FORUM 8®

8 Degrees of Freedom (8DOF)

High-Performance, Large-Scale Driving Simulator

Custom designed, built and delivered by Forum8 for the

Research Institute of the Chinese Highway Ministry of Transport (RIOH)

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1. Introduction

Following a competitive world-wide tender process, Forum8 was awarded a multimillion-dollar contract to custom-build an 8DOF, large-scale Driving Simulator for the Research Institute of the ChineseHighway Ministry of Transport (RIOH).

Needed to provide critical planning data for the Ministry's traffic management, vehicle and driver safety research work, Forum8 engineers project managed, designed and delivered the system in February 2014 based on the company's advanced Real-Time, Interactive 3D Virtual Reality Simulation & Modelling Software, **VR Design Studio** (aka UC/Win Road) integrated with specialist third party software and hardware components in accordance with the detailed specification set out by the RIOH.

2. System Core Features and Functions

a. Driver Behaviors

The completed system includes the ability to recreate realistic and common driving scenarios accurately to enable users to conduct research and analyse driving behavior against a wide range of factors, which may affect the driver under various diverse road and vehicle conditions including,

- Measuring and analyzing a driver's psychological characteristics and conducting research based on the results (lane change, acceleration/deceleration, turning, etc.)
- Researching the driving behavior of individuals divided into age groups (youth/adults/seniors, etc.)
- A function for researching the effects on traffic safety due to a variety of driver distractions (mobile phone, radio, etc.)
- The effect on traffic safety due to tiredness
- A function for researching the influence of alcohol, disease and drugs on traffic safety, and impaired driving behavior

b. Road Traffic Safety

Provides the ability to assess the road traffic safety characteristics for research into the status and design of the individual 'road' within the overall road traffic system.

- A function for road safety assessment at the design stage
- A function for road safety assessment at the management and maintenance stage
- Researching the technology for maintaining drivers' safety when they are traveling in special sections of the road (long downhill road, tunnels, sharp curves, intersections, etc.)
- A function that enables detailed research into driving safety under changing road conditions including lighting, induction, and visibility
- VR optimization design function for road landscape and traffic facility installations
- A cluster feature that enables detailed research on the technology for maintaining road safety under conditions in which multiple drivers are operating within the same transport network

c. Traffic Safety Research Under Different Environmental Conditions

This simulator enables the user to investigate the effects and subsequent driving actions under a range of different environmental conditions.

- Traffic safety research under bad weather conditions (fog, ice and snow, high and low temperature, snowstorm, wind, etc.).
- Traffic safety and emergency and security countermeasure research under extreme traffic conditions (traffic accidents, abnormal traffic incidents, etc.).

d. Other Functions

As the FORUM 8 Driving Simulator can faithfully reproduce the real driving sensation it has many other applications in driving behavior research including,

- The validation of the latest in-vehicle ITS systems such as ADAS, Autonomous Driving plus V2V and V2I simulation.
- The ability to reproduce traffic accidents and test other emergency events such as flooding, road subsidence and landslides.
- Off-road driving over various terrains.

3.   System Configuration

The drive simulator built for the RIOH combines 10 specialist hardware and software modules from leading international 3rd party vendors integrated with Forum8's VR Simulation and 3D Modelling Design Studio technology. The core elements of the solution include

- Dome with Multi-Projector System (8 units)
  - o   Real Car & Truck cabins
  - o   Yaw-table & Vibration system
  - o   6DOF Motion Platform & X-Table
- Clustered Computer System
- Eye-Tracking System
- Traffic simulator
- Vehicle Dynamics Simulator
- Other Sub-Systems

a. Dome Multi-Projector System

The customized dome is constructed using lightweight and highly durable Fiber Reinforced Plastic (FRP) flange sheeting to create an enclosed unit that can accommodate different vehicle cabin configurations including modified production saloon car and commercial vehicle cabs, whilst also functioning as a 360⁰ screen for the projection system.

i. Barco SIM5R Projector

The multi-projector system within the simulator is composed of 8 individual projectors. Using edge blending technology, the system provides a 360° simulation environment. The direction and angle of the projectors was determined after simulation verification by an expert consultant and does not obstruct the driver's view.

ii. Vehicle Cab Configuration Options

The simulator can be configured using either a modified production model of a Honda Accord or using the steering, accelerator & brake pedals, seat and seat belt from a Hyundai truck to simulate a realistic commercial vehicle driving experience.

The engine was removed from the Honda Accord to be replaced with equipment such as the electronic control system and an acoustic PC. A PC power and a connection terminal for the Internet were also positioned inside the cabin. The original vehicle's steering wheel and accelerator / brake pedals were retained to help achieve the real driving sensation.


b. Yaw-Table and Vibration System

To provide a fully immersive and realistic driving experience the vehicle cab is mounted on a motion platform which accurately recreates the driver road handling characteristics and conditions being displayed on the screen.

The platform was built using the following component parts:

i. Bosch Rexroth Yaw-Table for EMotion-4000

This was installed between the 6DOF motion platform and the vehicle cabin, which makes the vehicle itself rotate when it turns at an intersection or a sharp curve, reproducing realistic vehicle behavior.
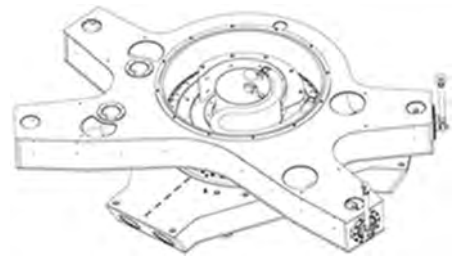
### ii. Bosch Rexroth EMotion-4000 Vibration Unit

This unit connects part of the Yaw-Table to the wheel and produces fine vibrations at high frequency to give the driver a different feel when driving on different road surfaces.

- Reproduces the feeling of driving on a rough road surface (Direct Set-point).
- Reproduces the vibration when driving on different roads (Frequency Spectrum).
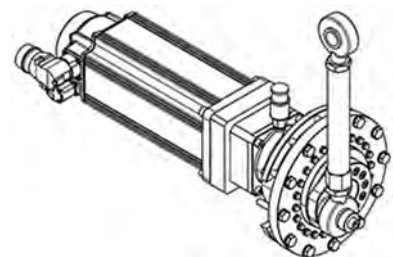
iii. Bosch Rexroth EMotion-4000-6DOF-700-MK2

This unit reproduces the basic vehicle motion model and faithfully reproduces the vehicle's 'posture' when driven by calculating the vehicle dynamics. Possible movements include a combination of the 6 directions: Pitch, Roll, Yaw, Sway, Surge, and Heave.
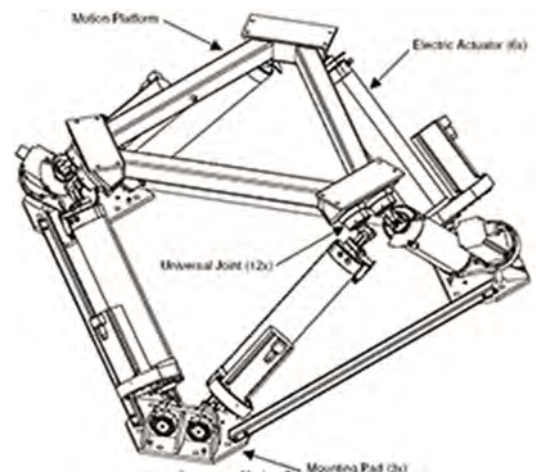
iv. Bosch Rexroth Order Made Long Excursion 1 Axis Motion Table

This is the long-distance linear motion system that supports the 6DOF on the floor. It transmits the centrifugal force to the driver in the case of long-distance acceleration.
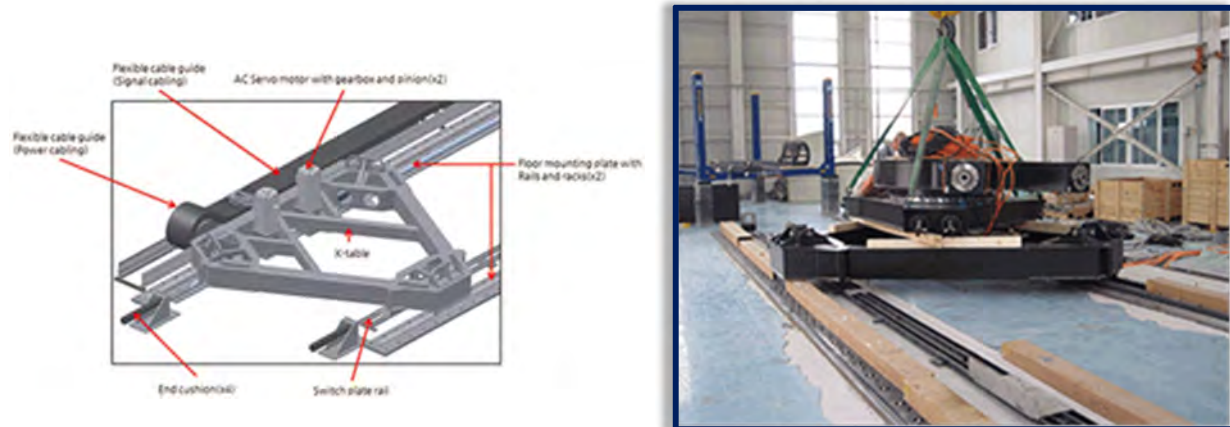
c. Cluster Computer System

Hardware Platform

The Cluster Computer System is composed of 1 master PC for control and another 8 PCs for display. Each channel is rendered using one of the 8 dedicated display screens, synchronized via the master PC, allowing the projection of a video to the 360-degree dome-shaped screen.
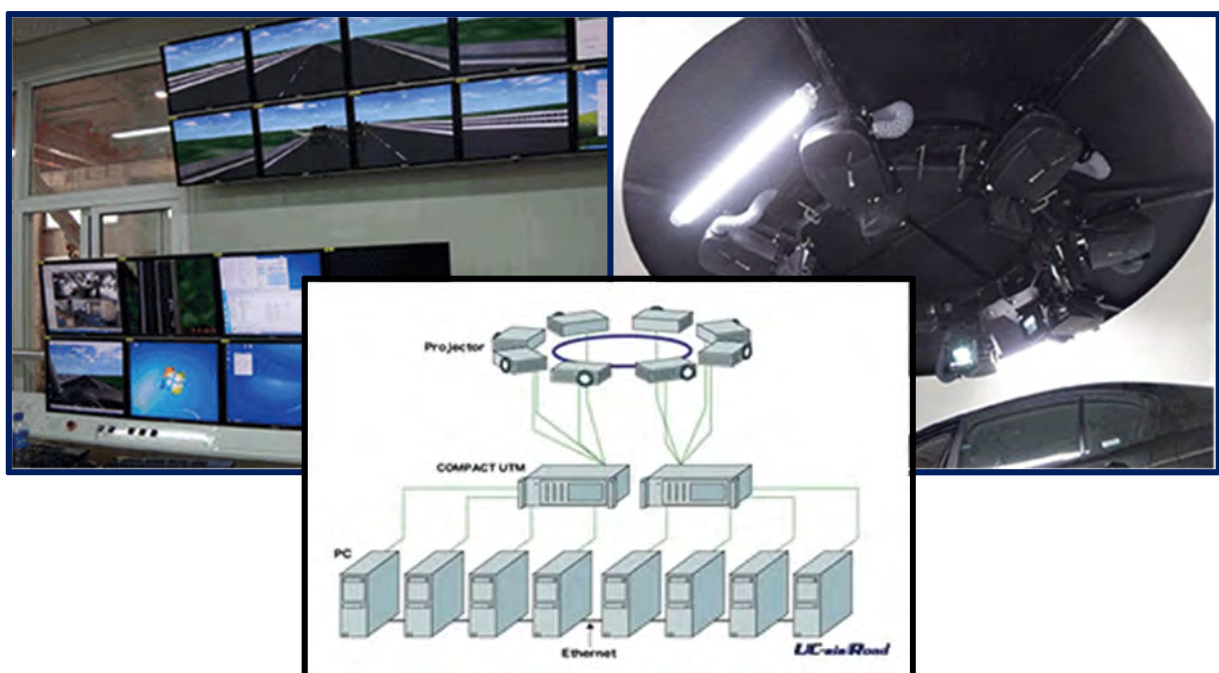
d. Software Modules

i. face LAB - Eye Tracking

Developed by Seeing Machines Inc., a spin-out company of the Australian National University (ANU), face-LAB measures the motion of the face based on information from two video cameras that automatically track the person's face in real-time. This software tracks, captures and extracts the user's facial features in 3D. When a facial feature changes on the screen, it will keep tracking even when the head rolls fast or when part of the image of the face on the screen is distorted, by choosing a new feature dynamically.

The output data includes eye movement, position of the head, rotation, tightness of the eyelid, movement of eyebrows and lips and the size of the pupil (pupillometer). By using this data the software is able to assess a person's intentions and the degree of attention based on the person's facial expressions.

ii. Traffic Simulation

PTV Vissim

Vissim is an industry standard micro-simulation traffic software product from German company PTV. It can simulate traffic flows by considering the way individual vehicles influence each other within a network. It is used in a variety of ways including helping in the identification of problems due to heavy traffic and congestion.
Vissim can run complex traffic simulations including; bicycles, cars, buses, taxis, short and long-distance trains, which makes it possible to predict delays in public transport due to congestion and to verify the effect of introducing bicycle lanes.

iii. Vehicle Dynamics Simulation

CarSim and TruckSim are vehicle dynamics simulation software systems developed and commercialized by US company Mechanical Simulation Corporation Inc. These software tools are used by automotive engineers to evaluate the dynamic behavior of vehicles under a variety of driving and environmental conditions (cars, trucks, buses, motorcycles). CarSim and TruckSim are industry standard products, used by over 30 auto manufacturers, 60 parts manufacturers and 150 universities and research institutes around the world. The products have an enviable reputation within the fields of vehicle dynamics, control engineering and ITS research & development. These software products are also used in rollover car accident analysis and road design.

e. Sub-Systems

i. Sound System

In order to ensure the highest level of performance, the sound system has an independent Sound PC, supporting the sound of the driven vehicle and the surrounding environment as well as the voice communication between the driver's cabin and the control room.
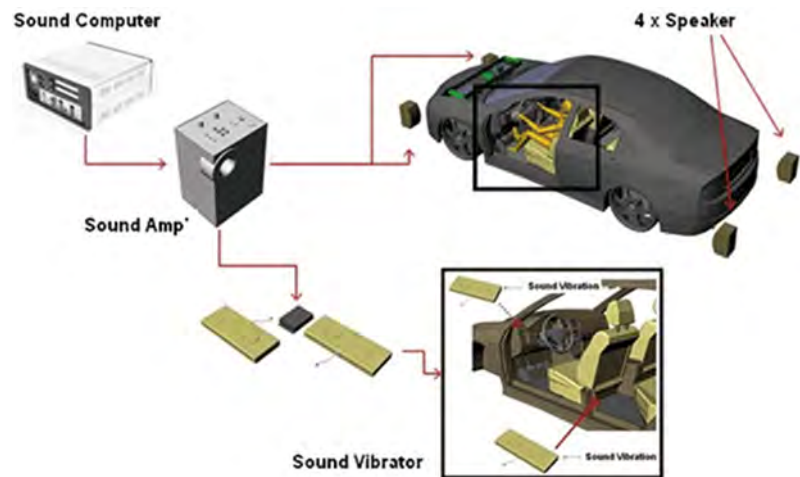
ii. Power Source System

A UPS (uninterruptible power supply) is connected between the power source and the computer system in order to protect the computers and the experimental data from any unexpected power failure. The UPS can supply a stable power source for 10~20 minutes, so providing the operators with enough time in which to shut down the system and return the motion platform into a settled position.

In addition, the operator can separate the ACC#1 and ACC#2 into 2 steps, controlling the 6DOF motion platform and other motions (X-table/YAW-table, Vibration) separately.

iii. DVR system (Digital Video Recorder)

Several CCD cameras are positioned within the cabin, DOME, and simulation room to continuously monitor the system in operation. There is a recording function, which along with the Data LOG function can be used to research drivers' behavior.
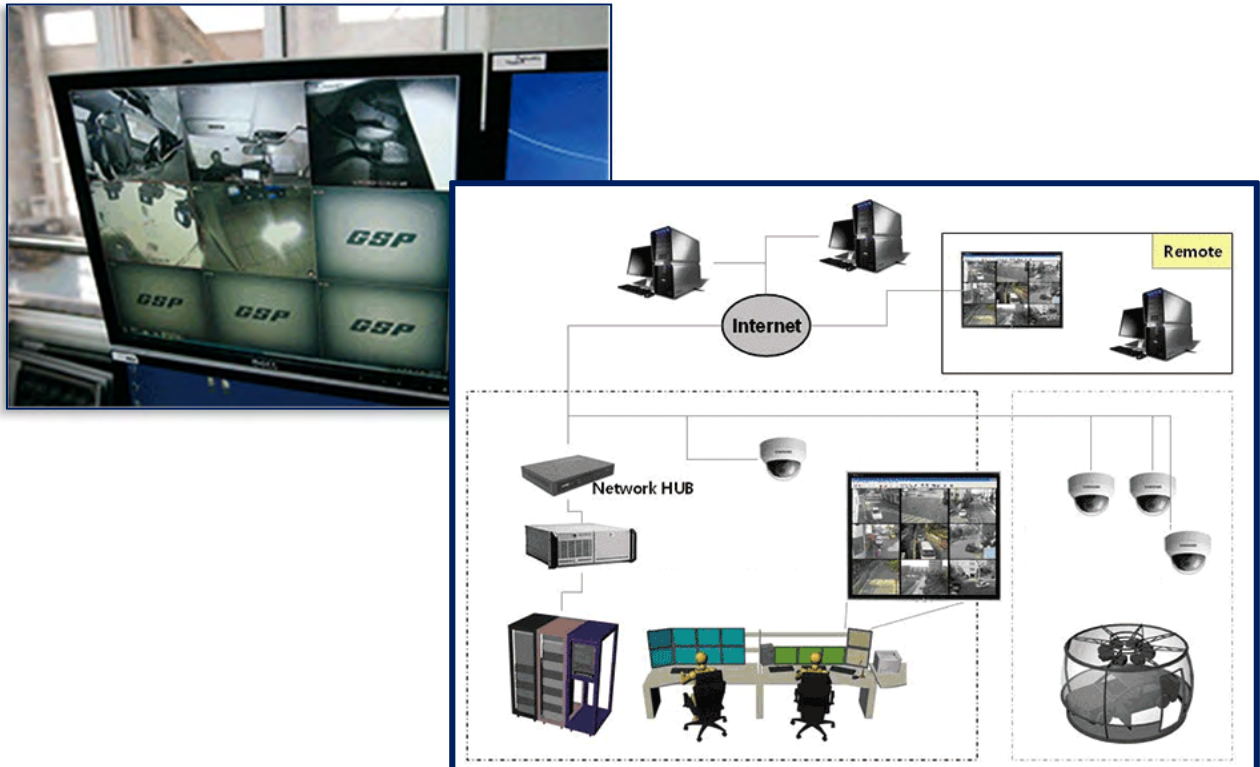
4. Interactive 3D VR Driving Simulation & Modeling Software (VR-Design Studio)

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VR-Design Studio won the 2002 Software Product of the Year (Japanese Ministry of Economy, Trade and Industry). It is an advanced real-time interactive 3D VR simulation & modeling software product that enables the user to replicate the real world in 3D Virtual Space.

i. Terrain modeling

Specification: The RIOH specification included the ability to import Chinese terrain Solution: CGIAR-CSI SRTM 90m Database is supported in VR-Design Studio. Functions to paste the satellite photographs, convert DXF-XML and edit 3D and 2D terrain are available.

ii. Road Modelling

RIOH Specification:
- Model a horizontal curve of a road including line, circle and relaxation curve (horizontal alignment)
- Model slope and vertical alignments
- Cross-sectional models including the shoulders of the road, traffic lines, curbs, median strips, emergency stopping lanes, etc. (transversal alignment)
- Simulate the road surface textures including asphalt, concrete, sand, soil, etc
- Special road models including; bridges, tunnels, crossings, interchanges, etc
- Slope models including the soil textures, frame protections and stones

Solution:

Forum8 VR Design Studio incorporates the ability to add a wide range of lines to depict roads, rivers, lakes or flight paths either free-hand or by inputting parameters. Also, roads, tunnels, bridges, rivers or pathways can all be automatically generated, and tunnel and bridge sections can be assigned by defining the horizontal road alignment and the vertical alignments.

Cuttings and embankment cross sections can be defined very accurately, and a wide variety of textures can also be assigned. The alignment / cross section generation feature helps the creation of roads with complicated geometry very easily.

iii. Special Weather Effects

RIOH Specification:

The characteristics of different road surfaces along with all environmental conditions including rain, snow, ice, fog, wind, sunshine, glare, storms etc. to be simulated.

Solution:

Forum8 VR Design Studio includes the ability to visualize any kind of weather condition as well as varying the texture and frictional characteristics of any given road surface can be assigned to reproduce the road-holding and vibration impact upon the driven vehicle.
The visualization of rain and snow is accurately simulated. Realistic rain / snow, splashing water and thunder bolts / lightning can all be visualized. Fog can have its area specified and visualized and windshield wipers, including those hanging down from the top of the windshield, can have their pivoting movement simulated.

iv. Road DB

RIOH Specification:

To include road signs, warning signs, information signs or other signs conforming to the standard of GB5768 (Can be made available using the SDK, or customized)

Solution:
The road signs in China and the standards of signs 'GB5768' are supported, along with many other signs from other countries, all downloaded from the free Forum8 database.
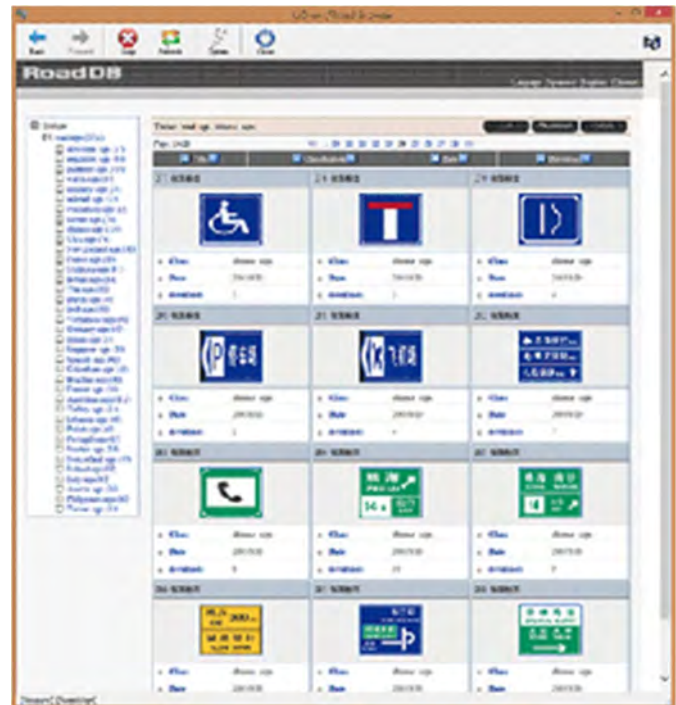
v. 3D modeling
RIOH Specification:

To support the following models:
- Trees, flowers, grasses etc.
- Buildings, toll gates, gas stations, service areas etc.
- Landscapes distinct to specific regions including plains, mountains, cities, suburbs, villages etc.
- Geographical landscapes including sky, mountains, rivers etc.
- Traffic facilities including traffic signals, guardrails, sound insulation walls, information boards, lighting facilities etc.
- Traffic flow models including vehicles or non-vehicles, pedestrians etc. or other objects including animals etc.

Solution:
Forum8 VR Design Studio features efficient VR data creation assistance using standard models / textures available via an extensive database. In addition to the standard 3D models and textures, over 6000 3D models are available directly from the VR-Design Studio DB on the Internet. Also, useful editing and movement tools are available, allowing scaling up and down, movement, rotation, inclination and arrangement of these models. Action settings offer the generation and control of moving models.

vi. Linkage Function

Specification:

Regarding importing the road models or facilities' models, other standard modeling software (Creator, VEGA etc.) to be supported.

Solution:

VR-Design Studio is compatible with the following model creation formats 3DS, FBX, MD3, COLLADA, OBJ

Data linkage

Specification:

Supports importing external data including AutoCAD etc.

Solution:

Useful features include DXF-XML conversion as well as a 3D and 2D terrain editing feature. Supporting the open format LandXML allows one to share the information of terrain, road linear and cross section by linking with CAD such as Civil 3D or InRoads. The output function of LandXML of VR-Design Studio has been certified.

VISSIM

Specification:

An interface to link with traffic simulation software (VISSIM) is available

Solution:

The imported analysis results of traffic flow from VISSIM can be visualized. Using the Micro Simulation Player, users can read ANSI.TXT files of VISSIM into VR-Design Studio. After reading the results of the simulation, set the position to display the simulation result and choose the models to show vehicles and pedestrians.

Finally, you can operate the reproduction of the traffic simulation result like a movie file and can check the traffic situation in 3D space.

vii. Driving simulation / scenario function

RIOH Specification:

Simulate specified traffic accidents (crashes, passing etc.) and a representation of traffic congestion

Solution:

Various pre-fixed movements can be set to models. A scenario is a flow from the start to the end of the simulation and composed of the various events that have been set. Scenarios can be set to simulate any type of real emergency in 3D VR Space

Audio system

RIOH Specification:

- Simulate the sound of the engine, horn, tires on the different road textures, tunnel wind and the crash between the vehicles and obstacles
- Simulate the sound of various kinds of traffic flow in a road traffic network
- The sounds of the environment, such as rain or wind

Solution:

Using OpenGL, a variety of surrounding sounds, the car's sound (sound of engine tire, wind, tunnel reflection sound) are supported. Low-pass filter is supported. Squeal sound (slip sound) and sound reproduction of 4 different wheels is also supported.

viii. Control system

RIOH Specification:

Accurate dynamics models, including the characteristics of tires to be supported so that the change in direction at curves, accelerating and decelerating performance matches the actual test parameters

Forum8 Solution:

Because the movement of all 4 wheels of the vehicle can be modeled, VR-Design Studio allows more realistic movement by implementing a model of the overall vehicle movements, engine and the transmission from engine to each wheel.

Vehicle movement model

RIOH Specification:

Dynamic models are accurately simulated according to the road surfaces in various kinds of weather (rain, snow and ice) as well as the performance under braking.

Forum8 Solution:

It is possible to simulate under-steering and over-steering. Under-steer is what occurs when a car steers less than the amount operated by the driver. Over-steer is what occurs when a car turns by more than the amount operated by the driver.

ix. VR-Design Studio Driving simulation standard models

In addition to the ability to create VR models for driving simulation, VR-Design Studio is equipped with the following 4 standard model types. All of them are real-time VR models that can make effective use of the features of the driving simulator modeled from real roads. It provides a flexible driving environment by means of the scenario function, environment switching function and the switching of cabin and motion model

Urban road VR data

As part of the project we reproduced the urban area road network of the Chinese capital city having the "No. 3 loop line" of Beijing City as the center. Modeling all lanes' road signs, marked lanes (Chinese GB5768-2009 criterion correspondence) and guide plates and placed them in accordance with local video coverage. Dozens of wide roads with widths of more than 4 lanes on one side and "solid cross - bridges" which are intersections of radiation path and loop line have been created, faithfully reproducing the road infrastructure, railroads and buildings. In addition to the landmark buildings, such as the venue of the 2008 Olympics (the 'bird's nest'), the 3D city model realistically reproduces Beijing's urban loop line network and the overall sense of urban space.

Highway VR data

An actual VR model of national road G110 was created. The conventional common national road with two-way two-lane has been extended to 2 one-way two-lane roads, separated from each other but running in parallel. The data creation was based on the design diagram of the extended road under construction. This model realistically reproduced the scene common to road construction sites in which passing vehicles are mainly large trucks. There are also various special environmental conditions built in such as rain and snow. Even a frozen road surface can be experienced from the driver's perspective in the driving scenario. The VR data has been designed to provide the optimum driving environment, allowing faithful reproduction of the vehicle behavior and driving sensation.

Mountain road VR data

This is a VR environment reproducing part of the national road G109. It has been designed to faithfully reproduce the road structure to provide a realistic feeling of acceleration and centrifugal force to the driver, especially when the vehicle passes curves of differing radii. The continuous curve in the VR space was created based on a video recording of the real road. The whole 3D environment was created based on the on-the-ground research photos such as those depicting the gutter structure of the road cross section, drainage ditches and the texture of the cut earth.

Infinite Loop Road Data

This VR environment was produced to research 'fatigue-driving' in which the driver keeps driving indefinitely using the newly developed 'traffic connection' function. A typical Chinese cross-section is applied for the road structure and for the traffic flow of vehicles the road information was obtained from actual on-the-ground research which faithfully reproduces the traffic flow.
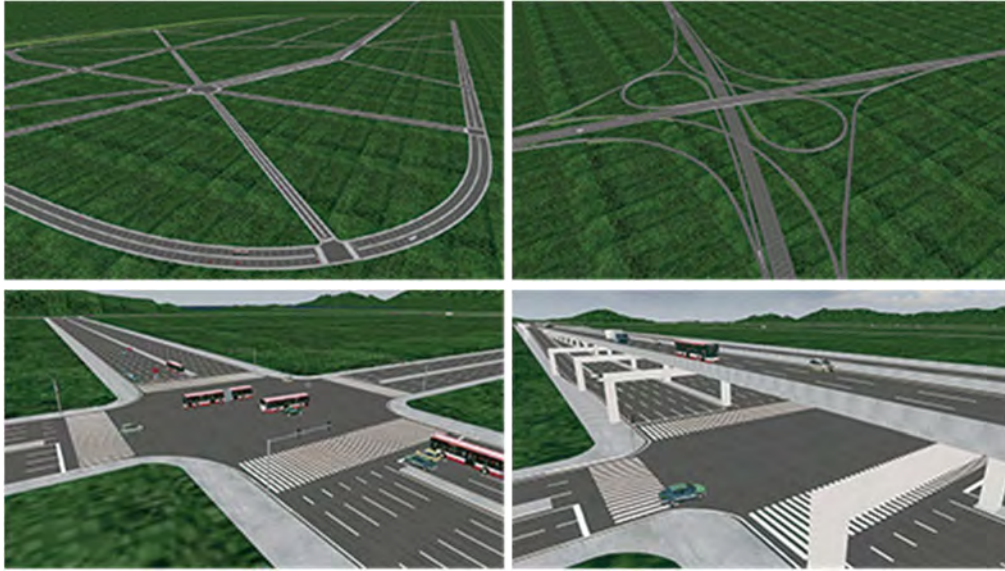
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FORUM8 is the leading Japanese producer of Interactive 3D VR engineering software.

It's premier product VR-Design Studio (formerly known as UC-win/Road), is at the forefront of Interactive 3D VR Transport Simulation & Modeling technology.

Established in 1987, this award-winning company has offices and partners on every continent and is a member of the US ITE and an associate of the US TRB visualization group.

VR-Design Studio is the ideal solution for urban, rail, marine & transport planning / design projects, as well as driving simulation and interactive visualizations of pedestrian-based events and emergency planning / training scenarios.

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