Biomechanics of the human-machine-interface
SIMPACK User-Meeting
November 2004

Theoretical Astrophysics
Dept. Biomechanics
University Tübingen
Project: Homunkulus

- Human MKS Model
- Flexible in application
- Easy to adapt
- Goal: widely validated model
Collaboration between

- **Astrophysics**: Prof. Ruder (Tübingen)
- **Sports**: Prof. Gruber (Koblenz), Prof. Wank (Tübingen)
- **Med.-Technology**: Prof. Buzug (Remagen),
- **Radiology**: Prof. Schick, Tübingen
- **Orthopedics, Legal-Medicine, Neurology, Surgery**
- **Industry**
Interdisciplinary development of a modular HOMUNKULUS

- Model-Definition
  - Equations of motion
  - Integration
  - Visualization

- Biological joints
- Muscle geometry
- Wobbling masses
- Muscle stimulation
- Interaction between Human-Model and environment

SIMPACK
Homunkulus: Lower limb Musculo-Skeletal-System

- Realistic joint models
- Muscle wrapping
- Hill-type muscles
- 44 Muscles per leg
- 6 DOF -> redundancy
Homunkulus: Wobbling Masses
Example Applications

- Man-Machine-Interface
- Synthesizes of human gait
- Sports (i.e. jumping)
- Computer assisted surgery / Medicine
Dummy and Man differ
Homunkulus: Upper Limb Model Vibration Response
Homunkulus: Whiplash

Experimental methods should be replaced by computer simulations in general!
Homunkulus: Occupant Simulation

Rear Impact / Whiplash  Ride Comfort
Example Applications

- Man-Machine-Interface
- **Synthesizes of human gait**
- Sports (f.i. jumping)
- Computer assisted surgery / Medicine
3D Model of Human Gait

75,000 € Budget
Bipedal Robot HONDA R3
250.000.000 $ Budget
Example Applications

- Man-Machine-Interface
- Synthesizes of human gait
- Sports (f.i. jumping)
- Computer assisted surgery / Medicine
Homunkulus: Sports and Biomechanics

- Measurement of outer loads
- + Videoanalysis of movement
- + Muscle activity (EMG)
- + Biomechanical modeling and simulation

\(
\Rightarrow\text{Calculation of inner loads}
\)
Example Applications

• Man-Machine-Interface
• Synthesizes of human gait
• Sports (f.i. jumping)
• Computer assisted surgery / Medicine
Homunkulus: Spinal Implants
Homunkulus: Spinal Implants
Computer Assisted Surgery
Homunkulus: Legal Medicine
Accident Reconstruction

Matching of deformations  Modeling and simulation
Homunkulus: Legal Medicine
Accident Reconstruction
Homunkulus: Conclusion

- Evolution of biomechanical models is progressing
- Concern human models in rapid prototyping: *Biomechanical Models may save time (and money) in R&D*
- Most of the really interesting values in living subjects can not be measured in vivo without harm
- By taking biomechanical properties of man-machine-interaction into account, R&D leads to better products, which fit best to customers needs
Homunkulus: Ride Comfort by means of a biomechanical Model

H. Mutschler
Description of Vibrations

Task: Objective quantification of dynamic ride comfort:

- Uses acceleration for description
- Perception
- Norm (z. B. VDI 2057)

\[ a_w = \left( \int_0^{f_{\text{max}}} \left( W_i(f) \cdot a(f) \right)^2 df \right)^{1/2} \]
Benefit of biomechanical models

Simulation

Excitation

Model

Transfer function

Rating the comfort

Acceleration
Pressure distribution
Perception
Biomechanical anthropometrical Model

- 22 rigid bodies for the anthropometrical biomechanical model (parameterized with NASA- and DIN-Data)
- 5 rigid bodies for the seat model
- 13 nonlinear contact elements between model and environment
- Nonlinear force elements (Bushings, Wobbling-Mass)
- Degree of freedom about 100
Comparison Simulation / measurement

Test ride (bad country road) delivers accelerations:

Simulation

measuring
Transfer function

\[ t_{ij} = \frac{\text{output}_i}{\text{input}_j} \]

Transfer function has to be (per definition) independent of the amplitude and the signal.
Transfer function

\[ t_{ij} = \frac{\text{output}_i}{\text{input}_j} \]
Method of analysis

Piecewise Fourier transformation with statistical analyses
Matrix of transfer functions

Simulation: Noise, excitation of one axes, different excitation-levels

Diagonal elements

Secondary diagonal elements

Dependent of the input-amplitude

$\leftrightarrow$ SISO-system
Simulation: Noise, excitation of one axes, different excitation-levels

Matrix of transfer functions

diagonal elements ⇔ SISO-system

secondary diagonal elements
Direct comparison of Model and measuring
Simulation and measurement with identical excitation

Partly very good match of model und measuring
Secondary diagonal elements $t_{xz}$

Simulation P3

Measurement P3, seat 3

Coupling of the x-z direction delivers good accordance (z-x not)
Problems with the analysis

- Coupling of axes → *MIMO-System*
- Dependence of excitation-signal (Sinus-excitation vs. Noise-excitation and „ride data“)

Matrix of transfer functions is *necessary*! → Should be determined through single-axes-excitation

- Uncertainties of transfer function
- Phase angle is difficult to determine (within realistic excitation)
Summary

- Matrix of transfer functions is necessary (Should be determined through single-axes- excitation)
- Model delivers good accordance, especially for the secondary diagonal elements
- Seat-model should be improved
Summary

- Matrix of transfer functions is necessary (Should be determined through single-axes-excitation)
- Model delivers good accordance, especially for the secondary diagonal elements
The End
**Benefit of the model**

**e.g. anthropometrical ride comfort**

\[ r_K = 1 - \frac{a_w}{a_{\text{Excite}}} \]

- Uses the transfer functions
- Comparison of individual differences
Causes of the secondary diagonal elements

Geometry causes axes-coupling