

A Collaborative Table-top Platform for Discussion and Development of Traffic Scenarios with Human Behavior

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Realistic traffic scenarios in driving simulators are a mandatory prerequisites for user studies on advanced driver assistance systems. A back-projection table-top environment in combination with miniature toy cars offers a new way for the creation of traffic scenarios with fine-grained human behavior. The system is linked to a driving simulator and enables direct experiencing. The platform also enables collaborative discussion and serves as a basis for new exploration principles where test subjects are taken in the development cycle. The paper illustrates the need for alternate traffic scenarios, introduces the new approach and the usage of the system. Areas of application together with new opportunities are then discussed.

INTRODUCTION

Driving simulators are important tools in the development process of man machine interfaces. In such simulated environments, test drives for user studies are conducted repeatedly on the same traffic scenario. A certain drawback in such simulated environments is the nature of the behavior of the other participants in traffic. The trajectories of cars in the vicinity of the own car follow predefined waypoints or programmed algorithms. Such path-ways incorporate a priori programmed routines and do not have a noise or bias. Scenario developers can generate effects of noise by adjusting the path-ways through fine grained extensions. This minor difference between human and generated behavior plays a significant role for cues in the anticipation of traffic events for a human driver. Drivers often, for instance, can deduce an upcoming lane change of a leading car just by its slow approach toward the border of the lane in conjunction with its approach to a slower car in front. Realization of such realistic traffic scenarios is a time-consuming task with many iterations until the result reflects uncertainty effects of human behavior in real traffic.

To bridge the gap between driving behavior in real and in simulated environments, this paper presents a new environment to intuitively and efficiently generate trajectories of simulator content. A back-projection table-top environment in combination with miniature toy cars enables creation of traffic scenarios (see Fig. 1). Developers move the toy cars on top of a road section displayed on the table-top surface. A tracking system monitors the position of the toy cars and sets their position and orientation to a 3D model of the car at the corresponding position on the table. Pathways and traffic scenarios can thus be recorded, replayed or altered. Pathways can be exchanged, replaced and 3D car models can be changed. The developer can link the camera point of view from where the scenery is shown to every predefined or previously created pathway. The pathways can be larger than the displayable area of the table. A wider range than the limited table-top surface thus is available for the development of traffic scenarios that are larger than the available table-top space.

This platform on the one hand enables collaborative discussion about human behavior and on the other hand enables creation of traffic scenarios for use in driving simulators. Instead sketching scenarios on napkins and then realizing them, the first sketch of a certain situation can directly be acted on

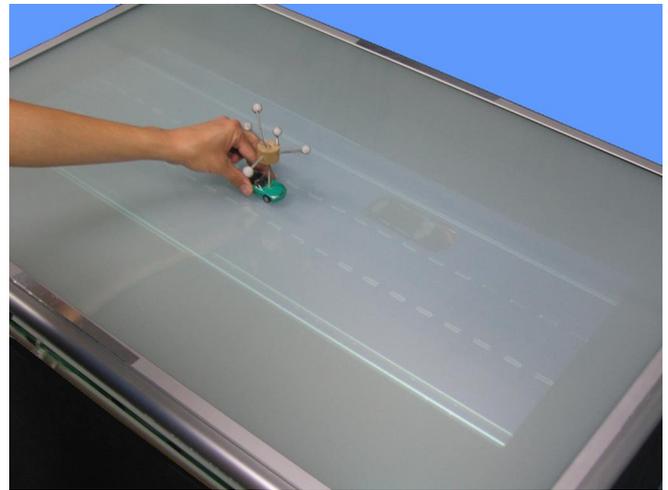


Figure 1. Back-projection Table-top Environment with Miniature Toy Car

the table-top surface. Collaborating developers use the toy cars to act as in real traffic. The play is recorded and can be visualized for inspection and refinement immediately after. Other trajectories of cars or alternatives to an existing trajectory can be added to the scenario in iterations. Combinations and mixtures of traffic scenarios can be created by adding or replacing pathways from previously created scenarios. The system has been integrated with a driving simulator. The driving simulator enables experience from a car driver's point of view. Either passive experience, or letting a test subject drive through the scenario manually, is possible.

REALISTIC TRAFFIC IN SIMULATED ENVIRONMENTS

Traffic scenarios play a major role in the development of advanced driver assistance systems (ADAS). While traffic scenarios in many simulator studies only play the role of a mandatory task which has to be performed while a new user interface is tested, traffic scenarios become an essential part of the system when ADAS systems are evaluated. Here, the traffic scenario states the baseline of concepts for systems that react on traffic behavior.

The ADAS system monitors the environment and the spatial setup of the participants in traffic in the vicinity of the own car. The system analyzes the situation and determines occurrences or events that might lead to dangerous situations. The ADAS system then generates a reaction, either an automatic intervention or a kind of notification to the driver. Especially automated adjustments to the driving behavior must adapt to the personal preferences of the driver (e.g. feeling of safety in respect to safe distances or speed). If such an ADAS system does not adapt sufficiently to a driver's personal behavior the risk of the system to get turned off increases. In-car systems that are turned off in general burden a driver's comfort because they annoy the driver, or because the driver is uncertain about the system's behavior in traffic, or because the system is boring for the joy of traveling. All intended aspects of enhanced safety thus would get lost.

To keep ADAS systems active, sufficient and valuable rules for the behavior of the ADAS system need to be defined. Such rules derive from the input, a car driver is exhibited to. Usually these rules derive from visual stimuli of a driver. The driver perceives the situation in the environment and decides for a certain action. Every action of an ADAS system must fit into the driver's personal threshold for his feeling of safety. Rules in an ADAS system that do not match to driver intrinsic rules, generate the so called *Delta* in behavior.

Every human driver certainly has another personal habit in behavior. Some prefer to drive more sportive than others or want to have larger distances between cars than required for safety. ADAS systems must adapt on those personal differences specifically. Still, a certain baseline enforced through traffic law and a baseline matching a general feeling of safety can be reached. To differ between personal and general human behavior, factors contributing to individual behavior need to be analyzed. Trajectories of cars in the vicinity play a major role here, but there are various additional factors, such as the type of the other cars, their relative speed, usage of turn signals, etc. The main factors are still the behaviors of driving. Even minor changes in a pathway can have a deep impact on the decision, how a driver decides to act.

To analyze which factors are relevant input for a driver's behavior and which are not, traffic scenarios are required that reflect even subtle human behavior. With such traffic scenarios, the effects of ADAS systems can be compared to human behavior.

The question is, how such traffic scenarios can be generated. Two general approaches are possible. The first approach uses real traffic, the second approach uses software tools to develop such scenarios manually.

Sensor Data from Real Traffic

The first approach for generating traffic scenarios uses sensor data recordings of real traffic. A car equipped with a spatial sensor, like the ACC sensor (Jurgen, 2006) is used to capture the position of the cars in the front area of the own car. The car is driven around until the predefined scenario occurs. The car's position, speed and steering activity is recorded. The recorded sensor data is then used to overlay the tracked positions by simulated virtual cars in a driving simulator.

This approach bears certain issues which are illustrated by sensor data captured with a second generation ACC sensor. This sensor tracks up to 32 objects and sorts them by relevance for the own car. The most important object, in general the own directly in front of the own car, is labeled as ID 1 and subsequent objects follow. If another object in the field of sight of the sensor gets more relevant, IDs are changed so that ID 1 always indicates the most relevant object. This approach

is useful for the application in an ACC system, but complicates reuse in driving simulators in four ways. First, the sorting of the objects according to their relevance would cause associated virtual models in the driving simulator to spontaneously jump to another position. Second, if an object leaves the range of the sensor and then comes back into the sensing field of the sensor it would be treated as another object and also cause a jump or show another car. Third, every object is tracked by the radar scanner and often multiple spots of a single object are detected. Two or more spots of a car or a guardrail can be detected as separate objects. Fourth, even if a unique spot is detected on a car, this spot still can move on the car. This spot can move over the surface of the tracked car and depends on the spatial setting between the sensor and the tracked car. The tracked car does thus not have an exact position, but rather an approximate location. A virtual car in a driving simulator would seem like it would be floating around.

The use of low level sensor data instead of preprocessed data intensifies analysis. A laser scanner, for instance, provides large data sets of positional measures. Attributing this data to cars or other objects is fully left to the analysis. Some work towards determination of road users has been conducted.

Darms (Darms, 2004), for instance, developed a system to deduce data for a Lidar Laserscanner. Resulting data sets contains points including speed.

Similar approaches were under examination by others (Walchshaeusl et al., 2006, 2007; Tatschke et al., 2007). They combined several sensors in a car to capture more data from the environment. Their work focuses on sensor-fusion and detection of different types of road users.

Kirchner et al (Kirchner & Heinrich, 1998) and also Polychronopoulos et al (Polychronopoulos, Scheunert, & Tango, 2004) use models to detect obstacles on road. In advance, they also detect the road-course.

Data from all these investigations can be used in a driving simulator to animate other cars. Quality of these systems, based on different sensors and sensor fusion outperforms single sensors.

Better and more realistic reuse of real traffic occurrences is thus enabled. but still requires intense preprocessing. Preprocessing is necessary to guarantee that a superimposed virtual car appears to be moving like a real car and that objects that left the range of the sensors are still recognized in the simulator.

Manually created Traffic Scenarios

The complicated and time taking procedure to reuse real traffic situations makes manually created traffic scenarios an interesting alternative. Trajectories of cars can be generated as absolute movements or as movements relative to the own car.

The easiest opportunity for developing traffic scenarios is general programming. Here the developer would need to learn the corresponding programming language, which apparently is not suitable for every researcher of usability but allows full flexibility for even the smallest behavioral action.

The next subsequent principle for the development of traffic scenarios uses specialized tools. Applied tools as OpenFlight (Presagis, 2009), Silab (WIVW, 2009) or Dynaware (TESIS, 2009) include sophisticated driving dynamics, traffic models and even sensor simulation environments. They apply for testing of ADAS systems and provide predefined procedures for certain maneuvers. These procedures base on mathematical equations and always reflect an exact

route. Single maneuvers can be integrated into a whole drive. A similar approach is used in the Iowa driving simulator (Cremmer, Kearney, Papelis, & Romano, 1994). Here dynamic and behavior models are separated and use a state machine to control dependencies between different vehicles. The Iowa system allows to focus on behavior modeling without taking care of a realistic driving behavior.

The development of scenarios with such tools is still a time-consuming process and never will reflect a test person's manner. The non-reflecting manner of such scenarios comes due to the computer generated trajectories that always are exactly computed pathways. A simulated car always thus follows a perfect course. Simulating jitter and effects of noise is possible but requires deep efforts to create a naturalistic pathway. Driver's often react on even minor changes in the trajectory or speed of another car. Such minimal changes in behavior are *somehow* noticeable for humans. These are difficult to generate with simulation systems and never reflect natural behavior. These minimal differences between simulated traffic and real traffic are crucial elements of a driver's visual input.

A BACK-PROJECTION TABLE-TOP ENVIRONMENT WITH TANGIBLE INTERACTION

Concepts of direct tangible interaction can overcome such issues. Instead using abstracted input techniques like keyboards and mice to set breakpoints for computer algorithms, manually controlled real objects serve as interaction devices for the computer system. Such concepts have already been investigated for their use in the automotive domain.

The Tangible Pathfinder (Sharlin et al., 2004), for instance, is a system based on tangible user interfaces for orientation and mobility training for visual impair. The Tangible Pathfinder is intended to allow detailed, autonomous learning of a new physical setting and self-assessment of the resulting cognitive map. It allows for gaining information about objects and route layouts by touch but is not intended to generate traffic models.

Kanev et al (Kanev, Mirenkov, & Urata, 2006) use a physical car model, moved by hand to maintain a virtual reality representation of the environment. They use their system for producing additional views and to provide guidance to users in a parking situation.

Novak et al (Novak, Sandor, & Klinker, 2004) use a miniature car in a table-top environment to generate a drivers personal view. The table-top environment is a bird's eye map, enabling test coordinators to move the miniature car through a city environments. Their system allows for evaluation of attentive in-car user interfaces.

The use cases described in these related works show the potential of tangible interfaces for efficient iteration cycles. Besides using tangible interaction devices for the exploration of concepts can they also serve for the creation of content for driving simulators. A system was developed to enable developers of traffic scenarios to use a tangible miniature car (see Fig. 2). Controlling this miniature car directly leads to a computer recorded trajectory. The street scenery is displayed on a back-projection table-top surface. The system incorporates a driving-simulator environment and the table-top environment into a hybrid multi-view setup. Fig. 3 shows the setup in the laboratory whose technical issues have been published in Tönnis (2007). One part of the laboratory is equipped with a driving simulator, consisting of a projection wall with a 40 degree field of view and a driver's cockpit on an aluminum

frame. This setup enables life experience from a driver's perspective. The driver's perspective is visible from the area of the laboratory where the development environment is placed. This second part consists of the table-top environment which placed in the tracking volume of a computer-connected camera system. The interaction devices, the tangible miniature cars can be placed on that table, while the road scenery and the pre-recorded other cars are projected onto the workbench.

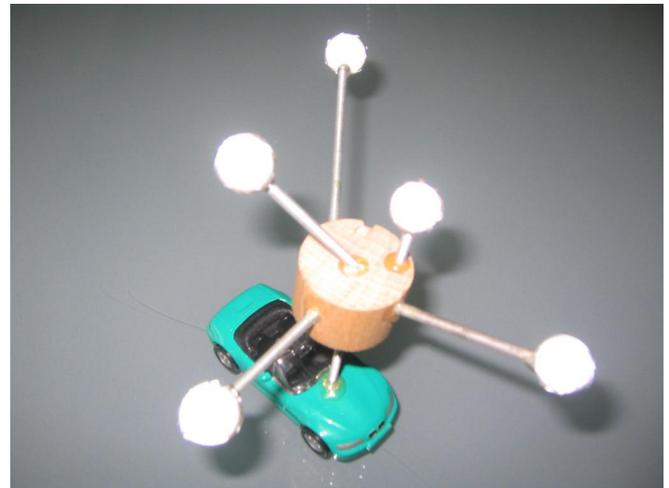


Figure 2. A Miniature Toy Car extended with a Marker Tree for tracking by a Computer System



Figure 3. The Setup in the Laboratory: The Table-top Environment in Front of a Driving Simulator

This approach keeps some metaphors of human behavior intact and allows for fast and intuitive traffic scenario development. To illustrate, how this concept incorporates in tangible interaction concepts, first reflection of application metaphors are discussed in general, followed by illustration of transported metaphors that are fully ported to the table-top environment.

Tangible user interfaces (Ishii & Ullmer, 1997) reuse real world metaphors in augmented or virtual environments. In general, one metaphor is selected and extended into the new application domain. In our concept the main metaphor of the car is to move through the environment. Already children playing with cars move them almost similar to real cars. They seldom move them sideways, mostly to naively simulate sophisticated parking systems. The main use is to drive them through the environment, and, in a children's case, to make races and accidents. Moving the toy car generally happens in a straight forward or curved manner, similar to a real car. Ex-

cept for producing accidents miniature cars are promising for use as tangible input devices. Moving the car directly affects the table-top presentation, where a virtual representation, a virtual car model moves around accordingly.

The driver's view in the driving simulator is also affected directly. People sitting in the driving simulator immediately get the visual feedback as if they were driving. Working at the table-top environment allows perceiving both views simultaneously, thus facilitating frontal as well as environmental recognition.

Interaction with the miniature car is enhanced by the concurrent showing of the driver's personal view. As if driving a car and seeing another car appearing spontaneously and quickly approaching can have an effect of surprise. The surprise can lead to a reflex, in general, pulling the own car sideways. This reaction is similar to a driver's action to avoid a crash in a dangerous situation. One can imagine the situation, when one forgot to look in the back-mirror or missed to check the dead-angle, starts to do a lane change and then realizes another car on that lane. The driver is alarmed and immediately pulls back to his own lane. The pull-back action is given by an immediate shaking with both hands on the steering wheel. This reflex reaction is also ported to the integrated table-top environment. Realizing that a car starts a spontaneous lane change also triggers an immediate reaction that can be compared to the reflex on the steering wheel. The shake on the steering wheel is transformed to a shaking action on the miniature car.

SYSTEM USAGE

To effectively deal with the system, the users first have to get familiar with controlling the tangible cars. A single user in addition has to familiarize with multiple iterations to develop a scenario. The restricted space on the table-top already led to certain further issues in the development of the system. The solutions found for these issues are discussed in the subsequent sections and illustrate how the system is used for larger setups.

Controlling the Tangible Car

When the system is in recording mode, every action on the toy car is monitored and stored for further use. A user thus has to ensure that no unintended action is performed, making the car jump, fly or drive different to a real car.

People can control the car from every side of the table-top environment. In general, right-handed people preferred to use their right hand and left-handed people used their left hand to control the car. Few people tried to stand on the small side of the table but quickly neglected the approach because they could not reach over the whole table with a length of about 1.1 m. Still, the side where the user faced in the driving direction of the cars was interesting because it gave a view similar to a third person view as in 3D action games. The general usage of the table-top thus was from the long sides of the table.

The whole setup in the laboratory enabled users of the table-top environment to monitor the scenery in a second perspective, the driving simulator view. Both perspectives helped people to perceive changes made to the trajectory of the controlled car. The orientation of both views follow the same direction. The tangible miniature car faces its initial position to the same direction as the driving simulator is oriented. Fig. 3 shows that the relative placement of both cars, the simulated red car and the toy car are equal, facing to the right with the toy car right behind the red car. Pushing the tangible car

in a forward direction changed the driving simulators view in the equal manner, making the driver's view going into the same direction in the laboratory. When the table-top environment was used with the driving simulator view, habits of usage changed. Due to the setup of the laboratory where the table was placed behind the driving simulator, reviewers of the system never tried to work from the small side facing to the simulator projection wall. They would not see the second perspective. Instead, they tried to operate the system from the opposite small side but also quickly realized their handicapped range of operation. Thus the tangible car was controlled from „besides“ the scenery, allowing people to stand facing in the same direction as if they would sit in the driving simulator. Even if right-handed, many people controlled the miniature car with their left hand (see Fig. 1).

While the reviewers can choose their favorite base position around the table with their personal preference, handling and moving the car appropriate is a topic of general concern. The current version of the system takes all tracked information into account. Three positional and three rotational dimensions are directly and without any filtering, applied to the movement of the virtual representant. Working on the table-top surface with a miniature car fixes vertical movements, but all others keep intact. The reviewer finally had to ensure that no unintended movement or jitter is generated, especially lateral ones. The virtual car then would jump spontaneous and unrealistic. Here the reviewers improved after a short training phase. Similar problems were observed for rotations. Complicated for scenario developers was estimating the correct heading angle during, e.g., lane changes. During the first trials, curve angles have been too large, but as people got used to it, became smaller and more realistic. Further observations made during scenario development showed that the toy car minimally rolls and nods (pitch). The review of the scenario showed, that in most cases this rolling and nodding often gave an even more natural feeling, showing the effect that the car bends into a curve, accelerates or brakes. In some cases otherwise these tilts went into the opposite direction, annihilating a natural impression. These unintended movements have to be compensated as we will mention in future work. Observing developers of traffic scenarios nevertheless showed that the handling of the toy car already is good enough to create usable traffic scenarios.

Iterative Recording

The system is designed for collaborative as well as for single user operation. While even complex traffic scenarios could be created simultaneously with several users, the system and general aspects of usability define a maximum number of objects controlled concurrently. The monitoring and tracking systems for the markers attached to the toy cars only allow parallel usage of about 10 trackable objects. While this number still could be sufficient for a wide variety of traffic scenarios, all such objects need to be controlled concurrently. Here, two problems reduce that number again. First, each user best controls only one object at a time. Ten developers around a table working on a certain traffic scenario handicap one another. Second, the cameras of the tracking system must have free lines of sight to all markers on the toy cars. Several users distributed around the table generally occlude at least some of the markers, thus prohibiting tracking. Experience shows that a maximum of four people can use the table suitably but still require a lot of agreements and planning. Two direct scenario developers at a time seem best for scenario generation. Others can consult the developers in the meantime or can create alterations later.

The open interaction model of the development system offers the opportunity for iterative scenario modeling. Generating a scenario can be an iterative process, where the trajectory of each car is recorded one after another. After a first trajectory has been recorded, the scenery is replayed and the trajectory of a second can be recorded in dependence to the course of the first one. All movements of further cars are recorded subsequently. Thus not only the limitation of concurrent users is compensated but also single users can develop complex traffic scenarios.

The iterative approach to develop traffic scenarios was easily understood and applied by the system reviewers. After familiarizing with handling on the first car, they immediately could start and record the trajectory. The reviewers then had to reassign the tracking system to now track the second car.

Reviewers in general used the table-top environment to generate a new trajectory and then used the driving simulator view to check the recorded pathway. Here, at least in the beginning, the reviewers were often not satisfied with the route and rerecorded the path of the car. In most cases the turning angles were too large. This is not necessarily visible in the table-top bird's eye view, but gets apparent in the driving simulator view.

Toolbox Building Kit

The concept enabling iterative recording over time establishes a kind of toolbox for scenario development. Every recorded trajectory is stored independently from the scenario. A whole traffic setup is generated by linking several trajectories together and by associating virtual 3D models. Over time, the set of available trajectories extends and provides a rich toolbox for creation of scenarios. Instead of newly recording all trajectories for a new scenario, previously recorded trajectories thus can be reused in other scenarios or different versions of a scenario.

Such trajectories always belong to a certain road course. This dependency is not maintained automatically. The developer has to ensure that a trajectory fits to the road course. Otherwise the simulated car could get off the road, probably making the scenario unrealistic.

Limited Interaction Space

The bird's eye camera showing the scenery on the table-top surface can be adjusted in height and can show the scenery in any scale. The standard setup places the camera in a height such that the scaling of the roads fits to the size of the toy car. The table which is about 1 m long then shows a range of the road scenery covering about 40 m in length and 30 m in width. This range surely is too short for traffic scenarios, it would only allow developing parking scenarios.

The camera could be placed in a greater height, thus giving a wider overview about the scenery. Here handling aspects generated through the tracking system come into account. The higher the camera above the ground, the larger is the scaling between the size of the table and the size of the displayed area. Moving a toy car in the above setup where the table shows 30 m by 40 m of the scenery for 1 cm generates a movement of 0.4 m of the virtual car. To generate accurate trajectories the developer has to maintain that the toy car is moved accurately. Observations showed that an accurate handling is possible at this scaling but already requires some training to familiarize with holding the miniature car in a convenient way. Lifting the camera to a higher position would require the scenario developer to move the toy car much more accurately. As observed, such an accuracy is not reachable if

the toy car has to be maneuvered to follow a trajectory in real time.

The available space for scenario generation thus keeps restricted to a relatively small area. To solve this problem, the bird's eye camera can move automatically. A trajectory can be attached to the camera. The camera then moves along the trajectory when the scenario is replayed. A certain, but adjustable offset lifts the camera above the ground and makes it look down on the street scenery.

The system therefore provides some predefined trajectories. One of these trajectories fits to a straight road, e.g. a highway. The trajectory moves a car with a speed of 80 km/h. Such a trajectory is only provided to ease initial recording of scenarios. It thus is the first element in set of the trajectory toolbox kit.

The development procedure is as follows. The developer links the predefined trajectory to the camera. The scenery will now move when the playback is started. Parallel recording composes the position of the camera and the position of the tracked car on the table-top surface. Every movement of the tangible car is computed to the correct position in the ground road setup. When the scenario is then replayed, both trajectories, the one of the camera and the one recorded with the toy car are used concurrently, letting the scene move and the virtual car as well.

The initial trajectory only enables straight movements. Given road courses with curves, the width of the table-top surface can be used to create curved trajectories. The camera is linked to the straight trajectory and the toy car is used to record a curve. This curve is then linked to the camera which then follows this curve. A new trajectory can now be recorded with the toy car. Repeated new recording of trajectories and attaching them to the camera enables reaching every point on any simulated road scenery.

Using a trajectory on the camera gives a base speed to the recorded car. Moving the car forward increases the relative speed of the car and moving it backwards decreases the relative speed. Passing scenarios are thus also possible to create. Trajectories with decreasing or increasing speeds can again be used for the camera to create stop-and-go or crossing scenarios. Here, a trajectory with, e.g., a speed decrease to a halt followed by a speed increase is recorded. When this trajectory then is linked to the camera, the whole road section moves according to the recorded behavior. Any car that is recorded then automatically follows this behavior when standing still on the table. Movements to the toy car create trajectories that differ relative to the prerecorded movement.

AREAS FOR APPLICATION

The system has initially been developed for the creation of traffic scenarios that reflect human behavior. In fact it serves for a much wider range of applications. These further areas of application range over collaborative discussion systems, direct control of other cars in a driving simulator and investigation of behavior of anticipation of traffic events.

Development of Traffic Scenarios

The initial reason for the development of the table-top system with the miniature car was creation of traffic scenarios. Usual development methods in general are asynchronous in development and experience. The developer implements or customizes a behavior and then checks the behavior by replaying the scenario. With the table-top environment, the experience phase still exists, but the development phase becomes interactive. With the toy car, the developer acts intu-

itively and immediate in direct correspondence to the so far existing scenario. The existing scenario plays in real time and every action of another car requires or rather enforces reactions of the controller of the toy car.

Traffic scenarios are developed by planning the order of recording the trajectories of each participating car and subsequently adding them until all are recorded. If a trajectory does not fit as desired it easily is unlinked and recorded again. Fig. 4 shows a user recording a trajectory for a traffic scenario. Here another car has already been recorded. It is currently changing lanes from the middle lane of a highway to the right lane. The developer currently records a second car that seems to pass on the left lane.



Figure 4. Recording a Trajectory with a Miniature Car

Collaborative Discussion

The option to track multiple miniature cars at a time not only can speed up scenario development but also extends principles of collaborative discussion between team members.

The traditional and still used way to develop a traffic scenario uses sketch-boards or, as in many cases, napkins, to draw a certain situation and specific maneuvers. The maneuvers of the cars generally are painted with arrows. Such arrows lack the information about timing. It can not be reproduced later at which point in time which car has to be at which location.

Here, the table can be used as sketch-board. It provides the advantage of direct interactive playing of the situation currently under discussion. The trajectories are recorded immediately and thus no later remembering of timing issues is necessary. Different alternatives or variants of specific situations can be played and recorded. Later, the best trajectories of all sketches can be combined to the final scenario.

Fig. 5 shows two developers discussing and recording a possible scenario in a crossing situation.

Experiencing in a Driving Simulator

The integration of the system with a driving simulator not only offers a second perspective for scenario development but also offers new ways for experience of and interaction with traffic.

The initial intention for the tangible table-top system focused on the development of traffic scenarios for use in driving simulators. The coordinator of the study has two options to use the resulting scenarios.

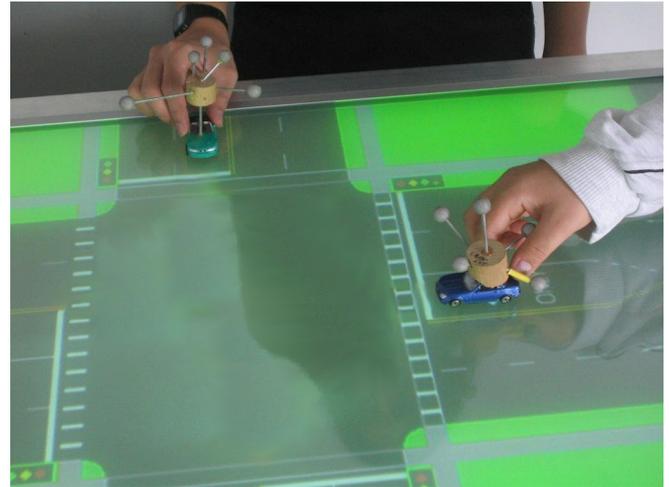


Figure 5. Discussion about a Scenario in a Crossing

The first option uses the traffic scenarios in a passive manner. Test subjects can be placed in the driving simulator and can experience the scenarios from the point of view of any participating car. This passive approach enables fully equal procedures for all test subjects. Measures, such as glance behavior, or physical and mental demand (skin resistance, heart rate, ...) can be taken while the test subject is exhibited to, e.g., a near accident avoidance. Effects can be fully and uniquely attributed to independent variables of the scenario. Also actions on the pedals and the steering wheel could be recorded, even if the test subject is not actively driving. Reflex reactions still occur and can give hints about a test subject's reaction that would occur when driving a real car.

The second option puts the test subjects in the active role. Here, either one trajectory of the scenario is discarded or a new additional car is integrated into the scenario. The car that has no external control is linked to the controls of the driving simulator. The test subject then uses the simulator as in usual user studies. Fig. 6 shows the scenery of a scenario from a car driver's viewpoint in a driving simulator.



Figure 6. Experiencing a Scenario in a Driving Simulator from the Viewpoint of a Car

A novel type of interaction with driving simulators is also enabled through the table-top system. A test subject can experience a traffic scenario, either active or passive, while one or more of the cars in the vicinity are directly controlled from the table-top. New concepts of interaction are possible. Test coordinators can directly react on actions performed by the test subject. Recording of all data, including the movement of the simulator car then allows later analysis or reuse of the specific behavior during the test drive.

Analyzing Behavior of Anticipation

Another new concept for system usage is driven through the increasing demand for the analysis of human anticipation mechanisms. Analysis of human anticipation mechanisms is the vice-versa issue of traffic scenarios with fine-grained human behavior. Drivers often, for instance, can deduce an upcoming lane change of a leading car on a neighboring lane to their own lane by two factors. First, the car is approaching to another car in front which is slower. Second, the car is slowly approaching the border of its own lane. Without that car having the turn signal set, we can estimate the upcoming lane change, because otherwise the driver of the other car should already have begun braking.

While user studies for assistance systems use premodeled traffic scenarios to evaluate the reaction of human test subjects, the analysis of anticipation intends to investigate how events trigger such reactions. To collect such events, one can go into the real world and can monitor test subjects while they are driving under normal conditions. The recording is tagged for later analysis when the predefined boundary conditions are met. Such an approach is time consuming until the necessary number of traffic occurrences has been collected.

The alternative is to let test subjects design traffic scenarios according to defined boundary conditions. Here, the table-top platform provides its potential for intuitive traffic development. The developer, here the test subject, does not have to learn a programming language or does not have to configure setups with complex tools. Test subjects can be brought into the laboratory, are instructed about system usage and the boundary conditions of the scenario and then develop a traffic scenario. According to the example above, the boundary conditions above could be as follows.

Create a traffic scenario on a three laned highway. You are on the middle lane. Two vehicles are on the right lane in front of you. Define a traffic scenario where the back car initiates a lane change that enforces you to brake (strongly) or to initiate a lane change to the left lane.

Collecting several solutions for the same given boundary conditions allows for analysis of similarities and differences in behavior.

CONCLUSION

Incorporating a table-top platform into driving simulator environments establishes a broad spectrum of new concepts for interaction and development. The table-top platform consists of a back-projection surface, a tracking system and one or more miniature toy cars. The system can show road setups on the table-top surface and can record positional data of the manually controlled toy cars. The toy cars transport several metaphors and behavioral principles from our real world to the simulated environment in the laboratory. The traffic scenarios created with the table-top system compromise these fine-grained differences in contrast to traffic scenarios manually modeled on a computer. Especially testing cycles for driver assistance systems that react on events and situations in the environment of the own car require such scenarios to be tested on their suitability and acceptance. The table-top platform provides an intuitive and easy to use interface for the development of such scenarios. Trajectories of cars can rapidly be recorded by single users or collaborative teams. The new platform provides enables or accelerates and eases several other applications beyond the scope of traffic scenario development. Already early discussion about certain situation

can be played on the table-top surface. Alternatives can be explored and compound to a final sketch. The sketch can much faster be converted or extended to the final scenario than paper based sketches can be. Through integration with a driving simulator further extensions in system interoperability and interactivity are gained. Tangible toy cars can be used to control cars in the vicinity of the car controlled by the driving simulator. The controllability of the traffic enriches the reactivity to actions of car drivers. The table-top system finally enables integration of test subjects in the development process of traffic scenarios. The ease of use of the system can be used to investigate principles of human anticipation. Test subjects create traffic scenarios which are analyzed to determine common types of human reactions. The easy usage of the system opens the possibility of traffic scenario generation to a much wider range of people than conventional tools. The fact that each trajectory is recorded in real time finally proves the high potential of the system to optimize development cycles of traffic scenarios.

The recording functionality of the table-top is the most crucial part of the system because it currently takes every moving action of the developer and stores it into a trajectory. To ease development of traffic scenarios, several extensions are possible here. First, instead taking all six degrees of freedom only the two horizontal dimensions and the heading will be used for trajectory recording. This step reduces effects of unrealistic behavior in the simulation replay. Further integration of a driving dynamics model can then generate nodding behavior of speed changes and rolling in curves. The extension of a driving dynamic models will also be used to smooth impossible movements of the toy car to movements that are possible with a real car. Spontaneous shifts to the left, for instance, are not possible with a real car. The system receives the tracking data, computes the possible limit through the mathematical simulation of the driving dynamics model and moves the simulated car according to the mathematical model until the position of the toy car is reached again. This step reduces effects of jitter and generates realistic trajectories but can generate handling issues for developers. The direct control of the virtual car gets lost, only an indirect coupling to the toy car remains. The indirect control can lead to effect of irritation because the virtual car follows other principles as the real toy car. Usability studies have to validate if such an behavior is suitable for users.

Also aggregation functionality for combining trajectories to scenarios can be extended. Currently only whole trajectories can be compound into scenarios. All trajectories therefore have to start at the same point in time. Synchronization mechanisms can enable timely distribution of trajectory playback. Further editing functionality can be used to copy parts of one trajectory to another or to combine different trajectories into one.

With all these extensions incorporated into the system, we will conduct usability studies to validate the usability of the system.

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