Dynamics Simulation and Comfort Analysis of Human-Vehicle Systems

Simo-Pekka Leino, Juhani Viitaniemi, Susanna Aromaa and Kaj Helin

In commercial terms, human factors are becoming increasingly significant. Comfort and health features make an increasingly larger contribution when a customer makes a decision to purchase a machine or a vehicle. In addition, demands on the comprehensive assessment of human comfort, health, and safety impacts are increasing in EU legislation.

A common hypothesis is that by virtual prototyping, a human-machine system can be designed more efficiently to provide comfort and safety features. In addition, accordance with requirements and legislation can be proved in the early design phase. The purpose of this study was to discover ways to simulate especially the dynamics features of human-machine systems, and find out how to analyse human comfort and safety as a part of the virtual prototyping process. An approach using a digital, kinetic human model and whole body vibration analysis in the virtual prototyping process of terrain vehicles is presented.

Summary

In commercial terms, human factors are becoming increasingly significant. Comfort and health features make an increasingly larger contribution when a customer makes a decision to purchase a machine or a vehicle. In addition, demands on the comprehensive assessment of human comfort, health, and safety impacts are increasing in EU legislation.

A common hypothesis is that by virtual prototyping, a human-machine system can be designed more efficiently to provide comfort and safety features. In addition, accordance with requirements and legisla-

Figure 1. Human test measurement system

tion can be proved in the early design phase. The purpose of this study was to discover ways to simulate especially the dynamics features of human-machine systems, and find out how to analyse human comfort and safety as a part of the virtual prototyping process. An approach using a digital, kinetic human model and whole body vibration analysis in the virtual prototyping process of terrain vehicles is presented.

Introduction

Machines or vehicles of different manufacturers are frequently technically equal. Therefore, the comfort and ergonomics could be buyers' most important factors in the decision to purchase. Driving and manoeuvring on a rough terrain exert dynamically reacting forces on a vehicle's chassis and body system and on a human riding the vehicle, too. This phenomenon is studied as a human-machine system application in virtual prototyping. Virtual prototyping can be defined as a software-based engineering discipline that includes modelling a system as well as simulating and post-processing the result [1]. Issues of particular interest here're human response to external impacts and human behaviour in different and varying conditions.

Dynamics simulation and virtual prototyping are common tools in product development processes of vehicles, and manufacturers are familiar with their benefits. Virtual prototyping reduces e.g. the need for physical prototypes, thereby saving money. However, there has been a need for tools to simulate human-machine interaction. A design engineer typically does not have a great deal of knowledge of ergonomics and even less knowledge of human models. One should have tools that are easy to use and smoothly integrated into the product design process as well as other familiar design tools and software.

The purpose of this study was to discover appropriate ways of modelling and simulating dynamics properties of a kinetic human system. Another objective was to investigate analyses for human comfort and safety properties in a context of virtual prototyping, especially the human biomechanics and behaviour and their relation in a human-machine system virtual prototyping. This paper introduces efforts to achieve these goals.

Digital human models and virtual prototyping

Various biomechanical models have been developed to describe the human body and its motion. These models can be grouped as lumped parameter or distributed parameter models. Lumped parameter models consider the human body as several rigid bodies, springs and dampers. Some distributed models treat the spine as a layered structure of rigid elements, representing the invertebral discs as finite elements. [2] On the other hand, lumped parameter models can generally be classified into: a) static, b) sequential-static posture models, c) dynamic motion models incorporating musculoskeletal mechanics, and d) dynamic motion models without musculature. [3] In this paper, the term *kinetic human model* stands for the dynamic motion model without musculature. The introduction of human motion into biomechanical models introduces two types of complexity. The motion must be described in a kinematics fashion and human motion biomechanics must model the kinetic forces and moments of complex linkage systems during motion. [4]

There have been few investigations into modelling digital humans in order to assess or analyse human comfort or to simulate dynamic human safety issues. Specific research problems investigated are modelling human responses for external impulses and modelling human-machine specific contacts.

Commercial modelling tools

There are few digital human models suitable for dynamics simulation. ADAMS (Automatic Dynamic Analysis of Mechanical System) was selected to be the dynamics simulation software because it is obviously the most common mechanical system dynamics simulation and functional virtual prototyping software in the Finnish machine and vehicle building industry. ADAMS is general multi-body system simulation software. McGuan [5] has introduced a digital human modelling tool called *Figure Human Modeller*, which is a plug-in to ADAMS. In addition, a new kinetic human modelling tool was created during the research project. The approach to building a new kinetic human model application for ADAMS software was to achieve compatibility with *Figure Human Modeller*. The goal was to create a kinetic human model aimed at fulfilling the special requirements of the off-road vehicle manufacturers that participated in this research project.

Human test measurements

Two goals were set for the experimental human measurements. First, human motions were measured in order to tune and verify the human models for the study cases. Secondly, subjective assessments were recorded in order to develop ergonomic analyses for dynamic cases.

Ten volunteer subjects were swung and waved on a motion platform (Fig. 1). The selected swing and continuous waving motion scenarios are typical of the case vehicles, i.e. big off-road vehicles. Motions included the three main motion directions and the alternation of rotations, frequency, and amplitude. The motion measurement system consisted of the *Ascension MotionStar Wireless* motion capture system with twelve sensors. Sensors were mounted on every body segment and the seat on which the subject was fastened with belts. Acceleration transducers were mounted on the subject's head and on the under side of the seat. After each test scenario, a subjective comfort assessment was documented. The measurement system and protocol were introduced in more detail in [6]

The ADAMS model (Fig. 3) of the human measurement system consists of a human model and a rigid seat model in which the seat was moved by the recorded motion spline function. Sensor markers were attached to same positions as the motion capture sensors and acceleration transducers of the human subject. The simulation results, i.e. position and acceleration data of the sensor markers, were compared to analogous test data. The human model's parameters were tuned to get correlation between test and simulated data.

Human models

Two Finnish frontline innovative and capable vehicle manufacturers having their own planning activity have acquired expertise in digital human modelling and simulation, and have put it in the design practice of their products. The development of digital human models is the consequence of the increased capacity of computation and visualisation in software applications directed at both industry and society in general.

One of the first models was BOEMAN (Boeing Corporation), which was applied in 1969 to cockpit layout design. Later, dozens of different human models were built for various purposes, either simple 2D or 3D geometric models of the human body or having kinematic or dynamic properties. Generally, every human model is focused on some specified problem such as surgeons planning their operations, production engineers designing work tasks and work places, and vehicle design engineers making better cushions with digital human models.

Figure 3. ADAMS model of the measurement system.

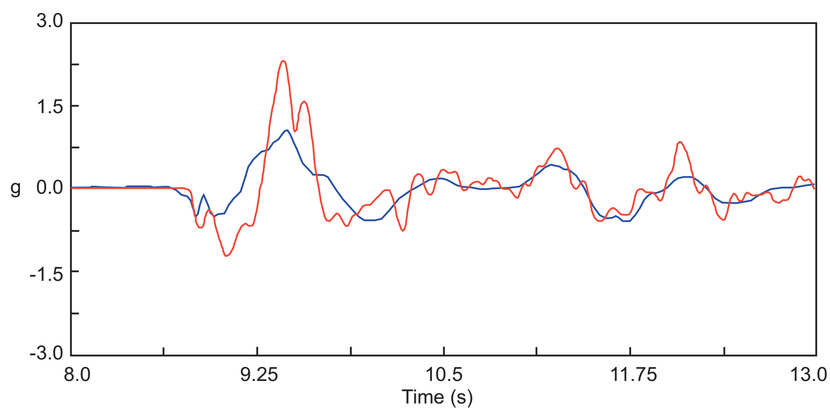


Figure 3. Example of comparing measured and simulated acceleration data. The blue curve represents measured data, and the red curve represents the simulated motion data.

Industrial case studies

The project was carried out in collaboration with two Finnish vehicle manufacturers, Patria Vehicles and Timberjack. Patria Vehicles manufactures armoured and wheeled military vehicles such as personnel carriers, and Timberjack is a manufacturer of forest machines, harvesters, and log forwarders. These machines are types of heavy off-road vehicles. Design engineers of the companies tested simulation and analyses tools, and provided feedback to the software developers.

Results

Modelling tools

The new digital human model was composed of fifteen rigid segment parts and torque functions in joints in order to maintain the posture of the digital human. The modelling tool was created using ADAMS macro language so it is amenable to future development. Within the project, this new human model was called *Hemmo*.

A commercial kinetic human modelling tool called the Figure Human Modeller was applied to simulation of a human-machine system in order to assess off-road vehicle comfort and safety. Simulation data was compared with experimental data. Fig. 5 shows that the tested kinetic human model could be tuned to perform moderately well at a certain working point in which accelerations, amplitudes, and frequencies were relatively small.

Comfort and safety analyses

Comfort and discomfort are subjective feelings, and feelings are a combination of physiological and psychological processes. Therefore, the assessment of comfort should involve both objective and subjective approaches. During the project comfort, safety and ergonomics methods were surveyed. It turned out that there are few methods suitable for assessing this kind of dynamic system which will need further developing in the future. The whole body vibration standard (ISO 2631-1) [7] describes methods for evaluating vibration in relation to human health, interference with activities, discomfort, and the possibility of motion sickness. RULA (Rapid Upper Limb Assessment) [8] is a screening tool that assesses biomechanical and postural loading on the whole body with particular attention to the neck, trunk, and upper limbs. OWAS (OVAKO Working posture Analysing System) [9,10] is a method for the evaluation of postural load during work, based on a simple and systematic classification of work postures combined with observations of work tasks.

Discussion and conclusion

The greatest benefit from exploiting digital kinetic human models is that the need for physical prototypes decreases. The degree to which a human-machine system accords with requirements can be tested in the early design phase. The system can be designed to provide comfort and to be ergonomic, safe, and efficient. Different options for the system can be tested and compared in the early design phase, which helps in decision-making. Without digital human models and virtual prototypes, the comprehensive analysis of interactive performance of human-machine systems is difficult. Using digital human models, dangerous operating situations can be identified, simulated, and analysed in a safe way.

The two Finnish manufacturers have expressed their pleasure in obtaining a practical human model with information on how to connect simulation to ergonomic assessment of vehicle planning. In addition, they welcomed the increase of designers' ergonomic knowledge and the tangible setting up of human factors to match their product development process. The participating companies consider comfort and safety as representing a competitive edge in the future market. Virtual prototyping and digital human models are of great benefit to designers. Safer and more comfortable systems can be designed when human factors are taken into account instantly at the beginning of the product development process. In addition, the research partners, VTT Industrial Systems, The Finnish Institute of Occupational Health, and Lappeenranta University of Technology have benefited from the concrete industrial research cases.

As the findings of the research show, the tested kinetic human models could be tuned moderately well to perform at a certain level of operation. Because of the complexity of human linkage systems and the number of joint controllers, manual tuning of a kinetic human model, i.e. seeking the best stiffness and damping set of values or other parameters, remains a formidable task. The controllers or spring-dampers of applied human models do not seem to be the best possible way to simulate human actions accurately in these types of applications because they over-simplify real human properties. They reckon without human behaviour in varying situations. A statistical approach and more sophisticated controllers could provide the solution.

The effective tuning of kinetic human models requires automatic tuning algorithms and programs (e.g. genetic algorithms). The use of soft computing (i.e., fuzzy logic, neural networks and genetic algorithms) offers great potential in the analysis and design of human motion control. Among others, Jacobs [7] has studied fuzzy logic applications in human control models. Neural networks could be implemented for tuning the controller.

References

1. Mikkola, A. Studies on fatigue damage in a hydraulically driven boom system using virtual prototype simulations. Doctoral Thesis. Lappeenranta University of Technology, Research papers 61,1997.

2. Kitazaki, S., Griffin, M.J. A modal analysis of wholebody vertical vibration using a finite element model of the human body. Journal of Sound and Vibration. 1997.

3. Zhang, X. Biomechanical Realism versus Algorithmic Efficiency: A Tradeoff in Human Motion Simulation Modelling. In: DHMC Conference Proceedings. Arlington, USA, June 26-28, 2001.

4. Chaffin D.B., Andersson G.B.J., Martin B.J. Occupational Biomechanics. 3rd edition. John Wiley & Sons Inc. 1999. 579 p.

5. McGuan, S. Human Modelling – From Bupplemen to Skeletons. in: DHMC Conference Proceedings. Arlington, USA, June 26-28, 2001.

6. Leino S-P., Viitaniemi J., Keula S. Human comfort and safety analysis in virtual prototyping. Case: Off-road vehicle. in: DHMC Conference Proceeding. München, Germany, June 18-20, 2002.

7. ISO 2631-1. 1997. Mechanical vibration and shock - Evaluation of human exposure to whole-body vibration - Part 1: General requirements. International standard. 31 s.

8. McAtamney, L. & Corlett, E. N. 1993. RULA: A Survey Method for the Investigation of Work-related Upper Limb Disorders. Applied Ergonomics, 24, 91-99

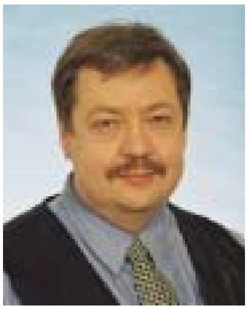
9. Karhu, O., Kansi, P. & Kuorinka, I., 1977, Correcting working postures in industry. A practical method for analysis. Applied Ergonomics, 8, s. 199-201.

10. Louhevaara, V. and Suurnäkki, T. 1992. OWAS: a method for the evaluation of postural load during work. Institute of occupational health and Centre for Occupational Safety, Helsinki, p.23.

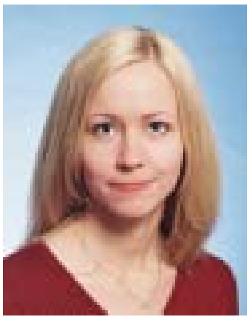
11. Jacobs R. Control model of human stance using fuzzy logic. Biological Cybernetics 77, 1997. p. 63-70.

Human modelling www links as example:
LifeMOD Biomechanics Simulation Program (former Figure Human Modeller):
http://www.lifemodeler.com/
Ergonomics Solutions
http://www.delfoi.com/products/products.html
Industrial Environments and Simulating Work Cells
http://www.irf.uni-dortmund.de/cosimir.eng/welcome.htm
Biodynamics Database – Air Force Research Laboratory
http://www.biodyn.wpafb.af.mil/

Simo-Pekka Leino
Research Scientist
VTT Industrial Systems



Juhani Viitaniemi
Senior Research Scientist
VTT Industrial Systems



Susanna Aromaa
Research Scientist
VTT Industrial Systems

Kaj Helin
Research Scientist
VTT Industrial Systems