Design and realization of road geometry alignment simulation

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Received 1 October 2014, www.cmnt.lv

Abstract

Embarking from road's characteristic and road design's demand to the simulation system, road simulation system's characteristics have been discussed, and then road simulation system frame based on multi-agent has been constructed. The simulation agents have been divided into response agent, corporation agent and interface agent, and their structures have been analysed too. The car dynamics model, road ground view model and driver model have been built, the simulation results are validated by basic experiments. The simulation system is an efficient tool for road design evaluation.

Keywords: road simulation, road engineering, multi-agent, simulation model

1 Introduction

Road engineering investment is huge; it is not possible to verify rationality of design program through making "sample". Design is influenced by many factors; it is difficult to use a mathematical model to evaluate. Because of the lack of enough information, experts can only rely on experience to judge, it is difficult to make an objective and comprehensive evaluation [1]. The computer simulation technology is introduced into the evaluation of road design, through studying and establishing the road simulation system, takes the road geometry linear as the main body, repeatedly carries on the simulation experiment to the road design plan, scientific analysis and evaluation of the simulation results, may achieve the purpose of scientific evaluation of road design program.

The road simulation system is continuous variable dynamic system (CVDS) and discrete event dynamic system (DEDS) interaction promiscuous system (HS), has complexity, hybridity, interactivity, timeliness and modularity and other characteristics [2]. Therefore, in the road simulation system, how to describe the interaction of the discrete event and continuous variable, portray promiscuous system behaviour essence of road, so coordinate news transmissions of among various agent based on DEDS and CVDS in the process of simulation, is one of the key of simulation system [3].

Under these guides, the characteristics of road simulation system, system framework and development method are studied in this paper, which lays a theoretical foundation for the development of the simulation system, and has an important significance to realize signification, visualization, intelligent of road design.

2 Characteristics and framework of road simulation

2.1 ANALYSIS OF ROAD SIMULATION SYSTEM'S CHARACTERISTICS

Time-variable characteristic in road simulation process may describes with the following the time-variable characteristic model of person, car, road and environment.

$$\begin{cases} \Phi(t_i) = \{\alpha^i, r^i, w^i\} \\ \alpha^i = \{\alpha_v^i, \alpha_{av}^i, \alpha_{aH}^i, \alpha_\beta^i, \alpha_o^i, \alpha_p^i\} \\ r^i = \{r_H^i, r_V^i, r_C^i\} \\ w^i = \{w_E^i, w_C\} \end{cases}, \tag{1}$$

where $\Phi(t_i)$ is the time-variable characteristic model of person, car, road and environment. α^i is car's condition at t_i moment. $\alpha_v^i, \alpha_{av}^i, \alpha_{aH}^i, \alpha_\beta^i, \alpha_o^i, \alpha_p^i$ are car speed, longitudinal acceleration, lateral acceleration, front wheel corners, car conditions as well as positions describes respectively at t_i moment. r^i is road geometrical characteristic at t_i moment. r_H^i, r_V^i, r_C^i are road's horizontal, vertical and Cross-section geometric characteristics respectively at t_i moment. w^i is surrounding environment characteristic at t_i moment. w_E^i is environment characteristic at t_i moment. w_c expresses weather characteristic [4, 5].

With $Q_{i+1}(\Phi(t_{i+1}))$ described transport condition that is determined by environmental information at t_{i+1} moment:

$$Q_{i+1}(\Phi(t_{i+1})) = p_i(Q_i(\Phi(t_i))), \tag{2}$$

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where p_i is an operator that has function to car, and non-correlated with road or environment, namely driver's operation to car. Type (2) also explained the transport condition $Q_{i+1}\left(\Phi\left(t_{i+1}\right)\right)$ that the process expected may achieves the travel goal, through adjusting process characteristic parameter α_i.

The above time-variable characteristic mode reveals, road simulation system has the following features:

1) Continued corresponding feedback character, the road simulation experiment advances continually along with extending of route. In this process, the driver model car model and road virtual environment model has the characteristic of persistent response.

2) Intelligent simulation characteristic, the road simulation system's pilot controls behavior is one kind of intelligent decision behavior, pilot model in the simulation system should have the auto-adapted characteristic, along with the change of person, car, road and environment time-variable condition, pilot model automatic adjust its control policy.

3) Hybridity, the road simulation system is promiscuous system that is unified of road and environment characteristic's discrete state, pilot manipulative separate behavior and car operational continual condition. The evolution of system is driven by the time (car movement) and event (pilot operation, road and environment state event) the two different mechanism, displays for the structure, algorithm hybridity.

2.2 MULTI-AGENT SYSTEM THEORY

Agent is a software entity that can realize the function under the specific environment continuously and spontaneously, and associates with the relevant agent and process. Continuous and spontaneous request originates from the change of environment, requests agent to real-time respond to user demand under nobody guides and interference by flexible, intelligent way. In addition, there is also hope that the agent could communicate and cooperate with other agent in the environment and the process [6].

The multi-agent system needs realizes with the aid of some correlation theories and technologies, mainly includes the knowledge expression and inference, agent communication language, multi-agent coordinates model, multi-agent to consult model:

1) Knowledge expression and inference. If a single agent in the system through a certain data structure and the corresponding operation to address the problem of modeling, must use the knowledge expression and inference method correlation theories.

2) Agent communication language. Communication and information exchange between agents need to a certain level of agreement as a basis, agent communication language can be used to accomplish this function.

3) Multi-agent coordinates model. In the multi-agent system category, reciprocity needs to be coordinated between agents. Coordination model is to provide a formal framework for the interaction among agent multi-agent coordination model can be divided into control actuation and data driven two types.

4) Multi-agent negotiation model. The multi-agent system is a system composed of a plurality of agent, which can solve the complex problem which single agent cannot solve, question solution network are formed by many agent coordinated cooperation. In multi-agent system, cooperation between agents is to be done through communication and consultation. Regarding multi-agent system model, has the different viewpoint, generally thinks that agent should include sensors, decision controller, mental state, knowledge base, communicator etc. several parts of compositions, Including the BDI model is a widely accepted model of agent negotiation model, it reveals the agent energetic factor including belief, desire, intention etc., as shown in Figure 1.

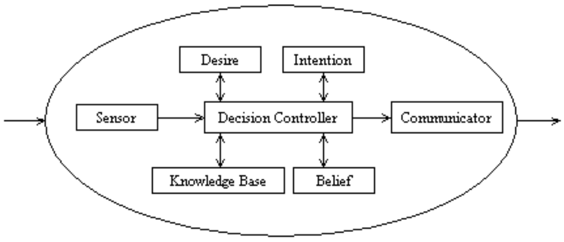

FIGURE 1 BDI model

2.3 DEFINITION OF ELEMENTAL AGENT

In order to facilitate the formal description of Agent, commonness of agent system can be abstracted, is defined as elemental agent. According to the characteristics of agent in the road simulation system and refers to the agent dynamics characteristic, defines agent as:

$$Agent = \langle A\cdot id, T, I, O, S, IA, OA, R\rangle$$
$$T \in R_0^+$$
$$I = EI \bigcup II \qquad ,$$
$$\forall_i \in I \Rightarrow i\cdot source \in IA$$
$$\forall_o \in O \Rightarrow o\cdot source \in OA$$

where $A\cdot id$ is identifier for the Agent. T is a logical clock. I, O are respectively for the input and output messages. EI is the external input news, II for internal input news. S is state set of elemental agent, the status in S is the limited dimensions real number vector. IA is all of the agent set that is possible to input message for this Agent. OA is all of the agent set that is possible to output message for this Agent. R is rule processing of elemental agent.

The message and the message flow in agent can be defined, according to the BNF form, the message is defined as:

*<system message>::=<message ID><message type>(:<parameters>)**

*<message ID>::=<digital>**
*<message type>::=<identifier>**
*<parameters>::=<parameter name><blank>(:<parameter value>)**
<parameter name>::=<identifier>
<parameter value>::=<identifier>
*<identifier >::=<letter>(<letter>|<digutal>|_)**
While the message flow can be defined as:
<system message flow>::=<message flow aim>
<message flow source>
<send time><effective time>
<message format><system message>

The status (*S*) of agent can be described by five vectors:

$$S=\langle A\cdot id, EI\cdot n, A\cdot e, EO\cdot n, t\rangle.$$

Type: $A\cdot id$ is identifier for the Agent; $EI\cdot n$ is name of input event for agent; $A\cdot e$ is activation state of agent; $EO\cdot n$ is name of output event for agent; *t* is the running time of agent after activation.

2.4 SIMULATION SYSTEM FRAME FOUND ON MULTI-AGENT

The above characteristic of road simulation system determines the software development method of traditional which is oriented to process oriented and object, is hard to process under the time-variable condition among the subsystems alternately, coordination, auto-adapted, self-feedback and other characteristics, simultaneously is also hard to solve the road simulation system hybridity problem. Statement of multi-agent system software development thought that to solve the software intelligence and cooperation has provided a new way.

According to person, car, road and environment simulation system's time-variable dynamic characteristic, the person, car, road and environment simulation system frame based on multi-agent as shown in Figure 2.

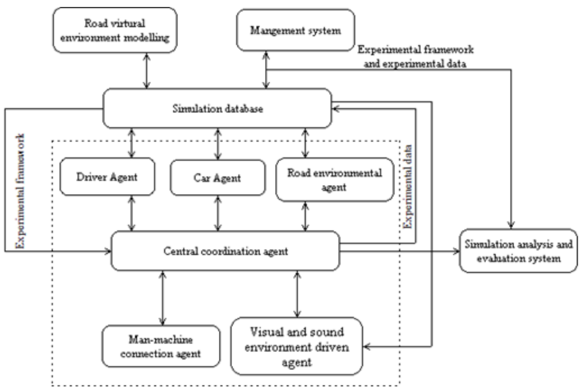

FIGURE 2 Person, car, road and environment simulation framework based on multi-agent

Here human, car, road and environment simulation system is composed of 6 interactions of agent, according to its duty and the difference of solution mechanism undertaking to duty, may be divided to respond agent, cooperation agent and interface agent 3 kinds. Driver agent, car agent and center coordinate agent to belong to cooperation agent, namely has internal behavior initiative agent, has knowledge representation, question solution expressed and so on. Road environmental agent and visual-audio driver agent belong to respond agent, but simply has the response to the exterior stimulation simply, is similar to customer/server architecture, agent is not only the customer, is the server, according to the procedure arrangement, makes to reply or send out the request. Man-machine connection agent belongs to interface Agent, can interactive with the user, carries on display and control [7].

In the road simulation system, various agent characteristics are different, its basic structure is also different, this article only describes the basic structure of central coordination agent, the center coordinates agent is at the core position in the multi-agent system, is responsible for message distribution, coordination, simulation clock coordination, its basic structure as shown in Figure 3.

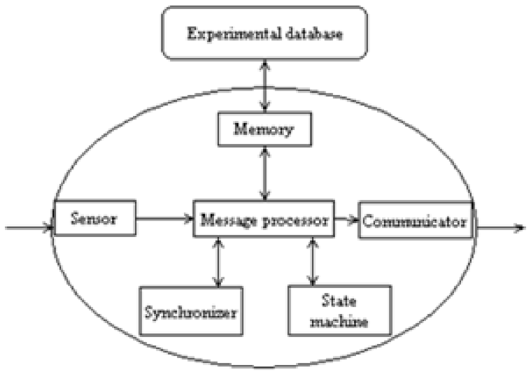

FIGURE 3 Center coordinates agent

Here the sensor is responsible for the receive of environmental information, distribute news through message processor to memory, synchronizer and state machine, the memory and experimental analysis, evaluation of relevant information store in the experiment database. The message processor has a message distribution function and agent internal state storage and adjustment function. The state machine memory system's time-variable environmental information, and distribute the previous time-variable environmental information by the message processor to the synchronize hand-in-hand processing row state renewal [8]. The synchronizer according to the definite rule, decided the message that in advance must distribute, uses the message processor and communicator distribution to other agent. For example, when central synchronizer receives driver agent operation information, the synchronizer compares the information with the information that state machine save, if there is no change, the information will no longer be distributed to the car agent, otherwise, then transmits [9].

3 Establishment of Road Simulation Model

3.1 CAR MULTI-BODY DYNAMICS SIMULATION MODEL

Traditional analyses of road alignment index is usually based on the classic car dynamic model, regards car as a particle, neglects various car part of relations, but does not tally with the reality. The car dynamics model established in this paper is based on multi-body dynamics system. In order to facilitate the modelling and the mathematical expression, simultaneously took into consideration the road simulation systems characteristic, has carried on the following simplification to the automotive system:

1) The car, frame and packing container as an object to be processed.

2) The front axle and rear axle of car may reciprocate to the car body and rotate around the longitudinal axis parallel to the axis of the car, around the shock absorber is simplified as a damping restraint, the frame and axles are connected by leaf springs and shock absorbers.

3) Steering system the steering wheel and column can be simplified to rotate objects around the car body, the steering unit is only considered that rotates around the body of the axle, the steering column and between steering units' axes with the universal joint.

4) The tire model uses the FIALA tire model.

3.2 DRIVER MODEL BASED ON PREVIEW THEORY

The car presents time-variable dynamic road environment to the driver in the process of travel, and the driving behavior the effect on the car displays for the driver to take operation behavior after the environment sensation. The basic principle of the driver control car is to cause car's movement as far as possible consistent with expected trajectory and speed. Therefore, according to person's behavior stimulation- organism - response classic mode, driving behavior can be divided into 3 stages, namely information sensation, judgment decision-making and operation adjustment. As shown in Figure 4:

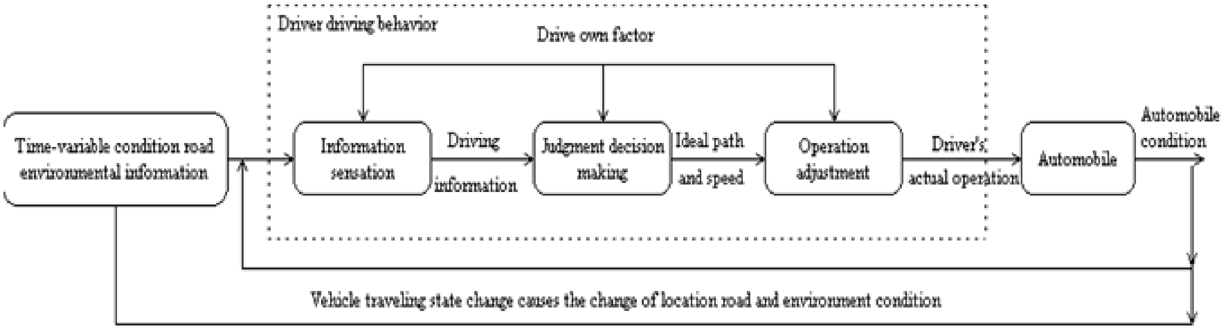

FIGURE 4 Driver operation behaviour flow char

3.3 ROAD SCENE MODEL BASED ON CONSTRAINED DELAUNAY TRIANGULATION

The request of road ground view model is expressed by the different resolution through constraint dlaunay triangulation (CDT), modelling plan of this system is used for road simulation model based on CDT, and the modelling process is described as follows:

1) Carries on the pretreatment to the topographical data, first carries on the data filters, the rejection wrong spot and closely coincide, next data grid, to enhance data retrieval speed.

2) Using the point by point insertion algorithm, establishes the basic Delaney triangulation.

3) Using "wears hat" principle of road cross-sectional design, obtains the intersection of road side slope and triangular net, forms the closed polygon.

4) Using the CDT algorithm, the closed polygon according to the line segment is inserted into the basic triangle net, forms the constrained Delaney triangulation.

5) Using triangular net virus algorithm, rejection closed polygon interior triangular net.

6) Using point by point insertion algorithm, builds the road three-dimensional model, the road three-dimensional odel and topographical model superimposition, forms ground view simulation model - line frame model.

7) Based on edge collapse algorithm,

Multi-level detail model of ground view simulation model has been built.

8) Enduing the model material and texture, finally builds the ground view simulation model.

4 Simulation Model Confirmations

Simulation model is set up for simulation experiments, to reveal the behaviour characteristics of the original system by simulation experiment. However, it is not possible to confirm whether a model is effective well at a modelling. When the system is quite huge and complex, in order not to make the cost of model establishing and running is too high, the complexity of the model is limited, has to make some assumptions or simplified, so it is necessary to verify the effectiveness of the model. Key field tests were conducted on vehicle dynamics. In model validation, using the method based on experimental data, in the same boundary condition and scene consistent situation, compared with actual experimental data simulation experiment data, the model was modified according to the comparison result.

4.1 EXPERIMENTAL DESIGN

Experimental road section is Dian Liang – Cai Guan Ling section of Bao Ji – Han Zhong road in China's Shanxi province. This road is second-class road of mountainous hilly area, design speed 40 km/h, asphalt pavement width 7 m, roadbed width 8.5 m. Region's altitude of the route is at 1 200m~1 350m, by the topographical constraint, this road section consecutively 5 km downhill, plane indices except sight distance of individual curves cannot meet the requirements, other indices conform to the standard stipulation.

Experiment vehicles and instrument: Test vehicle uses YaXin JS6820C32D1, maximum speed 110 km/h, carrying capacity 5 t; the car speed uses the fifth wheel instrument real-time collection and record.

4.2 SIMULATION EXPERIMENTAL PLAN

According to the uphill and downhill two cases are considered, in the downhill experiment the car is pressed 30,40,50 km/h to hang 3 grades of glides by the top of slope to the base of slope, in the glide process, loosens the accelerator pedal. In the uphill experiment the car is pressed 40, 50, 60 km/h to hang 3 grade and accelerator full hill climbing to go by the base of slope. In the simulation, road model is established according to the actual road, the car simulation model is built, which is consistent with 5 t experimental cars.

4.3 RESULT ANALYSIS

Figure 5 is the field test data and model test data of car with 50 km/h from top hanging 3 archives to glide. The test section longitudinal slope of 7%, there are two horizontal curve, radius is larger than 200m, In the simulation model, friction coefficient between tire and road surface takes 0.65, indicates that the simulated data and empirical datum have certain error, The error is mainly from the following two aspects: First, in simulation testing the road surface friction coefficient value and actual situation have the difference. This experimental road section puts into use for many years later, the different sector road surface attrition and destruction condition are different, cause the road surface friction coefficient to be different; Second, the local transportation department responsible for the work to prevent the vehicles exceeds the speed limit, has established the caution belt in the steep slope road section, has certain influence to the field test data. Even so, Figure 5 shows the simulation results and experimental data are in good agreement and the error is in the allowable range, so test data of 40 km/h and 30 km/h. therefore the simulation model is effective. In the later design proposal appraisal experiment, only need change parameter of path model, but does not transform the car model, may carry on to analyse and study to various parameters in road route design.

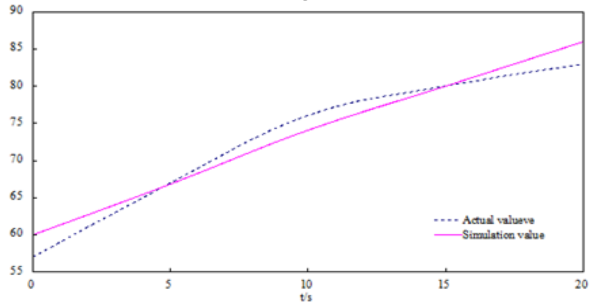

FIGURE 5 Actual data and simulated data contrast

5 Conclusions

The road simulation system has been established to evaluate the road design, on the basis of the analysis simulation characteristic, development and framework of road simulation system have been proposed, agents of road simulation have been defined, the center coordinates agent and driver agent have been discussed, and this system is confirmed through the project example, an important guiding significance for the development of road simulation system has been provided.

Acknowledgments

The research project was funded by a grant from the Ministry of Transport of China. The authors gratefully thank my professional brothers at Chang'an University in Xi'an. Finally, we would like to express our gratitude to the study subjects who uncomplainingly underwent the rather demanding trials.

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