86,897	92,879	116,232
Alignment element	Minimum curve radius (m)		550	500	550
	Minimum curve length (m)		230	259	308
	Minimum transition curve (m)		550	500	550
	Minimum transition curve length (m)		80	73	71
	Steepest vertical gradient (%)		3.8	4	
	Steepest vertical curve radius (m)		2486	12092	7446
	Steepest vertical curve length (m)		154	472	268

In terms of costs, Plan A, is the least expensive and will be the best option among these three. Also, because Plan A is the optimal result of the initial plan alignment, it verifies the validity of the actual design.

(5) Results of using DM and Problems

This system provides very simple functions, selecting a CAD element and then specifying its type of control point. A CAD element refers to an object, such as a line or a symbol, which describes a feature on a drawing. Even this simple function automatically contributes to reduction of the operator's burden in establishing control points on the structured data (e.g. separated into layers) compared with simple CAD data. Though time measurement etc. was not performed, the following processes became possible, for instance:
(1) Showing the road layers only, selecting them as a group, and setting them up as control points.
(2) Hiding the elements that have no relations with control points in order to improve visibility.

In addition, through functional development in the future, it will be possible to automatically convert a layer to a control point. In other words, when the map elements are drawn on designated layers, these elements on each layer can be converted together into control points as a group.

On the other hand, some problems that inhibit those effective uses were also found. As a matter of course, some of the control points in highway design are not defined in ASTER GDEM. These problems will be dealt with by revising the specifications of ASTER GDEM in the long term, and by judging control points through visual inspection and generating data through manual operation of CAD etc. in the short term.

5. DEMONSTRATION 2: LANDSCAPE EVALUATION THROUGH LINKAGE WITH A VR SYSTEM

Although roadside landscape is one of the most important considerations for road design, OHPASS does not have a function to evaluate it. In this experiment, a person will judge the landscape using computer graphics (CG). We have linked OHPASS with a VR system and examined its uses and effects. The VR system configuration is described in 3.(1).

(1) Automatic generation of VR spaces

Terrain data are loaded from 3D data created within Civil 3D via a LandXML format file. Next, horizontal alignment data for highways (linear coordinates and parameters), vertical alignments (intersection points, height, VCL, etc.), and highway cross sections (width of road surface, slope gradient / bench spacing, etc.) are loaded. A three-dimensional space is created by combining all these data.

3D geometries are not loaded directly from 3D CAD data. Instead, VR software is used to load the cross-section data and build its design geometries. The geometry created by the VR software does not differ from geometry created with 3D CAD software.

When creating a 3D VR space, we also used textures to represent details such as lane markings, road surface textures, and cutting / banking, which is not expressed in the process of 3D modeling. Figure 4 shows the link between the VR and Civil 3D systems.

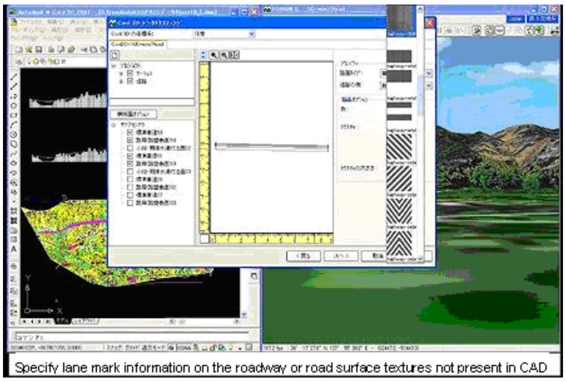

Figure 4 - Linkage of CAD and VR system

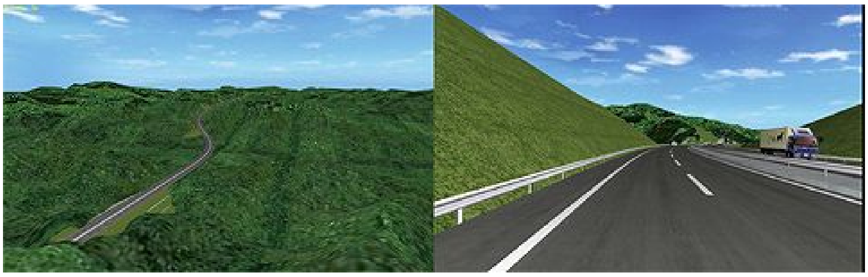

Figure 5 - Screen Example for presentation

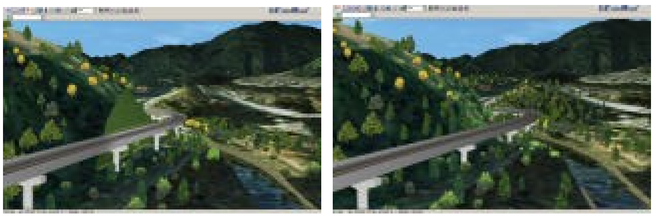

Figure 6 - Screen Example for presentation with UC-win/Road
(left: before alteration of the alignment, right: after alteration of the alignment)

(2) Evaluation and discussion

We made a presentation showing an animation with real-time CG. Figures 4 and 5 show the presentation screens. After presentation and examination the following results were achieved:

We made evaluations of the experimental results using the 3D VR screens automatically generated by

UC-win/Road. Figure 6 shows the VR screens comparing views before and after alteration of the alignment. On the left screen, a cutting face develops close to the present slope face. On the right screen, on the other hand, development of a cutting face is avoided by placing it at a distance of about 20m from the slope. After presentation and examination, the following results were achieved about the 3D highway-landscape design system.

a) Landscape evaluation from a driver's perspective

The VR simulation can be utilized for examination and evaluation of safety issues such as driver viewing distance and visibility with different alignments. The geometry of cutting and banking and road structure has only a limited effect on drivers. For example, the sense of apprehension that a driver might feel when passing through a steeply cut terrain area can be evaluated to a certain extent. However, for examining the geometry of tunnel entrances, separate model creation apart from the described workflow is necessary for evaluation in the VR space.

b) Effects produced by substantial reduction in time for image generation

Streamlining the image creation process (by loading ASTER GDEM in OHPASS to transferring it into 3D CAD and the VR system) can substantially reduce the working hours that would be required for image generation using a conventional method.

Table 4 shows the time required for these demonstration experiments. In this case demonstrations 1 and 2 are considered consecutive. Demonstration 1 was performed to search for an optimal alignment with OHPASS using the data converted into the specifications of ASTER GDEM. Demonstration 2 used the results produced by OHPASS and linked these with a VR system. In comparing the time required to generate alternative plans: (a) is equal. Yet this system makes it possible to generate alternative plans and preview them with the VR simulation in about 60 minutes, the total working time of steps (b), (c), and (d). For instance, when deciding between an embankment or an elevated structure, after calculating the alignments, the following procedure makes it possible to compare both plans in a short amount of time taking into account construction costs or volume of earthwork.

Table 4 - A comparison of working times

	Work contents	Working time required for the conventional method	Working time required for this system
(a)	Creating 3D terrains from DM and establishing control points	240min	240min
(b)	Optimal design calculation with OHPASS	420min	10min
(c)	3D representation of the calculation results from OHPASS	180min	30min
(d)	Creating data with a VR system	240min	20min
	Total	1,080min	300min

(1) Embankment geometry generation with a series of operations up to the VR system
(2) Establishment of an area to be made into an elevated structure as a control point for a "compulsory elevated section" using the function of OHPASS
(3) (b) Optimal design calculation using OHPASS --> (c) three-dimensional representation of the calculation results from OHPASS
(4) (d) Data creation using a VR system and comparison with the result of (1)

CONCLUSIONS

This study developed and added a function for using ASTER GDEM, highly accurate DEM covering all the land on earth, to Optimal Highway Path Automatic Search System (OHPASS). In specific, by creating 3D terrain from ASTER GDEM and using the control point set-up function, a foundation for utilizing ASTER GDEM has been created. In addition, by enabling the optimal design calculation results to be loaded into 3D CAD, graphical representations of the design results have been linked with a VR system.

Using the developed system, we performed simulated demonstrations using ASTER GDEM. It was concluded that use of ASTER GDEM is effective for time saving in creating three-dimensional terrain models of the present conditions, which are the essential data to input into the optimal design system. Next, we conducted a linkage experiment with a VR system. It was confirmed that use of ASTER GDEM as input data linked with the optimal highway alignment design system, 3D CAD, and VR system is effective in evaluating a landscape speedily or evaluating various landscapes in a short amount of time. We expect that a link between OHPASS and a VR system can be used effectively for landscape evaluation and road structure evaluation during highway alignment design stages, as well as for consensus building and presenting proposals.

Future issues include how to add height information other than contour lines to planimetric features in using ASTER GDEM, creation of graphics required as control points, and support for items that are not considered in OHPASS.

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