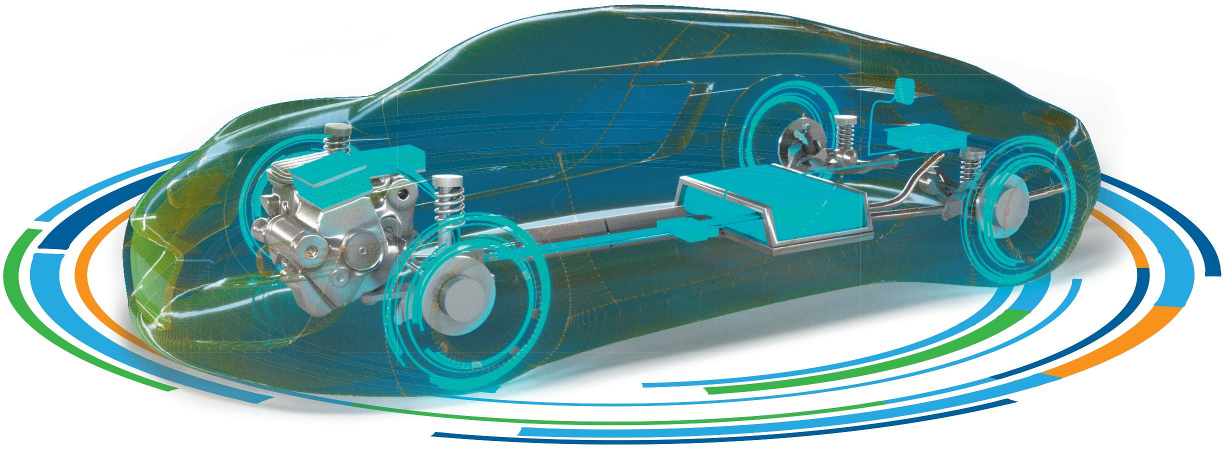

INTERNATIONAL SYMPOSIUM ON DEVELOPMENT METHODOLOGY

CityInMotion – A virtual urban test environment for automated mobility

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Abstract

Efficient methodologies for the development and validation of highly-automated vehicle systems play an increasingly important role in urban mobility. In addition, the requirements for simulation and verification environments are highly increasing due to a wide range of automation functions to be integrated and validated in the near future.

This paper presents a new approach for developing a virtual test environment for highly automated vehicles based on a high-end virtual reality (VR) engine. The basis is a realistic, geo-referenced city model, which is reactively connected in Co-Simulation to a highly detailed vehicle model or even a Vehicle-in-the-Loop test bed. Through specific sensor model systems like camera radar and lidar, the vehicle can interact with the environment and traffic participants like VRU (Vulnerable Road Users) in real-time. The behaviour of real VRUs in the virtual test field is based on high-end motion-capture technology, which enables the integration of highly realistic avatars in real time.

A proof of concept is shown by application of the virtual urban test field for validating an unmanned battery-electric vehicle. Finally, an outlook for the potential use of advanced VR technologies for agile development processes is given.

1 Introduction

Highly automated driving is one of the most tensioned mobility research topics of the decade. The advantages of this technological improvement are unneglectable and highly anticipated by society. Next to traditional vehicle concepts, completely new mobility approaches become possible. For example mobile supermarkets, which drive through inner-cities as shown in Figure 1 will participate in future urban traffic. Next to high diversity and perfect application to individual requirements, personnel costs are be minimised.

To accelerate this diversity of urban mobility, a safe and valid environment for testing and developing highly automated mobility systems is required. CityInMotion is a public funded project, with the goal of developing an innovative approach to a virtual test environment for this application. Therefore, a highly realistic virtual model of Colognes inner-city is used and fitted with real human and vehicle behaviour as shown in Figure 2. To enable real interactions between the different participants, probabilistic sensor models were used. Further, a co-simulation network is developed, which allows the real time exchange of data and additionally, the reactive communication of the different actors.

CityInMotion focusses on two essential goals. On the one hand a safe verification environment for automated mobility systems in each development stage. On the other hand, the generation of data sets to support development of data driven mobility systems.

Figure 1: Unmanned delivery vehicle interacting with VRU

Figure 2: Unmanned delivery vehicle in the CityInMotion virtual test field

2 Model Setup

The following section will introduce the innovative approach to simulate complex inner-city traffic scenarios to investigate and develop automated driving functionalities in urban application. Focus is the safe and realistic interaction of real traffic participants (especially VRUs) with automated vehicles in all aspects.

Figure 3 shows the general structure of the used and implemented model network.

The fundamental idea is the combination of a real, automated vehicle on the vehicle testbed with a digital twin of a real human movement behaviour.

a. City Model

The base of the Co-simulation environment is the city model, which relies on network communication. It represents a realistic, geo-referenced illustration of a modern German city, including buildings, city furniture and traffic with typical traffic participants. For verifying and testing modern automated vehicle functionalities there are some important requirements. The virtual city model has to be as realistic as possible in its optical aspects to stimulate the vision-based sensors of the human interacting with it. Furthermore, it is necessary to attribute the model with further metadata for environmental sensors like radar and lidar.

In Figure 4 the process to develop the city model is shown.

According to Figure 4 the process of developing the virtual city model can be divided into four essential steps. The geometries provide all necessary physical properties and dimensions of buildings and streets. All dimensional information of the model are based on laser scanned data of

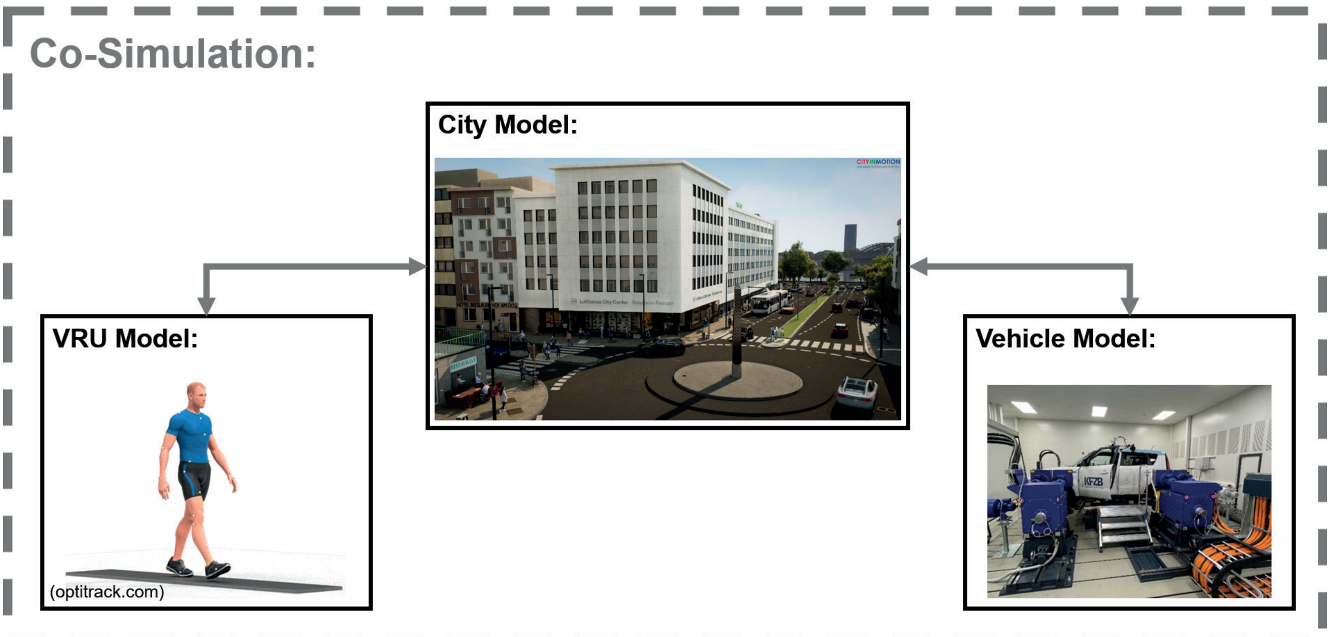

Figure 3: Schematically illustration of the overall model structure

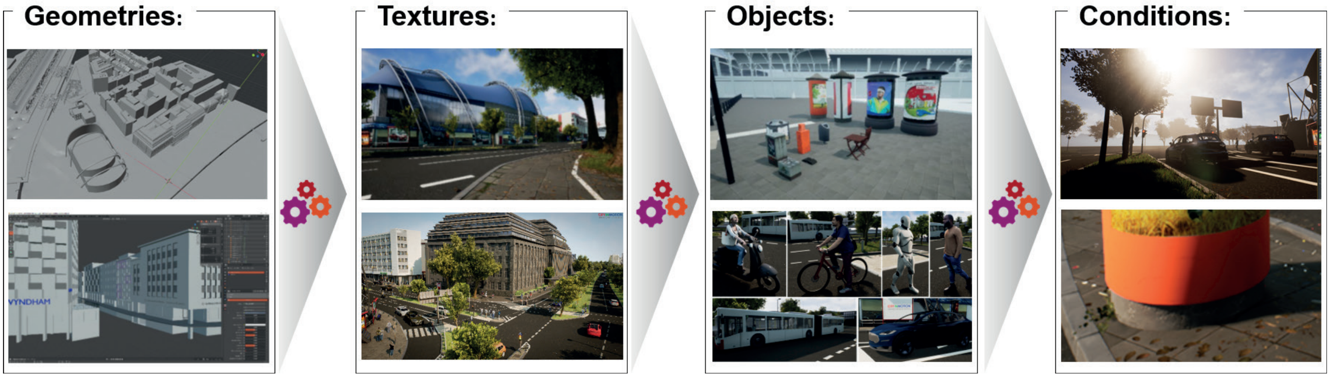

Figure 4: Development structure of the city model

Colognes inner-city, which are clustered into individual buildings and streets. To enable a realistic appearance of the model, colours, textures and further surface data were applied to the objects surfaces in the second step. Next to vision based information, even further metadata for the later described sensor models are added in addition. Further objects like street furniture, traffic lights and signs, as well as traffic participants are included into the model to enhance the level of detail. Cars and pedestrians following predefined courses generate dynamic traffic. In the final step, the overall scene is completed trough dynamic weather conditions like sun light, dust, rain and snow.

Next to the vision based information, the virtual city model is the essential module of the test environment. Roads and architecture provide the basis for a variety of urban traffic scenarios.

b. VRU Model

To investigate real urban traffic scenarios and generate realistic data for further development, especially the behaviour of the real VRU like pedestrians plays an important role. One innovative approach to enable safe and valid human machine interaction is the implementation of motion capturing technology. The process to generate and implement realistic human motion is shown in Figure 5.

As first processing step, motion capturing hardware is used to detect movement of a human. Therefore, a marker-based system consisting of twelve OptiTrack PrimeX 22 by NaturalPoint cameras is used. Since it is an active motion capture system, each camera actively emits light in the infrared spectrum into the capture volume which is reflected by markers attached to the targets body. The infrared camera sensors then record the position these reflective markers. The cameras can have an arbitrary position and orientation towards each other to cover the capture volume as completely as possible. In the next step, the corresponding motion capturing software utilizes the markers attached to the target to track their position inside the capture volume via triangulation. With this information, a skeleton with 21 body joints is derived. Each body joint has a unique ID inside its hierarchical skeleton and provides position and rotation data in relation to the world coordinate system or its parent joint. The resulting body joint model can then be applied to each kind of human model with a humanoid skeleton. Therefore, it is important to consider the differences in proportions between the captured human and the human model. For that reason, only rotation data is applied to each joint of the human model. Position data is used to move the model in world space only. In the last step, real human interactions with the virtual city scenarios are enabled by using a head mounted display (HMD).

c. Vehicle Model

The vehicle model play the focus role of the overall test environment. Therefore, on the one hand the vehicle dynamics are represented as realistic as possible by a vehicle dynamics model. It is combined with a vehicle testbed. On the other hand, due to detailed sensor models, the interaction

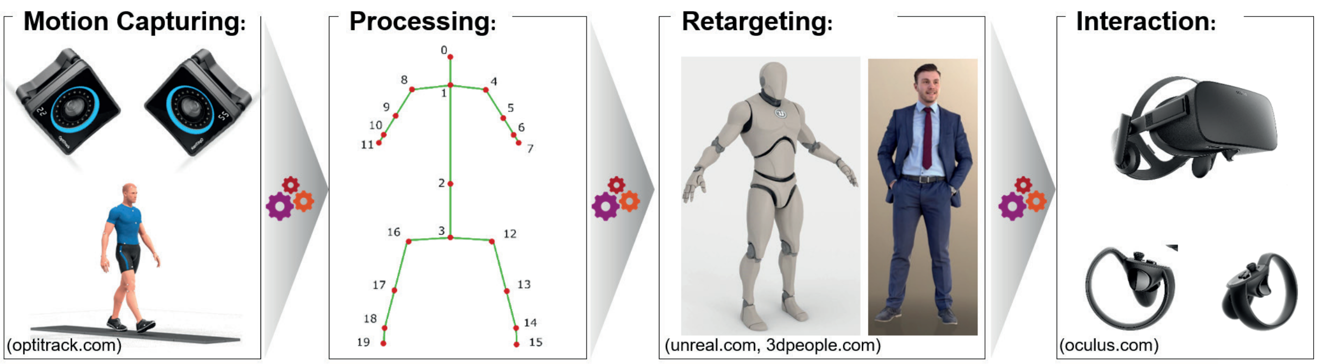

Figure 5: Process to include human movement behaviour into the virtual pedestrian model

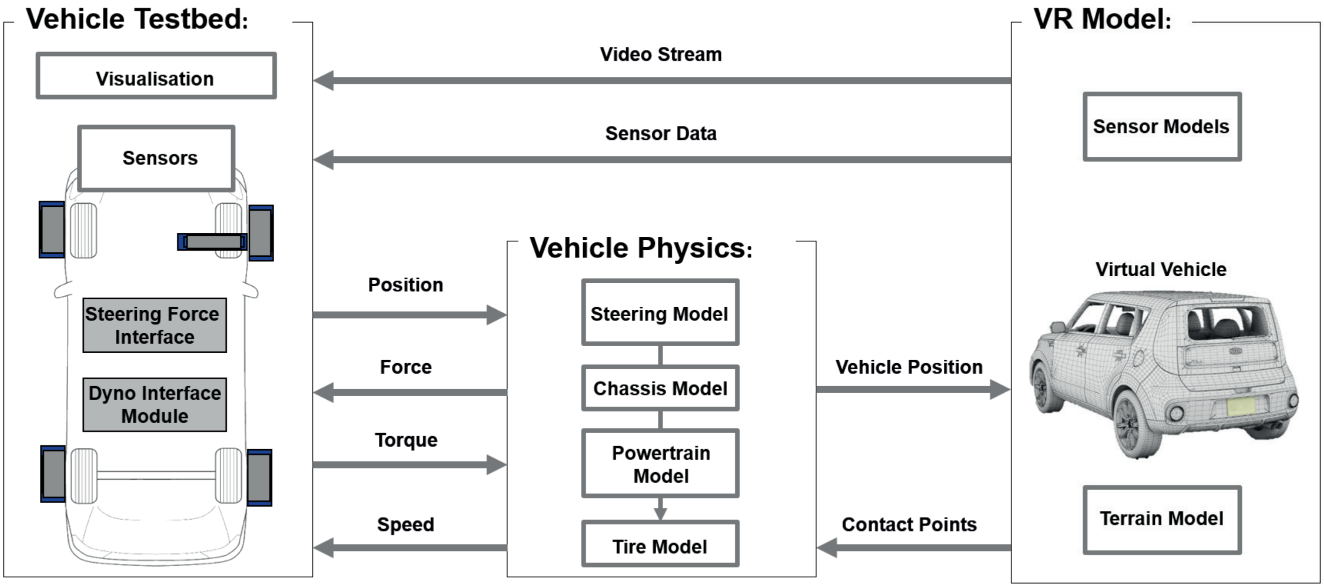

Figure 6: Structure of the used Vehicle Model

of the real vehicle is enabled with the virtual environment. Figure 6 illustrated the applied vehicle model structure.

A combined multi-body and two-lane model represent the general vehicle physics. By adding a simplified powertrain model, the first interface to the vehicle testbed is given. Furthermore, steering is implemented via a steering model, which enables manual steering through the testbed vehicle. Automated steering by a simplified driver model is also provided. Finally, a simplified tire model determines the contact forces to the road. The vehicle model plays an extensive role to connect the virtual vehicle in the virtual reality (VR) environment and the real vehicle on the testbed. It translates speed, torque, steering-force and position into a frequently updated localisation of the virtual vehicle in its virtual environment. Additionally, the geo-referenced height information of the virtual road are translated in adjusted torque requirements.

Further, probabilistic models for radar, lidar and camera sensors enable the communication to automated driving functionalities. Thereby, the radar and lidar models use raytracing to address objects in the sensors field of view (FOV). By using advanced mathematical and physical models of the individual sensor properties, the models represent realistic behaviour. As a result the model delivers an object list with all objects detected in the radar sensor FOV and a lidar typical matrix for the lidar dot cloud. The video stream is applied to a camera sensor model, which classifies the objects in the camera sensors FOV. A further description of the sensor models is given in (Degen et al., 2021a; Degen et al., 2021b).

3 Proof of Concept

In this chapter, the proof of concept of the previously introduced and implemented model structure is described. Therefore, a typical urban traffic scene is identified which allows a qualitatively quotation of functionality and reliability.

The chosen representative scenario is illustrated in Figure 7.

The "pedestrian crossing" scenario is very suitable for urban traffic scenarios. Here mobility systems and pedestrians meet

Figure 7: Representative traffic scenario

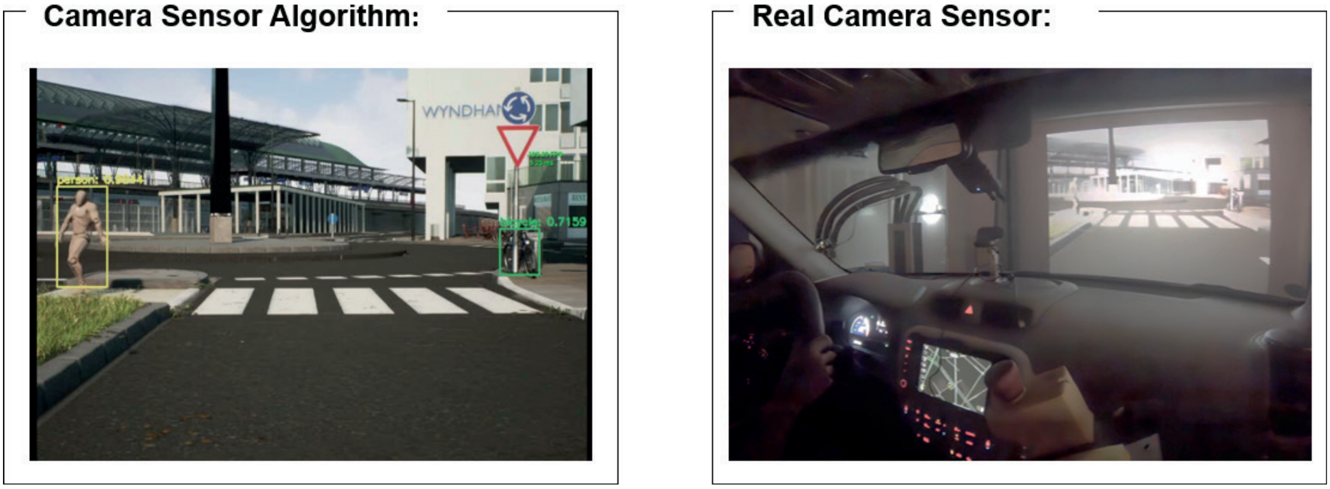

Figure 8: Pedestrian crossing scene. left: YOLO-algorithm result. Right: MobileEye setup.

and clear traffic rules coordinate the situation. The functionality of the automated mobility system is crucial for a safe handle. Basis for progression decisions of all traffic participants is the interaction, which mainly has to be investigated. Therefore, the introduced scenario is repeated with different velocities, different human avatars and different perspectives.

As first result of the study, a stable and performant communication is to be noted. The exchange of data works well and all co-simulation participants get the requested data in system real time. Next to qualitatively aspects, this real time functionality is essential for the interaction of human and machine. Further, the interaction of the car with the environment, enabled by the sensor models, works fine. The YOLO algorithm in the simulation, as well as the MobileEye System inside of the car detect a crossing pedestrian (see Figure 8).

Finally, the integration of the vehicle at the testbed and the real human in the motion capturing cage works well. The vehicle is stimulated by the virtual test environment conditions. Further, the real vehicle parameters were copied to the virtual vehicle behaviour. Additionally, the motion captured person movements were integrated into the virtual scene. Thereby, for example a walking scene at a pedestrian crossing is enabled. To reference in the scene, the actors view is forwarded from the virtual scene to the real humans view by the Head-Mounted-Display (HMD).

4 Conclusion

In summary, the proof of concept was successful. All connected systems perform in real time, whereby a fluid and valid exchange is enabled. Further, the quality of the virtual model is sufficient to integrated real and virtual environment perception sensors. The use of a highly-detail urban city model connected to a vehicle test bed enables new processes for validation and even certification of highly automated vehicle systems in an efficient lab environment.

Next steps are the further development of scenarios and the integration of further models – mobility systems as well as VRUs.

Acknowledgement

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