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Microscopic Simulation for virtual worlds with self-driving avatars

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Abstract—**Virtual worlds are a good platform to perform driving behavior experiments among a big group of people at low cost and high level of realism. Since driving behavior is highly influenced by the behavior of surrounding vehicles it is crucial to establish a realistic environment for the driving experiment. Thus, the avatars' vehicle needs to be recognized by the simulation and hence by the other simulated vehicles. In this paper we are introducing a microscopic simulation model that has this feature and allows users to anticipate as drivers in the simulation. Using virtual worlds with self driving avatars allows studying driving behavior in various situations under stable laboratory conditions. The virtual environment, allows the recreation of various scenarios from highways to city traffic under various traffic and environmental conditions.**

I. INTRODUCTION

USING virtual worlds with self driving avatars allows studying driving behavior in various situations under stable laboratory conditions. The virtual environment, allows the recreation of various scenarios from highways to city traffic under various traffic (congestion, free flow, ...) and environmental (rain, night, …) conditions. The avatar drives a vehicle inside a simulation and all movements are stored in a log-file for further analysis. This way of data collection allows a reasonable degree of realism and is still a fairly low cost solution to sample data from a big group of people, since the only requirement, for a participation in the survey, is a computer with Internet access.

Since driving behavior is highly influenced by the behavior of surrounding vehicles it is crucial to establish a realistic environment for the driving experiment. Thus, the avatars' vehicle needs to be recognized by the simulation and hence by the other simulated vehicles. In this paper we are introducing a microscopic simulation that has this feature and allows users to anticipate as drivers in the simulation.

Microscopic traffic flow models include mostly sub-models for driving behavior. Driving behavior models try to describe the driving task and are essential to predict the behavior of vehicle-driver combinations. The psychology of driving behavior is a complex topic and starts with the visual and audible perception. The behavior of a driver can be distinguished in three levels (see Figure 1), depending on the amount of conscious decision making. Nielsen [1] makes the distinction in routine or skill based, rule based and knowledge based decision making. Skill based is decision making where the person is fully accustomed to a situation and is able to decide without conscious deliberation. Perceptions lead automatically to the right (routine) action. In rule based behavior people decide on certain standard knowledge that could be represented as rules: if I see x, than I decide y. Finally in knowledge based decision making people observe the situations, they do not recognize it directly and they think bout the most appropriate action to take. Skill based behavior is the quickest, knowledge based takes the most time. Most driver behavior is skill based.

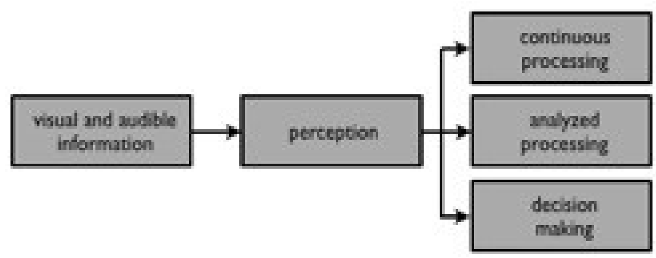

Fig. 1. Perception of a driver

For the visual perception, the driver is identifying the situation by a routine of eye movement. The more experienced a driver is, the eye movement gets more efficient and therefore lowers the needed mental capacity, since information from the periphery is filtered out. This leads to a better focus and allows the usage of more mental capacity to deal with unforeseen incidents along the trip [2].
Continuous and analyzed processing effects car following, speed decision and route guidance. During the continuous processing the car following is determined by the visual angle of two fixed points at the rear of the leading car or the tail lights by night. The speed decision is based purely on the road geometry and traffic signs have no influence on this level. In terms of route guidance, the driver just follows known routes in this level of processing.
In the analyzed processing the driver evaluates the gain of lane changes and overtaking maneuvers and recognizes the restrictions of traffic signs along the road. This leads to a speed decision based on the leading vehicle as well as on the restrictions. Further the driver will react on mandatory route choice information. In the decision making, the driver makes decisions about the departure time and mode choice

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depending on pre-trip information and plans the route, based on the knowledge of the network [3].

Riemersma [4] defines time horizons for these three levels of processing. The continuous processing of information is done with a preview in the order of maximally a few seconds, while the analyzed processing has a time span of some seconds to some minutes. Decision making is performed just occasionally and the horizon concerned may include the total duration of the trip. Further he defines three main factors influencing the driver behavior:

- Situational factors
- Individual differences
- Other traffic

Situational factors can be divided in two categories: First the environmental factors like time of day, day of the week, weather and road conditions and second the individual factors like hurry, distraction, impairment, trip purpose, trip length and driving time. Other traffic can be divided in three different car-following zones defined between the free flow situation and congestion.

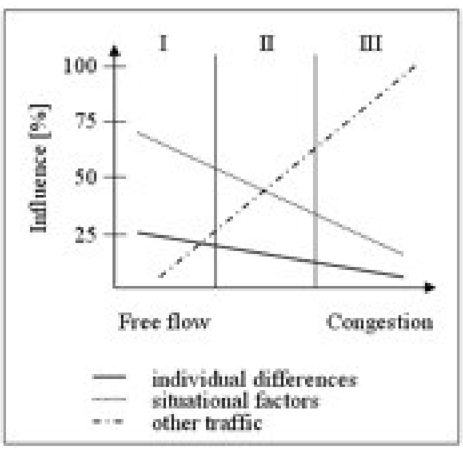

Fig. 2. Influencing factors to driving behavior [4]

In congestion the situational and individual factors become more and more meaningless and the other traffic determines the behavior. In free flow conditions the situational and individual factors have the major part and the other traffic becomes meaningless [4].Taken these things into account, the necessity is to provide those triggers of driving behavior to the users in the virtual world. In the following we will describe the virtual environment for clarification, before introducing the behavior model.

II. VIRTUAL ENVIRONMENT

Online virtual worlds are becoming increasingly popular [5] in the entertainment industry [6], but gaining more and more momentum in the scientific community [7],[8],[9],[10],[11]. Second Life (SL) is a prominent example of such a virtual online world [12]. SL provides a free networked multi-user three-dimensional (3D) environment and is very popular with an increasing amount of registered users (over 16.8 million as of May 2009) and about 40,000 to 60,000 users online at any time. The main features of SL are:

1) Support of social interactions between user avatars(called SL “residents”) via public chat and the Instant Messaging interface.
2) Support for user-created content.
3) Economy with a marketplace and own currency,
4) called “Linden dollars” that convert to US dollars.

Users of SL can design their own objects, such as buildings, vehicles, or even entire ecosystems, and upload this content to their privately owned virtual locations – ‘parcels’ of an ‘island’ (a land unit in SL), or entire islands – which are open to the SL community. OpenSimulator (OpenSim) is an open source project aiming at the creation and deployment of virtual worlds [13]. Since the beginning of 2007, it is being developed under the BSD (Berkeley Software Distribution) license. The goal of the originators is to provide an open and extensible platform, which can be run on virtual worlds creators’ own servers, rather than on servers of Linden Lab (the company running SL). Otherwise, the motivation, goals and challenges of OpenSim are quite similar to those of Second Life [14]. Using OpenSim we have created a virtual world after the city of Kashiwa in the outskirts of Tokyo, Japan. The modeled area consists of a highway section with an off-ramp to local roads connecting to a train station and bus hub in conjunction with a big department store. The road network has been modeled as existing, with s few adaptations such as:

1) adding additional road connections to connect existing links
2) adding areas of easy entry such as parking lots
3) shortening straight sections to limit overall space

Figure 3 shows a bird-view image of the highway section of the virtual world.

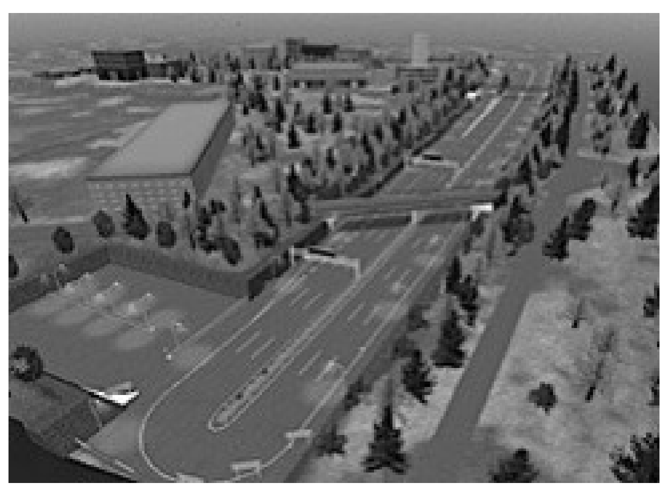

Fig. 3. Bird-view on the virtual world, build after the City of Kashiwa, Japan

The world is populated by computer simulated vehicles and pedestrians. Motions are controlled by a microscopic simulation model that can be set to generate different traffic conditions from free-flow to heavy congested. Additionally, users of the system can use their avatar (person representation in the virtual world) to pick up a vehicle and drive within the simulated network, experiencing the generated scenario.

The vehicles used by avatars are controlled by keyboard, joystick or driving set known from video game settings. Next to the basic driving functions, the vehicle can display messages from an inboard unit to the driver, which are controlled by the simulation. Figure 4 shows the inside view of a user controlled vehicle.

Fig. 4. Interior view of a user controlled vehicle with an onboard display for message dissemination.

To represent the traffic control strategies of the simulation for the user driven vehicles, the virtual world contains traffic signs, traffic signals and variable message signs as show in Figure 5.

Fig. 5. Representations of traffic control installations in the virtual world, consisting of traffic lights, route information and variable message signs for dynamic information.

While the amount of simulated vehicle is theoretically unlimited, the number of user driven vehicles at any given time is technically limited. While an island can host about 100 avatars simultaneously, the number of vehicles is about 10% of this due to the computational effort to move the user driven vehicles in the virtual world. However, taking into account that usual driving simulators just allow one driver at a given time, this limitation is considered minor.

Having the virtual environment, we have the boundary conditions for our simulation in which the behavior model is needed. Next we will investigate possible users' actions in the virtual environment which we have to anticipate in the behavior model, before introducing the behavior model itself.

III. AVATAR DRIVEN VEHICLES

Vehicles driven by avatars can theoretically drive everywhere in the virtual world and are not bound to the road. However, to limit the the drivers, invisible walls are created at the outer lane markings of the road. That means, that a driver can move freely on the road (over all available lanes), but is not allowed to leave the paved area. As a further limitation, the vehicle will not be able to crash into simulated vehicles. The vehicle will be slowed down and a message is given to the driver that the safety measure is active.

The information gathered from the vehicles is the position in x,y, and z, the directional speeds v_x, v_y, and v_z in the virtual world, and a flag if safety measures apply or not, at any given time. This allows to determine the link the vehicle is on and gives an indication of the lane (see Figure 6).

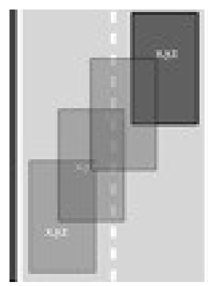

Fig. 6. Lane changing vehicle positions over time in the virtual world.

In contrast to lane based simulators, the avatar driven vehicle will perform lane changes over time, which has to be taken into account in the car following model, by blocking both lanes for the following traffic. Additional information, such as the usage of indicators is planned, but not yet implemented.

Having the set of information of the non-simulated vehicles the following will describe the models for car following and lane changing used in the microscopic simulator.

IV. USED MODELS FOR CAR FOLLOWING AND LANE CHANGING

In the simulator we are using two different car following models. One is the Intelligent Driver Model (IDM) developed at the University of Stuttgart, which is defined as followed [15]: IDM describes the dynamics of the positions and velocities of single vehicles. For vehicle α, $x\alpha$ denotes its position at time t, and $v\alpha$ its velocity. Furthermore, $l\alpha$

gives the length of the vehicle. To simplify notation, we define the net distance $s\alpha := x_{\alpha-1} - x_\alpha - l_{\alpha-1}$, where $\alpha - 1$ refers to the vehicle directly in front of vehicle α, and the velocity difference, or approaching rate, $\Delta v\alpha := v_\alpha - v_{\alpha-1}$. The dynamics of vehicle α are then described by the following equations:

$$\dot{x}_\alpha = \frac{\mathrm{d}x_\alpha}{\mathrm{d}t} = v_\alpha$$
$$\dot{v}_\alpha = \frac{\mathrm{d}v_\alpha}{\mathrm{d}t} = a\left(1 - \left(\frac{v_\alpha}{v_0}\right)^\delta - \left(\frac{s^*(v_\alpha, \Delta v_\alpha)}{s_\alpha}\right)^2\right)$$
$$\text{with } s^*(v_\alpha, \Delta v_\alpha) = s_0 + v_\alpha T + \frac{v_\alpha \Delta v_\alpha}{2\sqrt{a b}}$$

v0, s0, T, a, and b are model parameters which have the following meaning:

- desired velocity v_0: the velocity the vehicle would drive at in free traffic
- minimum spacing s_0: a minimum net distance that is kept even at a complete stand-still in a traffic jam
- desired time headway T: the desired time headway to the vehicle in front
- acceleration a
- comfortable braking deceleration b
- The exponent δ is usually set to 4.

The other car following model is the Gazis-Herman-Rothery (GHR) model, well-known from the late fifties and early sixties. Its formulation is:

$$a_n(t) = c v_n^m(t) \frac{\Delta v(t-T)}{\Delta x^l(t-T)},$$

where a_n is the acceleration of vehicle n implemented at time t by a driver and is proportional to, v the speed of the nth vehicle, h_x and h_v, the relative spacing and speeds, respectively between the n^{th} and n-1 vehicle (the vehicle immediately in front), assessed at an earlier time t-T , where T is the driver reaction time, and m, l and c are the constants to be determined [16].

Next to the longitudinal driving behavior, another important aspect is the lateral, or lane changing, behavior of drivers. The model used, is the one Gipps [17] proposed - a framework for the structure of lane changing decisions in urban driving situations including the influence of traffic signals, obstructions and different vehicle types such as heavy vehicles. The model concentrates on the decision-making process considering the potentially conflicting goals and assuming a logical driver behavior. The model also considers the urgency of the lane changing maneuver in terms of the distance of the intended turn of the driver. The urgency of the maneuver is modeled through the drivers' gap acceptance and braking behavior [18].

Set with the models for lane changing and car following, the simulation can be implemented. This is where the external vehicles have to be combined with the simulated vehicles to create a realistic environment.

V. Implementation to Allow External Vehicles

To combine the simulated vehicles with the user driven vehicles we have to use a unified mapping of both worlds as basis for the position update of the simulation. To do so, we map the traffic per link and per lane. The simulator keeps a linked list of vehicles for each lane, which without lane change would reassemble a first in - first out pipe. If an external vehicle enters the simulation it will be added to the pipe as well. When entering a pipe we have to consider the following cases:

- vehicle is the only one in the lane
- vehicle becomes leading vehicle on the link (former leader becomes follower of the entered vehicle)
- vehicle becomes last vehicle in lane (former last vehicle becomes leader of the entered vehicle)
- vehicle enters between two vehicles (link between those two vehicles gets cut open and both get connected to the entered vehicle)

During lane changes, the user driven vehicle gets duplicated and while the vehicle enters a new pipe, a shadow vehicle will remain in the old pipe until the lane change is performed completely. With the pipes mapping both worlds, each link can be updated in two steps. First, the decision values such as gaps, relative speeds, and others are determined in the following steps:

- detect leading vehicle among all lanes
- set the front gap information for the following vehicle
- set the back gap information for the vehicle itself
- remove vehicle
- continue until all vehicles visited

After having all vehicle on a link examined, the surrounding variables of each vehicle are known and the the lane change decision followed by the calculation of the new acceleration can be performed.

An external vehicle that is not moving is equal to a road blockage, a slow external vehicle will have the effects of a moving bottleneck and the crashing of the user vehicle into the leader is impossible due to the safety measures. Lane changes remain allowed with every gap, and possible crashes are handled by removing the simulated vehicle the user crashed into. This results in a robust simulation for driving behavior studies in an virtual environment.

VI. Conclusion and Future Work

Virtual worlds are an ideal environment to generate various real life situations with a high degree of realism to test reactions of drivers. To be able to gather information from drivers in the virtual world, one needs a robust simulation model to control the desired traffic situation, gives freedom to the external driver and can handle unavoidable crash situations.

In this paper we have presented a virtual environment as test platform for such studies and have introduced an implementation of a microscopic simulator using two different car following models and the Gipps lane changing model. Mapping the virtual world and the simulated world in linked vehicle pipes per link and per lane allows a robust usage of the well known model with the additional input of external vehicles.

Future work will make use of a decision network as driving behavior model. This decision network will be generated from a dynamic Bayesian Belief network (see Figure 7), that will be fed with feedback data from external drivers to map their individual behavior into probability tables, representing the drivers' decision in a given situation.

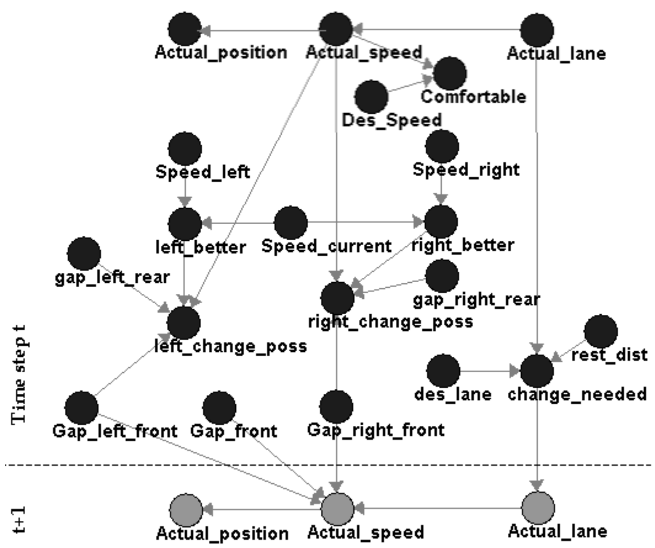

Fig. 7. Structure of the Bayesian network to map the believe state of a driver.

Further is to investigate what kind of additional parameters can be extracted from the virtual world. Influence of weather conditions, visibility and other outside factors are on the list.

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