On the progress of knowledge-based motion simulation techniques in ergonomic vehicle design

Hans-Joachim Wirsching[1] and Norman Hofmann[2]
[1] *Human Solutions, Germany*
[2] *Institute for Mechatronics, Germany*

Abstract

Applying DHMs in ergonomic design of vehicle interiors has been established for many years. Most use cases focus on various aspects of static driving configurations. But several dynamical occupant tasks must be evaluated for new vehicle concepts in addition. Because of the task complexity these tests are still performed in physical mock-ups. Over the past years new DHM technologies have supported evaluating dynamic ergonomics of interior designs in digital mock-ups more efficient. Nevertheless, there are still simulation aspects to be improved for proper industrial applications. This paper presents the recent development progress on knowledge-based motion simulation techniques using motion capture data and DHM prediction methods. The focus was put on a large variability of motions in the database, more user control on the simulated motions and functions for collision avoidance. Based on adjustable mock-ups, a range of ingress and egress motions into a truck and a passenger car were systematically measured taking various positions of vehicle components like steps, doors, pillars and roofs into account. These motion takes were reconstructed and annotated by DHMs and stored in a database. A new simulation tool was developed which use the database to predict motions in virtual environments. The GUI provides a range of motion components subjected to various motion data and simulation methods. These components can be combined to create a cumulative motion. In addition, the intersection frames of consecutive components can be controlled by user-defined postures or tasks. Smooth transitions are supported by specific truncating and sewing up consecutive motions. In addition, the tool got new functions to consider collision avoidance during simulation. First, characteristic parameters (door angle) are extracted from the environment and used to find corresponding collision-free motions in the database. Second, specific geometric constraints avoid collisions at key frames. Applying both functions supports qualitative motion strategy changes and quantitative body positions to cope with collision situations. The tool development is accompanied by user evaluations with respect to usability and prediction capabilities. These identified open issues to be solved and pushed the tool further forward to a productive level.

Keywords: Motion measurement and analysis, Knowledge-based motion simulation, Motion control, Collision avoidance

Introduction

DHM applications in ergonomic vehicle design have a long history. Nowadays industrial engineers use DHM systems to optimize the interior ergonomics focusing on static aspects of driver and passenger configurations like comfort, vision, reachability and roominess (Raschke 2019, Wirsching 2019). But several design questions require the analysis of dynamic aspects like ingress / egress motions which currently are not provided by these tools in a sufficient matter and hence require still expensive physical tests in mock-ups.

A necessary technology for this would be a task-specific simulation of human motions in vehicle environments. While the digitalization and analysis of real motions have reached a sufficient application level (Hermsdorf et al., 2019), the simulation of complex motions is still under research. Cherednichenko (2008) proposed a functional model for predicting ingress motions into a car. Model approaches like this require an extensive investigation and understanding of real motions to catch characteristics which can be represented by a simulation model. These models can hardly be used in a generic way and their complexity increases with the number of parameters to be considered.

A more pragmatic approach for simulating motions is the direct use of captured motions in a database which showed promising results with respect to usability and functionality (Wirsching et al. 2013, 2016). This approach does not require to understand drivers of motions, but just a standardized description how the motion looks like with respect to the environment. It provides a generic procedure which can be applied to all kind of motions, especially highly constrained motions. Just the size of the database determines the simulation quality.

Nevertheless, this approach suffered from several shortcomings like restricted data pools, inflexible user control and insufficient collision handling. This paper focusses on these shortcomings and describes the next evolution step for this technology applied in a car and a truck ingress use case.

Methods

Overview

The methods utilize a simulation framework which simulates task-specific motions by extracting a best fitting motion from a database and adapting this motion to the given environment. The system architecture and motion digitization & simulation process is similar to Wirsching et al. (2016), but enhanced in the following aspects to overcome the identified shortcomings:

- The experiments are setup to provide a large variability of annotated motions in different car and truck ingress concept variants.
- The motion simulation environment allows flexible input and more control on the simulated motions, especially the concatenation of motions.
- The simulation engine has several functions to handle collisions in qualitative and quantitative aspects.

These enhancements are described in the following sections.

Experiments

Real movements are necessary for realistic movements in the virtual world. Therefore, motion studies were realized on a real mock-up for a truck and for a car. The mock-ups were designed in such a way that certain geometric parameters could be varied. In the case of the truck, the height, width, and angle of the steps can be varied as can the door opening. The experiments for truck ingress have already been explained in Dorynek et al. (2021). In the case of the car, the variations concerned the height of the sill and the roof. Figure 1 shows a photo of the car mockup.

An optical motion capture system made by ART is used for high-quality digitization of human movement. Nineteen targets are applied to the human body to record the motion trajectories of the segments. Further targets are also applied to parts of the mock-up to record these. In case of the truck these are the mock-up itself, the door, seat and steering wheel and in case of the car these are the seat backrest, seat surface, steering wheel, roof and sill. Figure 1 shows the visualization of the recorded targets and the colored point clouds for seat, steering wheel, roof and sill.

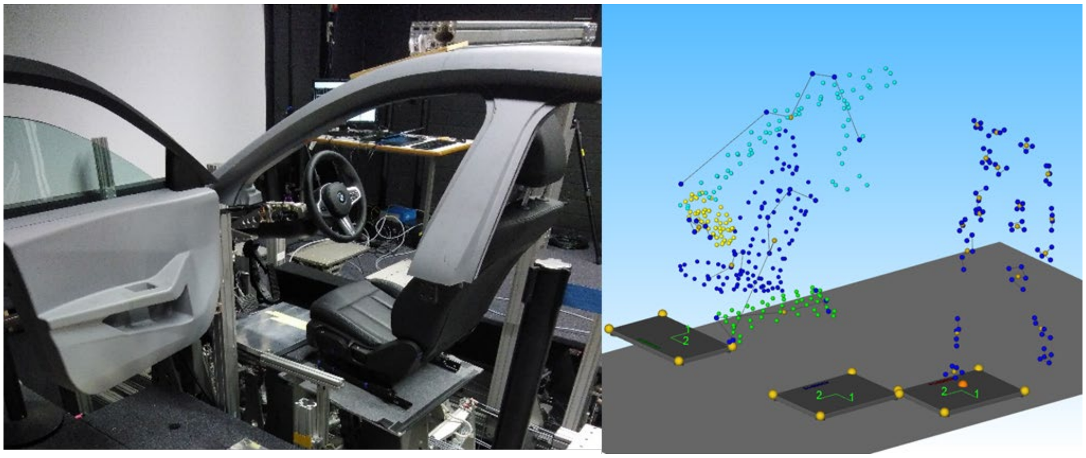

Figure 1: Car mockup and visualization of the recorded targets

The truck ingress study included 29 subjects with 9 to 12 mockup variations. The car ingress study contained 10 subjects with 9 variations of the mockup. Each subject completed 10 trials per variation. After completion of the measurements, the database contains ingress and egress movements into a truck (approximately 3000) and a car (approximately 900).

Data processing

The simulation model consists of the two components human and environment. The methodical description and application of the Dynamicus model can be found in (Hermsdorf 2019). Dynamicus is a biomechanical human model which uses the methods of multi-body dynamics. It consists of 43 bodies that describe the kinematic structure of the human body. The bodies are connected by joints where the movement possibilities can be configured. The spine represents all vertebral bodies and is controlled by a movement pattern. The individualization of the human being is represented in Dynamicus via the parameterization of anthropometry. The model of the environment is based on the construction data. The motion of the human and the environment is based on the captured marker trajectories. This information is transferred to the human model Dynamicus. The inverse kinematics methodology is used for this purpose. For the analysis of the interactions, geometric equivalent bodies are used, which, analyze the contact between the model bodies. The following Figure 2 shows the model of the human and the environment (colored point clouds) as well as the functional model (red planes and boxes).

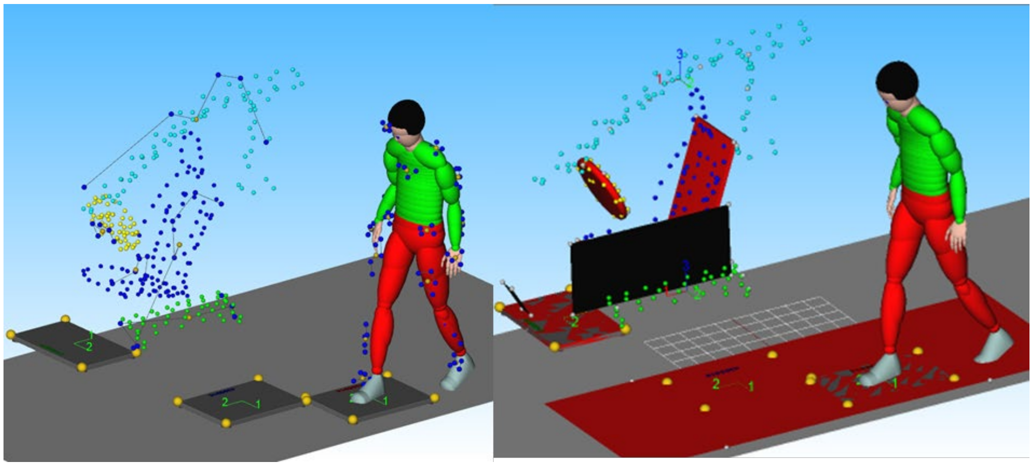

Figure 2: DHM Dynamicus, environment and the functional model

The interaction between the reconstructed motion of the DHM and the functional model of the mock-up can be detected and analyzed. The functional model contains in case of the car the ground outside, cabin floor, sill, roof, seat backrest, seat surface, pedals, and steering wheel. In the case of the truck the functional model contains of the ground outside, cabin floor, steps, handrails, steering wheel, seat backrest, seat surface and the door. But there is also a functional model for the human model, and this includes contact elements in hands, feet, head, and pelvis. By linking the results of the interaction analysis with the biomechanical parameters of the movement, it is possible to describe an annotation of events. An example is shown in the following Figure 3.

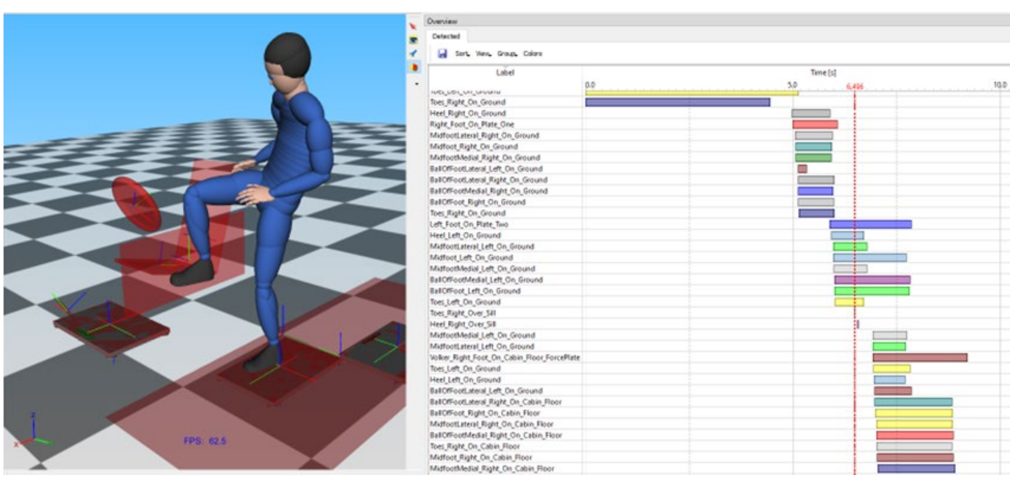

Figure 3:Annotation of events along the motion

Simulation framework

While the framework in Wirsching et al. (2016) focusses on one motion for one manikin, the current framework allows the concatenation of various motion components (e.g. car & truck ingress. walking) from a library and the application to manikin samples. Each motion component runs an individual simulation engine (e.g. database or animation techniques) and requires corresponding input parameter like geometry and strategies. The connection between consecutive motion components is controlled by connectors which define the transition postures. In the connector mode "free" this posture is calculated from the motion component, in mode "posture" the posture is given by the user and in mode "restrictions" the posture is calculated from restrictions given by the user. The final motion sequence is calculated in an iterative process by successively predicting transition postures and motions in-between.

This procedure guarantees continuous transitions between consecutive motion components. But this leads into a non-smooth total motion in many cases because motion-capture-based motion components start or end in static standing postures in general. A possible solution is to intelligently truncate the motions before concatenating them. The implementation of this procedure is shown for the concatenation of a walk and a truck ingress motion (Figure 4). The ingress motion is simulated starting at the key frame when the manikin grasps both handrails and lifts the left foot from the ground (Figure 4, top row, image with star). The original segment from the start standing posture is automatically truncated. The walk motion is simulated until the key frame when the manikin lifts the left foot from the ground, but requiring to adopt the start posture from the ingress motion (Figure 4, bottom row, image with star). The original segment to the end standing posture is automatically truncated.

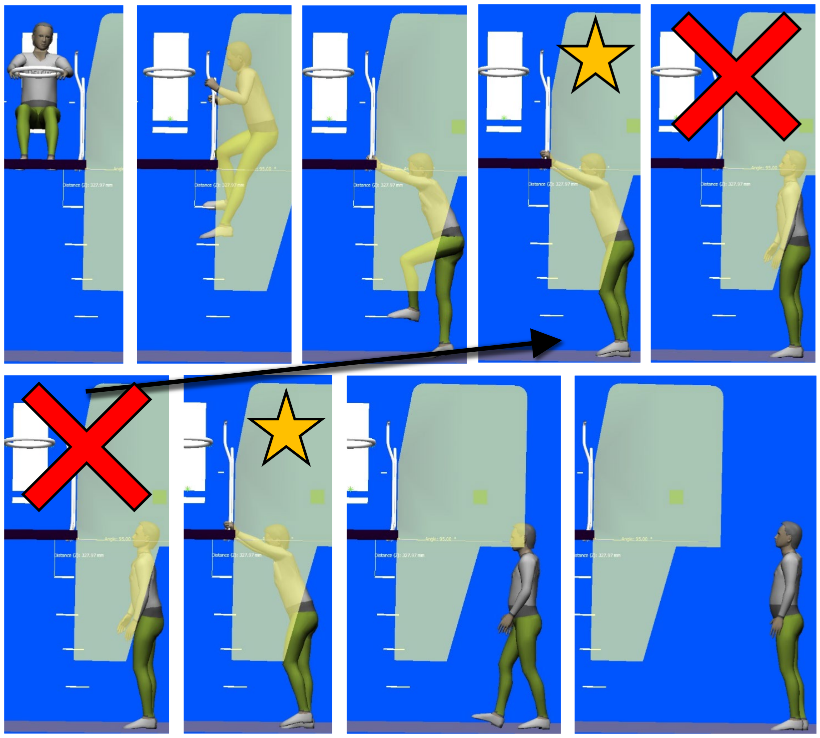

Figure 4 Concatenation of walk (bottom) and ingress (top) motion

Collision avoidance simulation

The collision avoidance is done on two levels. First collision relevant parameters are extracted from the environment (e.g. door opening angle) and a best fitting motion to that parameter is extracted from the database.

Since the best fitting motion may show a qualitative motion strategy change for the collision but does not guarantee to quantitatively fulfill all collision requirements, this motion is additional adapted in a second step on key frame level. A key frame defines a frame of the motion when the interaction of the occupant with the environment changes, for example when a foot is placed on the first step. Specific collision avoiding restrictions are added to these tasks from which the relevant key frame postures are calculated.

This method is illustrated for the truck ingress use case (Figure 5) in the following. For the specific step height and door opening angle in the environment the best fitting motion is extracted from the database containing motion patterns for step heights 280mm - 400mm and opening angles 30° - 95°. From this motion, the prediction of the key frame postures while the manikin grasps the handrails takes collision avoiding restrictions between the door surface and the shoulder, elbow, hip and knee into account.

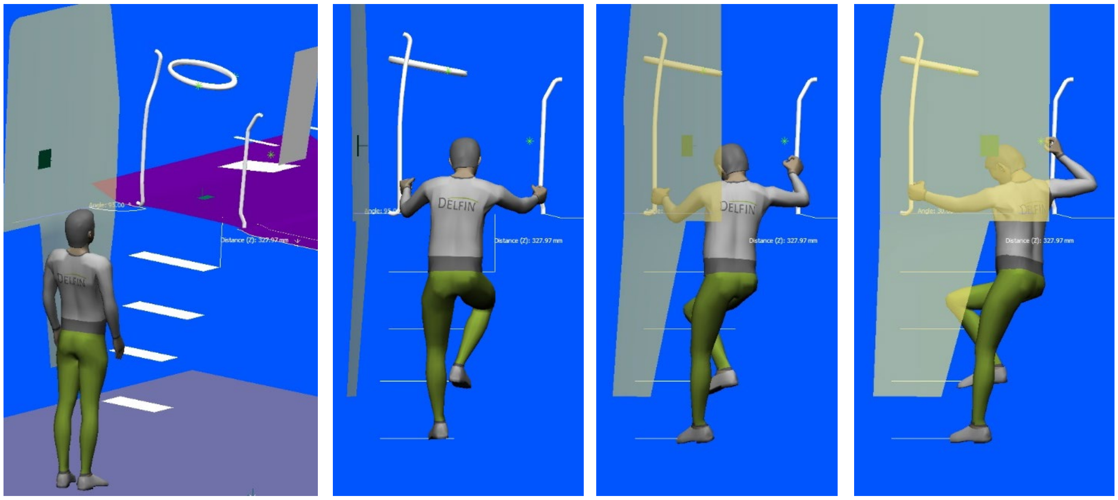

Figure 5 Collision avoidance of cabin door during truck ingress (door angle 95, 60, 30) (left to right)

Another application of this method is illustrated for the car ingress use case (Figure 6) in the following. For the specific roof and sill height the best fitting motion is extracted from the database containing motions (with different patterns) for roof heights 1237mm - 1558mm and sill heights 315mm – 450mm. From this motion, the prediction of the key frame postures while the manikin feet are above the sill and the head is below the roof takes collision avoiding restrictions between the sill and the foot and between the roof and the head into account. This leads to an evasive movement starting before and ending after the phase when the collision originally occurs.

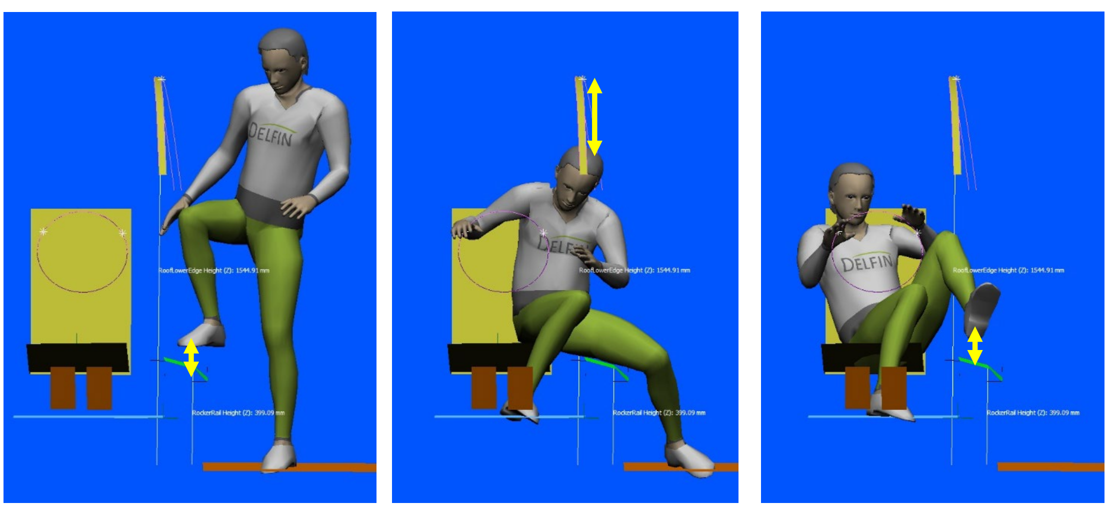

Figure 6 Collision avoidance of during car ingress (r. foot to sill, head to roof, l. foot to sill) (left to right)

Results

The results can be separated in a structured motion data pool and a DHM simulation tool making use of that pool. The motion data is transferred from the DHM Dynamicus to the DHM RAMSIS following the principal process in Wirsching et al. (2016).

The simulation framework and the collision functions are integrated into a tool based on the DHM RAMSIS. The GUI supports the user specification of concatenated motions (Figure 7).

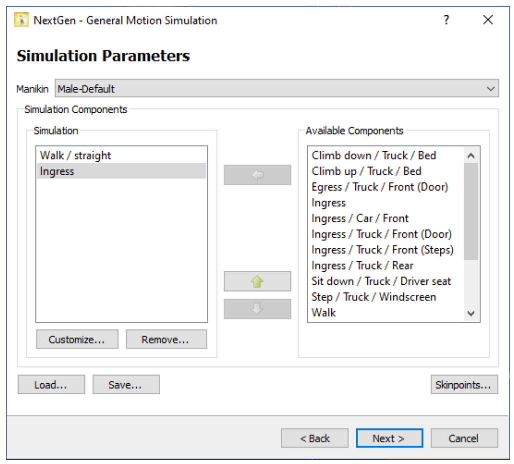

Figure 7 GUI for definition of concatenated motions

From the (right) list of available motion components the user can assembly the desired motion in the left list. The necessary parameters for each motion component and the connectors are defined by the user through specific masks (Figure 8).

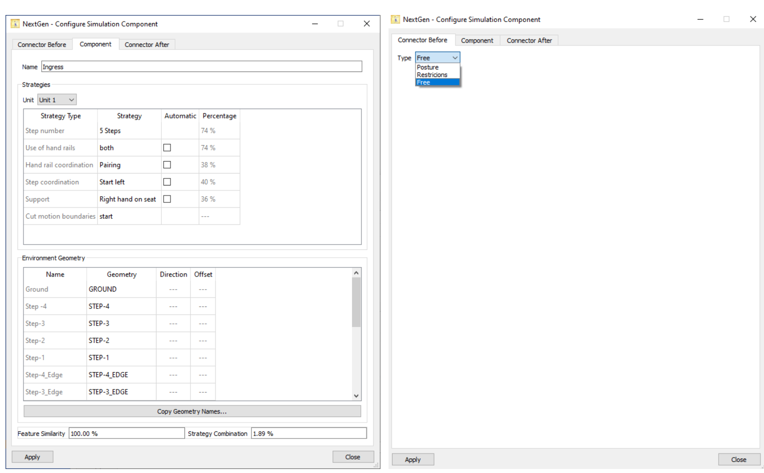

Figure 8 Motion component (left) and connector (right) definition

The motion component parameters depend on the available motion data of the specific component (Figure 8 left). First the user specifies the available strategies for the motion. The GUI supports here by displaying the percentages of the strategies and providing the option to automatically determine the most probable strategy. Second the user has to define geometrical objects which are required by the motion component simulation engine. The percentage of the selected strategy with respect to the entire database as well as feature similarity is displayed at the bottom of the mask. The latter measures the similarity between the best fitting motion and the to-be simulated motion with respect to features like stature and vehicle parameters.

The connector parameters depend on the user selection “Free”, “Posture” or “Restrictions”. In the latter two selections the user additionally specifies which posture or restriction set should be used for the connector posture. Selecting “restrictions” enables the user to run the entire motion component definition (Figure 8) on different sized manikins.

Discussion and Conclusions

The presented motion simulation approach shows promising results and resolved the following formerly shortcomings:

The motion measurement procedure has been applied to truck and car ingress applications considering several vehicle variations which increases the prediction capabilities of the entire system. Nevertheless, especially in the car use case the number of measured subjects should be increased in the future.

The user control of the simulation is now more flexible. Motions can be concatenated and the transition postures can be defined. The method to smoothly join motions is promising but requires a lot of manual modeling work in advance to define the segments to be truncated. This procedure should be done automatically in the future.

The collision handling is now more powerful than in formerly versions. It still focuses on discrete key frames which is suitable for many applications. But the collision control of the entire motion should be investigated in a next step.

The user evaluation of the tools is still in progress. A big user benefit of the tool has been perceived, but it is currently open how it finally can be used in the daily productive engineering work. This is closely related to the possibility of assessing motions with respect to various ergonomic criteria. This function would be very important for engineers to compare different design variants.

Most simulated truck and car ingress motions are smooth and plausible, but the planned quantitative evaluation of the motion simulation quality will bring more confidence in the tools.

Acknowledgments

This study was conducted in the context of the project DELFIN funded by the Federal Ministry of Education and Research of the Federal Republic of Germany.

References

Cherednichenko, A. (2008). Funktionales Modell der Einstiegsbewegung in einen PKW. Zugl.: München, Techn. Univ., Diss., 2007. Utz Herbert: Ergonomie. München.

Dorynek, M., Zhang, H., Hofmann, N., Bengler, K. (2021). New Approaches to Movement Evaluation Using Accurate Truck Ingress Data. In book: Digital Human Modeling and Applications in Health, Safety, Ergonomics and Risk Management. Human Body, Motion and Behavior (pp.110-121), DOI:10.1007/978-3-030-77817-0_10

Hermsdorf, H., Hofmann, N., Keil, A. (2019). alaska/Dynamicus – human movements in interplay with the environment, Editor(s): Sofia Scataglini, Gunther Paul, DHM and Posturography, Academic Press, 2019, G.,978-0-12-816713-7, Elsevier

Raschke, U., Cort, C. (2019). Siemens Jack. Editor(s): Sofia Scataglini, Gunther Paul, DHM and Posturography, Academic Press, 2019, Chapter 3, Pages 35-48, ISBN 9780128167137. https://doi.org/10.1016/B978-0-12-816713-7.00003-9.

Wirsching, H.-J., Bichler, R. (2013). Integrating motion capture data into knowledge-based ingress motion simulation tool. Digital Human Modeling Symposium, Ann Arbor, USA.

Wirsching, H.-J., Enderlein, V., Stechow, R. (2016). On the application of a knowledge-based motion simulation tool to ergonomic truck cabin design. 7th International Conference, DHM 2016, Toronto, ON, Canada, July 17-22, 2016 : proceedings

Wirsching, H.-J. (2019). Human Solutions RAMSIS. Editor(s): Sofia Scataglini, Gunther Paul, DHM and Posturography, Academic Press, 2019, Chapter 4, Pages 49-55, ISBN 9780128167137. https://doi.org/10.1016/B978-0-12-816713-7.00004-0.