Ramsis – The Leading Cad Tool for Ergonomic Analysis of Vehicles

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Abstract. Early integration of ergonomics in the vehicle design process requires appropriate CAD tools. 15 years ago, the German car industry developed a new, three-dimensional tool for computer-aided ergonomics and occupant packaging, called RAMSIS. Its goal was to overcome the limitations of two-dimensional human templates, as well as to provide methods for predicting driver postures and comfort. The core of RAMSIS is a highly accurate three-dimensional human model that can be made to simulate occupants with a large variety of body dimensions and based on anthropometry databases from around the world. Extensive research was conducted on driver postures and comfort, which resulted in a probability-based posture prediction model. No subjective manikin manipulation by the user is necessary, so that fast, realistic and consistent analysis results are ensured at all times. An assessment of comfort allows designers to optimize packages with respect to driver comfort early in the design process. RAMSIS offers a number of other analysis tools, for example for vision, reach, force and seat belt studies. Over the years, new research projects have resulted in more sophisticated RAMSIS functions, such as a force-based posture and comfort prediction model, seat belt certification, compatibility with full body laser scanners, simulation of the interaction between seat and occupant and simulation of ingress and egress.

1 Introduction

Manufacturers around the world recognize that occupant comfort and safety contribute significantly to a car's economic success. They are major areas in which manufacturers can distinguish them selves from the competition. This is demonstrated by the emphasis on ergonomics, comfort and safety in today's car brochures, as well as by the increasing attention car magazines devote to ergonomics and safety in test reports.

To ensure adequate comfort and safety levels, it is essential that manufacturers systematically address ergonomics and safety throughout the car design process. Today, a major part of that design process is digital. To study occupant comfort and safety in 3D CAD, an accurate representation of the occupant in the digital world is necessary. However, human beings come in many shapes and sizes, have many different

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preferences and can adopt many different postures. Standardized representations of the human body for automotive design, such as the widely used SAE J826 drafting template, do not describe the human body in its full complexity.

In the 1980s, the German car industry recognized that the ergonomic tools available then were insufficient, as they were two-dimensional, not based on up-to-date research and not integrated in 3D CAD. The German *Forschungsverein für Automobiltechnik* (FAT) initiated development of a new tool that would provide German car engineers with an accurate, three-dimensional representation of the human body in their CAD environment [Seidl]. An Industry Advisory Panel (IAP) was created, consisting of the manufacturers Audi, BMW, DaimlerChrysler, Ford, Opel, Porsche and Volkswagen, as well the seat suppliers Johnson Controls and Keiper, that oversaw development of the human model. The Technical University of Munich conducted the necessary research and Human Solutions GmbH of Kaiserslautern (then called Tecmath) was responsible for software implementation.

The tool was named RAMSIS, an acronym for *Rechnergestütztes Anthropmetrisches Mathematisches System zur Insassensimulation*, which translates as computer-aided anthropometrical mathematical system for occupant simulation. After its introduction to the German automotive industry in the early 1990s and subsequent adoption by the American and Asian automotive industry, RAMSIS has become the world's most sophisticated and comprehensive system, if not the de-facto standard, for ergonomic vehicle layout and occupant packaging. Over 70% of the world's major vehicle manufacturers use RAMSIS.

This paper highlights some of the research that has been and is conducted as part of the continuous effort by the IAP, Human Solutions, the Technical University of Munich and others to provide vehicle designers around the world with a state-of-the-art software tool that allows them to address ergonomics and ensure proper occupant accommodation from earliest stages of the design process.

Fig. 1. The digital human model RAMSIS

2 Benefits of Digital Human Models

The use of digital human models like RAMSIS offers many advantages over traditional ergonomics methods, such as guidelines, tables, two-dimensional templates or user clinics. Porter et al. distinguish time-related, cost-related and accuracy-related advantages.

Time
Detailed evaluation of designs with user questionnaires, clinics or mock-ups can take weeks or months. Digital human models allow designers to simulate user and task with CAD data only. Without a digital human model, designers must often wait for a mock-up to conduct ergonomic studies, which causes delays to the design process, or, more likely, the design process continues without the benefit of timely ergonomics input.

Cost
In addition to being time-consuming, the production of mock-ups is an expensive process. The cost of a digital human model can be less than the costs of making one full size mock-up. Most important, digital human models enable ergonomics input to be provided much earlier in the design process, which reduces the likelihood of expensive or unfeasible modifications being necessary later on.

Accuracy
3D human models offer far more accuracy than guidelines, two-dimensional templates or numerical tables. The human body is highly complex and a large variety of combinations of and correlations between body dimensions exists. Three-dimensional human models are able to reflect this complexity.

3 Initial Approach for Posture Prediction and Discomfort Assessment

The IAP decided that for effective use, it was essential that every user in every design centre produce realistic, reproducible and consistent analysis results with RAMSIS. Thus, the creation of manikins, the process of positioning a manikin in a CAD model and the analyses had to be non-ambiguous and require as little subjective judgment by the user as possible.

For the manikin positioning process, an automatic posture prediction model was developed. RAMSIS can predict, with minimal user interference, how a person with given anthropometric features will most likely perform typical driver tasks in the car that is being designed. Based on such predicted postures, for example, possible collision with the interior can be detected, vision studies can be conducted and feasible reach zones can be generated.

For the development of the posture prediction model, postures of a sample of test subjects, representative of the German driver population, were recorded in three simulated package configurations, one representing a sports car, one a sedan and one a minivan. The subjects performed typical driving tasks, including normal driving, using pedals, shifting gear, looking in different directions and reaching for a number of target points. Using a photographic analysis system that allowed projecting a RAMSIS manikin with the same size as the subject on the recorded images, the joint angles of the subjects in their respective postures were extracted.

From the extracted joint angles, multi-dimensional probability distribution were derived, i.e. for each joint it was determined which angle range is most likely to be used for driving tasks.

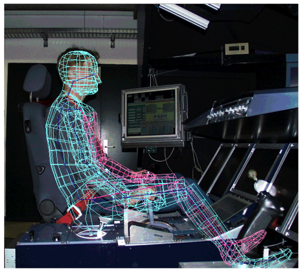

Fig. 2. Photographic analysis of driver posture

To position a RAMSIS manikin in a CAD model, the user must give the manikin a "task" in the form of a number of simple geometric constraints. For example, the user can define connections between body parts and geometry parts (put hands on steering wheel), force the manikin to stay on a particular side of a geometry part (keep head below roof trim) or assign directions to body parts (look 5 degrees downwards). The automatic posture prediction then finds the posture in which all constraints are fulfilled, while at the same time, each joint angle is within a range of high probability. Thus, at all times, the user can be sure that the occupant postures that RAMSIS predicts for a given task are as probable or realistic as possible.

In addition, the German manufacturers wanted to be able to evaluate and compare package designs with respect to driver comfort early in the design process, a possibility not available until then.

After the subjects had performed a typical driving task for 10-15 minutes and their postures were recorded, they were requested to rate self-perceived discomfort levels for a number of body parts on a scale, developed especially for this purpose [Krist].

The (subjective) discomfort levels on each subject's questionnaire were statistically correlated to their (objective) posture data using a multi-linear regression analysis. These correlations are used to predict postural discomfort levels for occupants in new car designs. Thus, designers can study the effect of design changes on driver posture and comfort and optimize packages with respect to driver comfort early in the design process.

4 Force-Controlled Posture and Comfort Prediction

In the late 1990s, the IAP decided to enhance RAMSIS' posture and comfort prediction capabilities with a force-based model. This would allow prediction of postures and comfort levels in terms of joint load for situations in which drivers exert or are exposed to external forces, such as pushing a pedal or shifting gear. Additionally, such a model would allow prediction of postures and comfort levels for non-driving and even non-vehicle-related tasks.

Research resulted in the Force Controlled Comfort and Posture Prediction (FOCOPP) [Seitz]. The FOCOPP assumes that humans try to minimize the relative load in each of their joints when performing a task. Thus, for a given task and combination of external forces, the FOCOPP calculates a manikin posture in which the relative load in each joint is as small as possible.

Relative joint load is defined as the ratio between effective torque in a joint and the maximum torque that that joint can generate/absorb. Maximum torque for all joints of the human body was determined through experiments at the Technical University of Munich, in which subjects' joints were isolated and maximum torque was measured for a range of excursions around the joints' axes of rotation. It was found that maximum torque changes with joint angles and thus with posture.

There is a linear correlation between relative joint load and joint discomfort. Thus, from the relative joint loads, it is possible to associate a comfort rating with a posture.

Currently, the FOCOPP is integrated in RAMSIS in the form of a prototype. Initial validation of the FOCOPP has shown plausible results [Seitz]. A full implementation of the FOCOPP in RAMSIS is expected to be available in 2008.

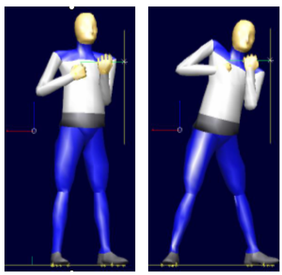

Fig. 3. postures for drill forces of 10N and 100N

5 Enhanced Anthropometry

RAMSIS manikins can be made to represent occupants with a large variety of body dimensions and be based on a number of anthropometry databases from around the world. Currently, databases for Germany, France, USA, South America, Mexico, Japan, Korea and China are available.

In the past, anthropometry data were collected by hand, measuring subjects in standing and seated postures with special measurement tools. Obviously, manual

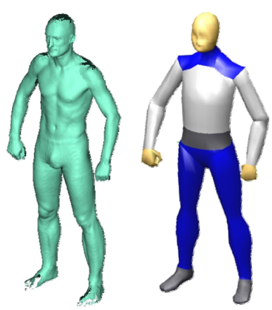

Fig. 4. A RAMSIS manikin based on a full body laser scan

measurement is prone to inaccuracies. Therefore, digital measurements methods, such as full body laser scanners, are increasingly being used for anthropometry surveys. The full body scans that they produce are point clouds that can not be used and animated in CAD. RAMSIS offers the possibility to automatically transfer body dimensions of a scanned subject to the RAMSIS manikin, that *can* be used and animated in CAD. This enables direct application of new anthropometry data to product design, as well as the creation of "individual" RAMSIS manikins, for design of race cars or customized vehicles.

6 Interaction Between Occupant and Seat

Similar to SAE packaging regulations, in RAMSIS, the connection between manikin and CAD model is the H-point. However, when RAMSIS was developed, it was found that real occupants' hip centers are not located exactly on the H-point, but at an offset that correlates to an occupant's height, weight and gender. For a number of seats, H-point offset was measured and statistical correlations with occupant height, weight and gender were determined. A RAMSIS manikin' H-point is not located in its hip centre, but at an offset from the hip centre, that correlates with the manikin's anthropometry. This H-point offset approach requires designers to use statistical correlations found on existing seats to predict occupant postures in other or new seats. The properties of the new seat are not considered in the manikin positioning process.

In many cases, it is useful to study the effect of seat geometry, stiffness or adjustability on occupant postures (and thus visibility, reach, etc.) in an early design phase as well. In the late 1990s, the project RAMSIS Sitzt (RAMSIS Sits) was initiated by the IAP, with the goal to develop a method for predicting an occupant's exact position in a seat, based on the seat's geometry, stiffness and kinematics. The project consisted of three phases:

1. Simulation of torso posture and load distribution in seats
2. Modelling of a detailed contact surface between (loaded) seat and occupant
3. Posture simulation in CAD seats

For simulation of torso postures, the kinematic coupling between pelvis and thorax found in the ASPECT program is used [Hubbard et al.]. The ASPECT model assumes that pelvis and thorax rotate evenly, but in opposite direction, when moving from a kyphotic to a lordotic posture.

Research for phase 2 was conducted by Michigan State University in the USA and resulted in a method for predicting load distribution in a seat [Radcliffe], as well as an accurate surface representation of the human back and buttocks when seated [Zhenyu]. Both the load distribution and surface are posture-dependent.

The position and posture of a manikin in a seat is based on a force-equilibrium. The back-and-buttocks-surface is pressed into the seat, with local forces according to the load distribution of phase 2. The seat pushes back with a force that is related to its stiffness or force-deflection behaviour.

Rather than using FEA or similar methods to model seat stiffness, it was decided to measure seat stiffness locally in a number of specified points with a force-deflection gauge and transfer the measured stiffness to the CAD surfaces that represent the seat's cushion and back.

Fig. 5. Accurate surface representation of human back and buttocks

The model was validated in a posture experiment [Wirsching et al.]. Real postures of 20 people in 2 seats were compared to RAMSIS posture simulations. The validation showed that the model consistently simulates the observed driving postures. Significant systematic deviations are caused by the fact that the model cannot properly simulate a phenomenon from reality: people do not move their pelvis to the backrest as closely as possible. Hence the observed horizontal offset between pelvis and backrest must be analyzed and integrated into an enhanced simulation. The new approach was also compared with the H-Point vector method. The models show equal accuracy and predictive power. Nevertheless, the simulation approach opens the door to further research on the effect of seat parameters on driver postures and, possibly, seat comfort.

7 Seat Belt Simulation

Throughout the 1970s, 1980s and 1990s, in attempt to reduce the risk of accident injuries caused by inappropriate belt fitting, Transport Canada developed the Belt-fit Test Device (BTD) [Balzulat et al.]. The BTD is a hardware measuring device that tests whether the lap and torso belt are appropriately positioned with respect to the bony structures of the pelvis and rib cage of a restrained occupant. The premise is that belts that meet the fit criteria established by Transport Canada adequately restrain the occupant in a crash, without causing serious injuries to soft tissue and organs from belt forces.

In 1995, amendments were proposed to two Canadian Motor Vehicle Safety Regulations relating to seat belts: CMVSR 208 (Seat Belt Installations) and CMVSR 210 (Seat Belt Anchorages). The proposed amendment to CMVSR 210 included provisions for abdominal protection using BTD test procedures.

To overcome the deviations of physical hardware tests and to enable review of belt design in early design phases, Transport Canada, the Canadian Vehicle Manufacturers' Association (CVMA) and the Association of International Automobile Manufacturers of Canada (AIAMC) agreed to participate in a joint working group to develop a computer simulation of the BTD test procedures. The development of this "electronic" Belt fit Test Device (eBTD) was funded by the Alliance of Automobile Manufacturers, a leading US advocacy group for the automobile industry on a range of public policy issues. Because of the widespread use of its products by the global automotive industry, Human Solutions was selected as the partner for developing the eBTD software.

In 2006, Transport Canada and vehicle manufacturers that sell cars in Canada signed a Memorandum of Understanding (MOU), called “Seat Belt Fit Evaluation for the 50th Percentile Male ATD in Front Outboard Seating Positions”. By doing so, the manufacturers made a statement of commitment to identify to Transport Canada each new vehicle model equipped with front outboard seat belt systems that have been evaluated in accordance with the fit criteria established by Transport Canada.

The eBTD is one of the world’s first digital certification tools.

The seat belt routing and anchorage simulation developed for the eBTD project can also be applied to RAMSIS manikins, so that besides checking compliance with Transport Canada’s belt fit criteria, seat belt systems can be evaluated from an ergonomic point of view.

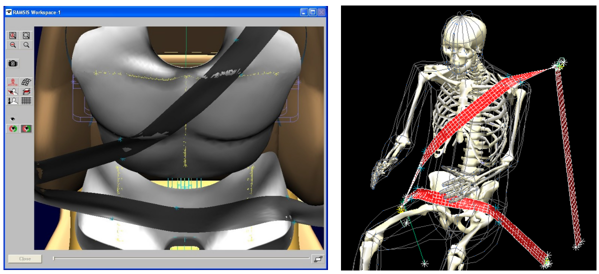

Fig. 6. eBTD and belt simulation on a manikin

8 Ingress/Egress

A major area of attention of human factors and vehicle engineers is the effort required by a person to get into and out of a car. Styling and aerodynamics have pushed the A-pillar and roofline down, while new vehicle concepts, such as minivans, SUVs and cross-overs, have unusual entry opening configurations. At the same time, the customer population is ageing and therefore less flexible or willing to sacrifice comfort for styling.

People use a variety of ingress strategies, such as head-first, foot-first or buttocks-first. A person’s ingress strategy correlates to the geometry of the door opening, his or her body dimensions, as well as to seat and steering wheel position, age, and habit.

A number of RAMSIS customers is conducting research on ingress and egress. Their goal is to be able to predict how people get in and out of vehicle based on the vehicle’s geometry on the one hand and occupant parameters, such as body dimensions, age and habits, on the other. Accurate prediction of ingress/egress motion in RAMSIS allows for early optimization of vehicle geometry.

For these studies, the parameters that affect ingress/egress motion are varied systematically while subjects repeatedly get in and out of a vehicle. Their motion is recorded and analyzed using motion capture systems, such that statistical relations between ingress/egress strategy and the relevant parameters can be established.

An example of an ingress/egress study for which RAMSIS was used in conjunction with motion tracking is the REAL MAN project [Lestrelin et al.].

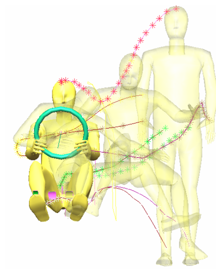

Fig. 7. Ingress postures measured with a motion tracking system

9 Conclusion

Since the early 1990s, the digital human model RAMSIS has become the preferred CAD tool for ergonomic vehicle layout and occupant packaging. Developed by a consortium of German companies, it is now used by the majority of car manufacturers worldwide.

The primary function of RAMSIS is to provide designers with an accurate representation of occupants in their CAD model, both in terms of anthropometry and posture, so that they can ensure proper accommodation of these occupants right from the start of the design process.

Extensive research on anthropometry and driver postures was conducted to build the core of RAMSIS. However, the system has been and is continuously enhanced, as science and experience provide new information, data and insights all the time.

A focus for further development of RAMSIS will be on cognitive ergonomics. In today's vehicles, a large amount of information is presented to the driver. Board computers, navigation systems, car phones, and an increasing number of operating elements all compete for a driver's attention. At the same time, the influx of information from outside the vehicle increases, too, due to intensified traffic, more complex road situations and an abundance of traffic signals. For driver comfort and safety, the way in which all this information is presented is of great importance. Proper ergonomic design of displays, HMIs and operating elements is one of the major future challenges for human factors and vehicle engineers.

Obviously, for car companies as much as for anyone, only a system that keeps pace with science and technology is a justified investment.

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