DHERGO

Digital Humans for Ergonomic design of products

DIGITAL HUMAN FOR ERGONOMIC DESIGN OF PRODUCTS

MAIN RESULTS OF THE PROJECT

DATA COLLECTING :: MODELING :: DEMONSTRATOR

Editorial

The-three-year collaborative project DHErgo is approaching its end. This leaflet summarizes the main results of the project. A large amount of human data has been collected in this project for developing realistic human models. For instance, data of joint strength and joint range of motion with consideration of adjacent joints are collected at TUM and IFSTTAR. In addition to detailed musculoskeletal data, ULB also investigated shoulder complex motion both in vitro and in vivo so as to find the mechanical relationships between the humerus position and orientation and the related attitude of the scapula and clavicle. CEIT has proposed a dynamic motion simulation method which takes into account the constraints due to motion dynamics. The reconstructed motions using a multi-body human model can now be exported into ESI's musculoskeletal model including deformable soft tissues so as to estimate muscle forces as well as contact pressure. A generic motion-related discomfort assessment approach has also been proposed using the concept of "less-constrained motion". The less constrained motions are those preferred by users and can be experimentally obtained, making it possible to evaluate a design solution by comparing it with the less constraint motions. Three automotive application oriented case studies have been carried out at IFSTTAR in close collaboration with three car manufacturers as end-users in project. These data sets are used for testing the motion and discomfort simulation methods. In addition to the implementation of the new functionalities from the project research, design orientated interfaces have been also proposed in the DHErgo demonstrator. Most of these results have been presented at the 1st International Symposium of Digital Human Modeling which was hosted by IFSTTAR in Lyon, France, June 14-16, 2011 www.iea-dhm2011.univ-lyon1.fr

Xuguang Wang, Scientific Coordinator

Content

Front page: 'An example of workflow as a whole'
Credits: • Anatomic data (ULB) • Case studies (IFSTTAR) • Functional data (TUM) • RAMSIS (Human Solutions) • Pam-Muscle (ESI) • Pam-Comfort (ESI)
Page 10: RPx / Ifsttar & Renault

Human functional data for a more realistic representation of human physical capacity

To achieve a more realistic representation of human physical capacity, extensive experimental data were obtained during the project. Both maximum joint range of motion (RoM) as well as maximum joint torque data were measured for all major joints of the human body.

To account for expected differences in age and gender, 18 males and females were studied forming two age groups each: younger than 35 years and older than 65 years.

An important and new aspect of these measurements was the consideration of dependencies between different joint degrees of freedom of one joint as well as adjacent joints due to bi-articular muscles, which had not been done to this extent before. These relations were studied using specially designed measurement devices and motions were recorded using a Vicon motion capture system.

On the basis of anatomical considerations and experimental feasibility, thoroughly planned, experimental protocols were defined allowing for a very detailed analysis while limiting the experimental effort of the subjects to an acceptable level. The measurements were distributed over 20 sessions per subject lasting about two hours each (Figure 1).

The resulting data were analyzed using inverse kinematics and dynamics and statistical methods.

One exemplary result for joint RoM was the relation of maximum hip flexion and knee flexion RoM which could be quantified and modeled. Considering maximum joint torque numerous relations were found. It was, for instance, shown that elbow flexion torque is highly dependent on the elbow flexion angle as well as the shoulder flexion angle. Furthermore, the expected decrease of joint torque due to ageing and the differences in gender were confirmed and partially quantified.

The resulting mathematical models of joint torque – joint angle relations as well as inter-joint relations can now directly be applied to digital human models allowing for a more realistic simulation of physical capacity.

by F. Engstler & F. Guenzkofer [TUM]

Elbow flexion and extension *Knee flexion and extension*

Figure 1. Joint torque measurement devices used at LfE

Detailed human anatomic data collection

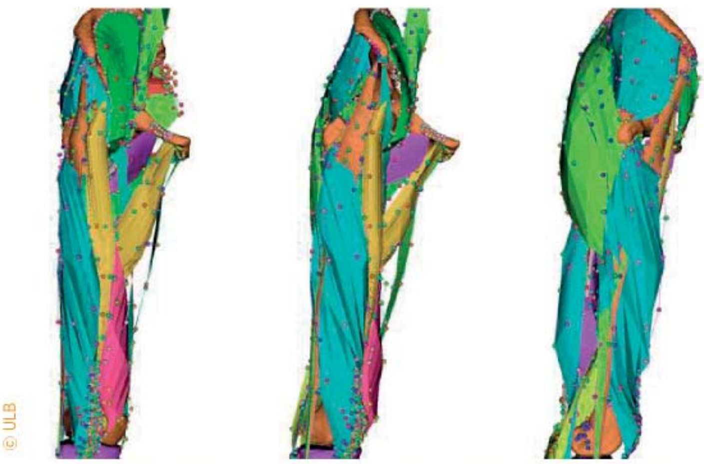

Figure 2. Right thigh muscle fibres and surfaces reconstructed by stereophotogrammetry

Musculoskeletal data collected from ULB past projects (e.g. VAKHUM and LHDL) were extended during DHErgo project by accurate full body soft tissue reconstruction, kinematical data collection for lower limb (e.g. daily motion and pedal clutching) and upper body (e.g. shoulder complex rhythm evaluation).

These data were also reconstructed by ULB to obtain anatomically correct joint motion behavior for muscle force evaluation, taking into account electromyography of the selected muscles.

Bone and soft tissue (muscles, ligaments) 3D morphology reconstruction, including extraction of muscle and tendon fibre topology and attachments, contains 3D reconstruction of dissected soft tissues as an alternative to high resolution MRI that shows some limitations when the whole specimen body has to be scanned.

ULB proposed a method using stereophotogrammetry on the basis of digital cameras allowing soft tissue data collection and maintaining anatomically-correct results. Prior to dissection, a specimen were fully CT-scanned to obtain bone 3D models. During specimen dissection, pins with colored heads (CHs) were inserted in muscles and ligaments to characterize muscle and ligament fibre path, musculo-tendinous junctions, origins and insertions (Figure 2). CHs data registration to the 3D bone models occurred using technical frames including reflective markers and aluminium balls inserted into the bones for better accuracy. Once registered, CHs information was reconstructed in 3D together with the bone models (Figure 3). Muscle and tendon fiber length and pennation angles were evaluated after piece-wise linear approximation of the reconstructed points. The method has been applied on an entire human body.

by V. Sholukha and S. Van Sint Jan [ULB]

Figure 3. Right shank muscles (thick lines) and tendon fibers visualization

EVALUATION OF THE SHOULDER RHYTHM MECHANISM BY QUADRIC MULTIPLE REGRESSION

The human shoulder complex allows an important spatial displacement of the underlying bone segments thanks to the sequence of three intermediate joints connecting the humerus to the thorax. Due to anatomic constraints, their motions are coupled.

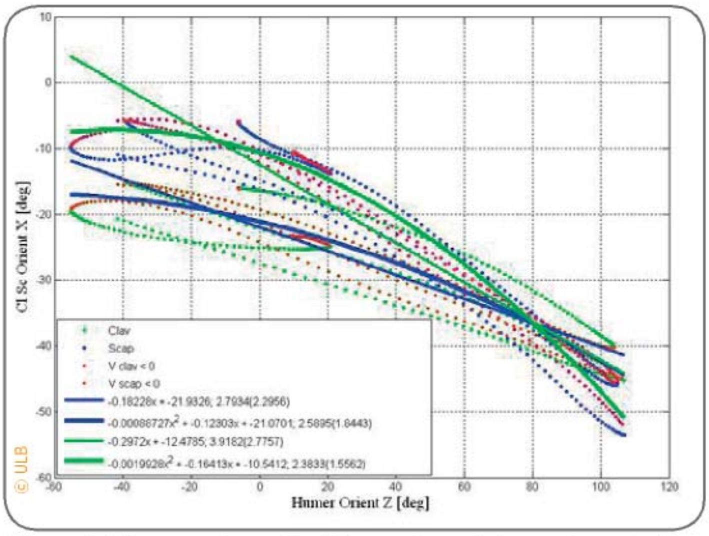

Figure 4. Linear and quadric fitting polynomial equations (and residuals) of the clavicle (Cl) and scapula (Sc) elevation (vertical axis: Cl Sc Orient) versus humerus flexion/extension (horizontal axis: Humer Orient Z)

The contribution of the scapular displacements, linked to the clavicle behavior, within the overall arm elevation follows a general pattern in which scapular motion is responsible for approximately one third of the total arm elevation. The natural shoulder motion pattern (shoulder rhythm) is therefore respected when reconstructing and simulating human arm motion.

The main challenge of the underlying research was to find the mechanical relationships between the humerus position and orientation on the one hand, and the related attitude of the scapula and clavicle at the same moment of time at the other hand. This answers a practical problem of in-vivo motion analysis. Indeed, if data related to the humerus instantaneous spatial position is relatively easy to obtain, the same information is more difficult to collect for the clavicle and the scapula. Furthermore, a unique and straightforward mechanism like in the knee or the ankle joint is not possible, e.g. the humeral head shows similar displacement during shoulder elevation or scapula-humeral abduction due to the fact the vertical displacement of the humerus is closely linked to clavicle elevation. An algorithm that aims to estimate the clavicle and scapula pose compared to the humerus instantaneous posture, must first deal with the differentiation between a shoulder elevation due to either a humerus rotation or a translation, to only then combine correspondent fitting curves to evaluate motion prediction by quadric multiple regression.

In a study by ULB , data from three volunteers and two specimens were processed for a total of 51 different motions including abduction-adduction (frontal plane), flexion-extension (sagittal plane) and humeral head vertical ascent-descent. Typical examples of the rhythm components fitting by linear and parabolic polynomial functions are presented in Figure 4 for three repetitions of flexion/extension. Figure 5 presents results of motion reconstruction and application of prediction-correction shoulder rhythm. Analysis of 15 different motions shows a mean accuracy for the clavicle and scapula rhythm reconstruction of 8.5 (SD=6.1) mm and 19.8 (SD=5.2) mm, respectively. Accuracy of the reconstruction allows application of the developed method in ergonomics and daily activity analysis.

by V. Sholukha and S. Van Sint Jan [ULB]

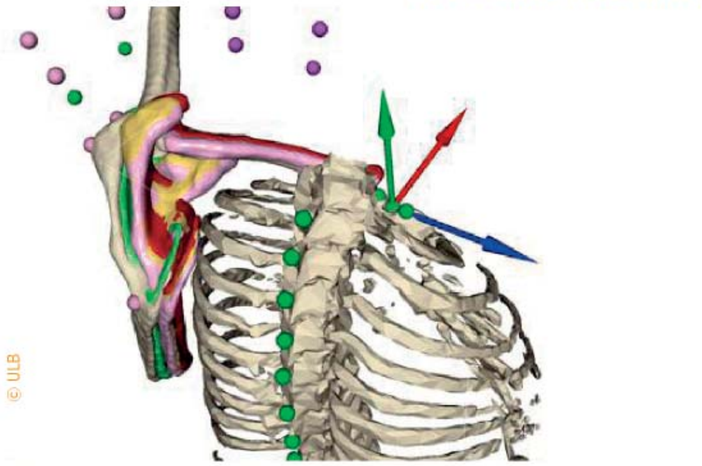

Figure 5. LEFT shoulder flexion-extension motion (models displayed in natural bone color) and examples of shoulder rhythm application (colored bones). Green color corresponds to the shoulder rhythm fitting from real measurements. Red color corresponds to models which orientation and position have been set from the shoulder rhythm fitting. Yellow and pink colors correspond to shoulder rhythm determined from RIGHT shoulder and LEFT shoulder mirrored to the right side

INVERSE KINEMATIC AND INVERSE DYNAMIC MOTION RECONSTRUCTION METHODS

One of the major results produced by CEIT, as expert in dynamic multi-body modeling, is a method for whole body motion reconstruction. This method was implemented in a software tool used for reconstructing the motions recorded during the project experiments.

A novel feature of the proposed method was that a generic human model is automatically scaled to the subject's actual dimensions, based on palpated anatomic landmarks and anthropometric measures.

The motion reconstruction is a two-step process.

First was the kinematic motion reconstruction, which calculates the joint angles as a function of time, using the recorded markers trajectories as input data. This process takes into account joint constraints and subject anthropometric dimensions, thus obtaining a consistent motion.

Once the joint angles were known, the inverse dynamics reconstruction was performed. This second step allowed

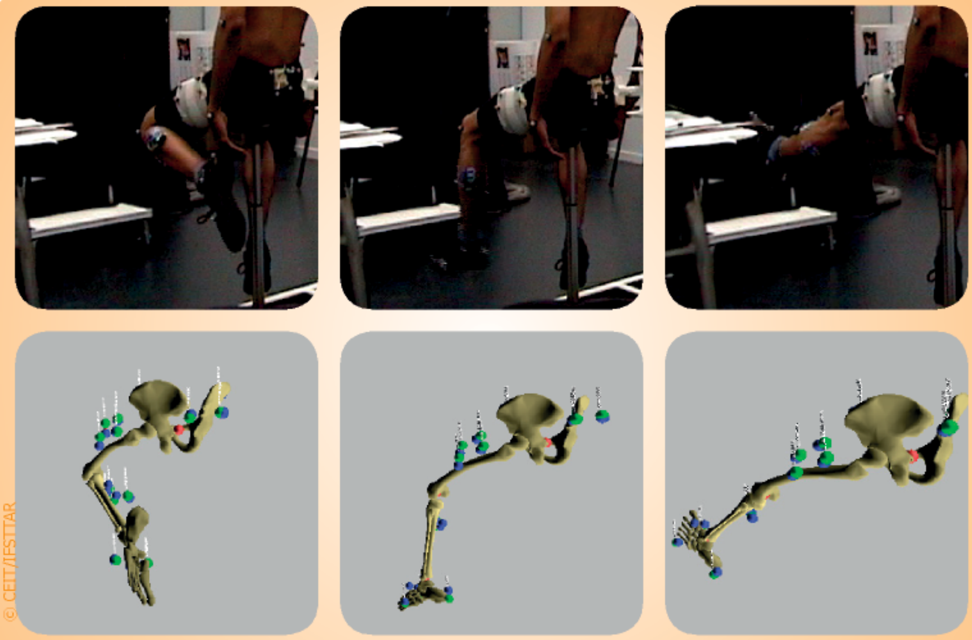

Figure 6. Illustration of a reconstructed lower limb motion using the reconstruction tool provided by CEIT

calculation of the reaction joint forces and torques as well as the motor forces that were needed to produce the recorded motion. These motor forces were equivalent to all the forces applied by the different muscles.
In addition to the recorded motion, the inverse dynamics reconstruction required the external forces applied to the body, that were also provided by the experiments. Figure 6 shows an example of reconstructed motion for the lower limb.

by S. Ausejo, J.T. Celigüeta [CEIT]

Multi-body dynamic motion simulation

Figure 7. A frame of the predicted motion (red) compared to the reference motion (natural). The green spheres represent the targets to be met by the pink sphere during the motion

One of the objectives of the DHErgo project was to predict a task-oriented motion. The motion prediction method developed in DHErgo is dynamic, in order to take into account the dynamic variables in the motion (such as joint torques, external contacts). Moreover, the developed motion prediction method is a hybrid data-and-knowledge based method, relying both on a database of captured motions as reference and on the definition of a motion control law to guide the predicted motion.
The motion prediction is carried out by selecting from the database the motion which most suitably resembles the prediction conditions (subject and environment characteristics) and modifying it to meet the new goals in the motion. The predicted motion is obtained by solving a constrained optimization problem. The constraints to the motion are the fulfillment of the task as well the dynamic equilibrium of the DHM across the motion. Contact models have been employed to estimate the reaction forces of the environment due to its interaction with the DHM.
On the other hand, the objective function seeks to resemble the joint angle profiles of the reference motion and to follow the motion control law defined as the resemblance with the joint power profiles of the reference motion.

The method has been applied to clutch-pedal depression motions (Figure 7), predicting the motion of a subject (which does not match the reference subject) in an environment (which does not match the reference environment), and validating it against actually performed motions in the predicted conditions. The results show that the predicted motion resembles the real motions both in trajectories (Figure 8) and in joint torque profiles (Figure 9).

by I. Pasciuto, S. Ausejo, J.T. Celigüeta [CEIT]

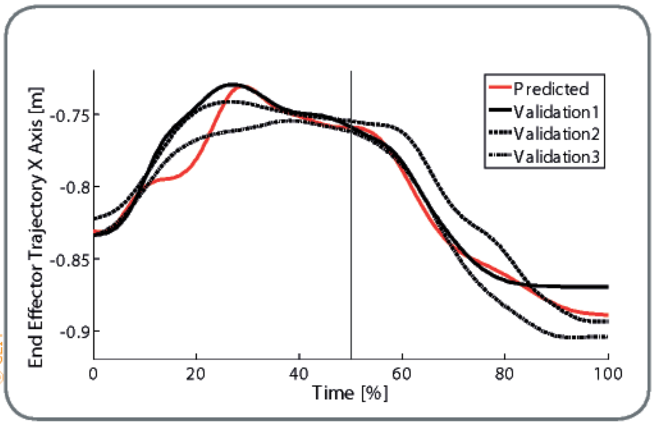

Figure 8. Trajectory of foot along the longitudinal axis of the vehicle

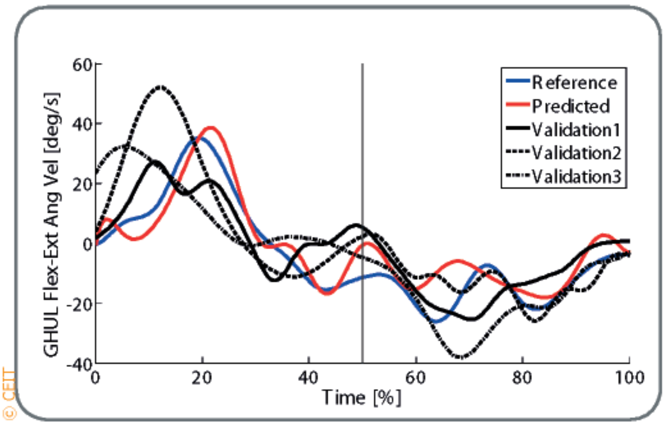

Figure 9. Flexion-extension torque profile in the hip

Human musculo-skeletal motion reconstruction with consideration of the physical contact with a deformable environment

One of DHErgo objectives was to achieve a model for the reproduction of human musculo-skeletal (MS) motion, coupled with an accurate estimation of the contact between the MS model and its environment, by taking physical deformations of model and environment into account. The proposed methodology focused on the interaction between human occupant and driver seat in passenger cars in order to precisely define the seat contact force acting on the back, buttock and thigh segments and to model the compression of soft tissues. The methodology was applied to pedal clutching motions in DHErgo. The MS model and environment are represented and analyzed by the PAM-Comfort™ software, commercialized by ESI Group for the industrial design of car seat structures.

A complete procedure from model scaling to MS motion reconstruction and estimation of the muscle force distribution was developed. Firstly, the MS model needs to be scaled according to a subject anthropometry. The bones are scaled based on anatomical landmark palpation, while the soft tissues are scaled from external dimension measurements like circumference (see Figure 10).

The muscle parameters are adjusted, in particular using their maximum isometric forces.

In a second step, the motion of the scaled MS model is reconstructed from the captured motion performed by a human volunteer. This inverse kinematics motion provided by CEIT is converted into kinematic constraints to reproduce the motion with PAM-Comfort. The calculated human/seat interaction corresponds to a dynamic distributed loading at all skin nodes in contact with the seat. Then, at each selected time frame the muscle force distribution can be calculated with PAM-Muscle by taking into account the external forces (gravity, pedal force and human-seat interaction) and the inertia forces.

This process of MS motion reproduction was applied to clutch pedal operation. After the scaling of the MS model to a specific subject, one of the clutch pedal motions performed by this subject was reproduced with the scaled model through PAM-Comfort in order to obtain the different steps of this motion as well as the estimation of the physical contact with the deformable seat (see Figure 11). Based on the pedal force measured during the experiment and the calculated human-seat interaction, the joint moments as well as the muscle force distribution were calculated (see Figure 12).

Figure 10: MS model – example of external measurements used for scaling

The different experimental data measured for this subject were analyzed by ULB. Relationships between muscle activity and expected muscle force could be obtained by taking into account muscle moment arms behavior. For the analyzed range of this pedal clutching motion, mean value of the moment arm is ~0.06 m. By this value maximum agonist force values are expected about ~500 N for the group of Rectus Femoris and Vastus Intermedialis as well as for Vastus Lateralis and about ~300 N for Vastus Medialis. The maximum calculated forces of the three main muscles acting in knee extension are in agreement with the expected values defined by this analysis. While Vastus Lateralis and Vastus Medialis present a similar behaviour along the motion, Rectus Femoris + Vastus Intermedialis group is more activated at the beginning and the end of the motion. This can be explained by a high contribution of the hip joint at these stages and by the fact the Rectus Femoris muscle is bi-articular, acting on the hip as one of its main flexor. The correlation with the knee extension moment is better for Vastus Lateralis and Vastus Medialis than for the group of Rectus Femoris and Vastus Intermedialis. In fact, Vastus Lateralis and Vastus Medialis act on the knee only and are its main extensors.

by M. Beaugonin [ESI]

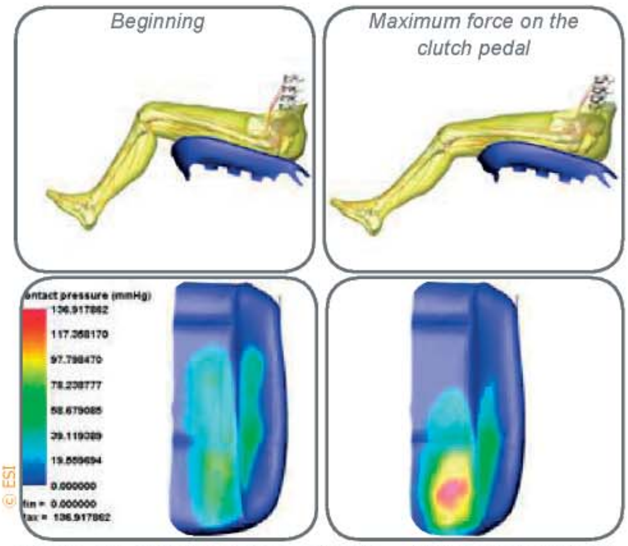

Figure 11: Clutch pedal operation – MS motion with human-seat interaction

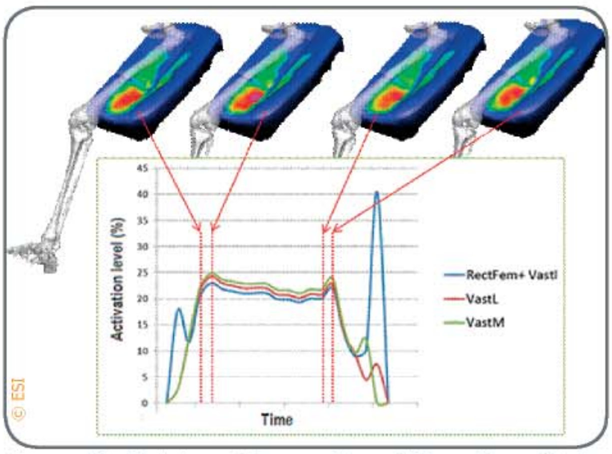

Figure 12: Clutch pedal operation - MS motion with human-seat interaction: joint moments and main knee extensors contribution over time

Motion related discomfort assessment and application to three case studies

The evaluation of motion-related discomfort is one of the critical issues for digital human modelling. Existing ergonomic assessment methods were initially developed for the observation of working postures in the industry. They can be helpful in detecting the main risk factors at a workplace but can hardly be used for ergonomic evaluation of a product such as a vehicle. In DHErgo, an integrated approach for modelling both motion and discomfort has been adopted, based on the hypothesis that a better comfort can be obtained when people can make the appropriate adjustments by themselves. These less constrained motions can then be used as reference data for comparing a proposed solution. This approach, illustrated in Figure 13, was investigated through three case studies which were performed at IFSTTAR with the active support of the three car manufacturers involved in the project:

- A lower limb task: clutch pedal operation
- An upper limb task: handbrake operation
- A whole body task: car ingress/egress

For each case study, the main critical design parameters that may affect the discomfort perception were identified and studied in an experiment with voluntary subjects and a well -planned experimental design. To manipulate the independent variables and to measure the dependent responses, a multi-adjustable experimental mock-up was used, with the necessary adjustments allowing the participants to easily choose their preferred car configuration. An optoelectronic motion capture system was also used to measure the trajectories of the markers attached to the body surface. Meanwhile, external contact forces were measured using force sensors. With these inputs and an individualized DHM, the movements were reconstructed using inverse kinematics and inverse dynamics procedures to access joint angles and torques during motions.

Then the basic idea of our approach is to compare the imposed and less constrained movements in order to identify relevant biomechanical parameters for defining objective discomfort indicators. In the case study of automotive clutching task, four indicators were defined and succeeded in differentiating the tested configurations in agreement with experimental observations.

by R. Pannetier [Renault/Ifsttar] and X. Wang [Ifsttar]

Different steps for identifying motion related discomfort criterion

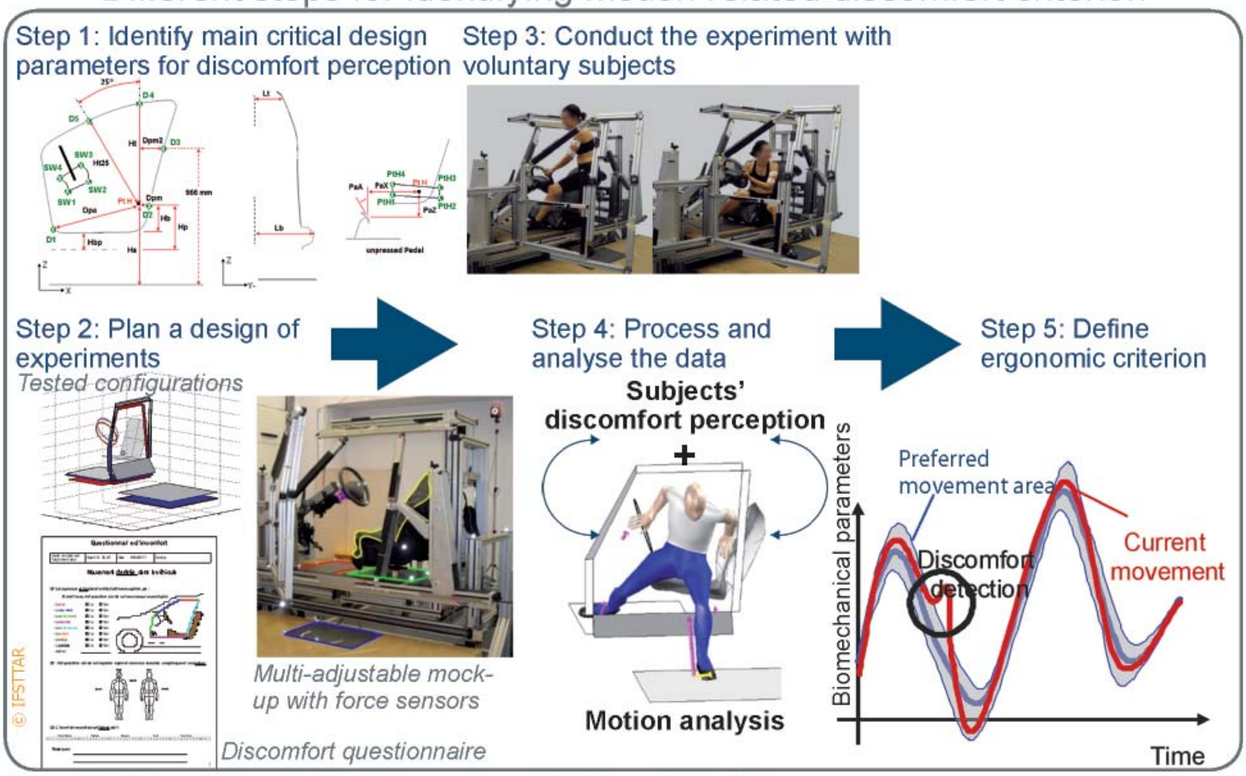

Figure 13: Different steps for identifying motion-related discomfort criterion

Pedal clutching   Handbrake tightening   Ingress/egress

Figure 14 Three case studies performed at IFSTTAR. For each case study, 10 young and 10 older males and females participated in the data collection.

DHErgo demonstrator and design orientated solutions using a digital human simulation tool

The design and implementation of the project demonstrator was driven by two main objectives. First the simulation tools, which are generated in the various research fields of the project, are integrated into a common software platform. On the one hand a DMU (Digital Mock-Up) environment is established to simulate the design in a virtual way, and on the other hand, kinematic, dynamic and muscular motion and discomfort simulation tools are integrated into this environment based on the existing human models RAMSIS and PAM Comfort (Figure 15).

The second main objective is the demonstration of the feasibility of using the tools in design applications. In this context, several design questions have been collected at the beginning of the project.
One of the main questions concerns the investigation of critical product users for a specific design.
These users cause the design to lose against a given benchmark and hence to have to be analysed by designers in a detailed way. This analysis is supported by the demonstrator through a critical manikin identification feature (Figure 16).
The designer specifies a design evaluation score or rating coming from guidelines or a reference vehicle design and the demonstrator provides the percentage of the population below the benchmark and the corresponding virtual manikins representing this population segment. The detailed investigation of the human-design interaction of these manikins will reveal information to improve the design.
The second main design question deals with the identification of optimal designs by comparing design alternatives.
This task is supported by the demonstrator through a design comparison and optimization feature (Figure 17).
The designer specifies a population percentage for which the design should fit properly and the demonstrator provides the corresponding benchmark scores of different design alternatives, in particular the design with the optimal score. This analysis helps the designer find optimal designs with regard to objective criteria and the target user population. Both features are implemented into the design solution architecture and design developed in various work packages and displayed in Figure 17.

by Hans-Joachim Wirching [Human Solutions]

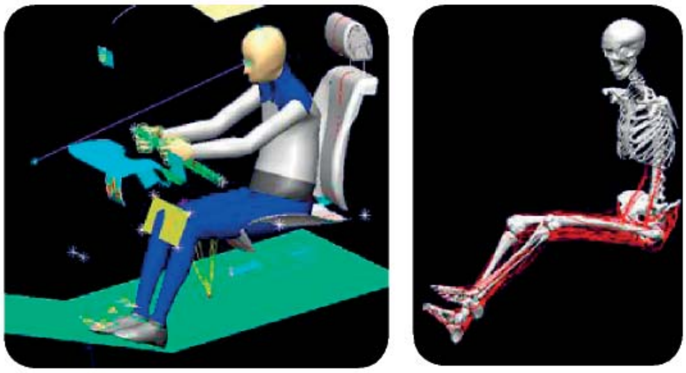

Figure 15 Kinematic, dynamic and muscular simulation tools on RAMSIS (left) and PAM Comfort (right)

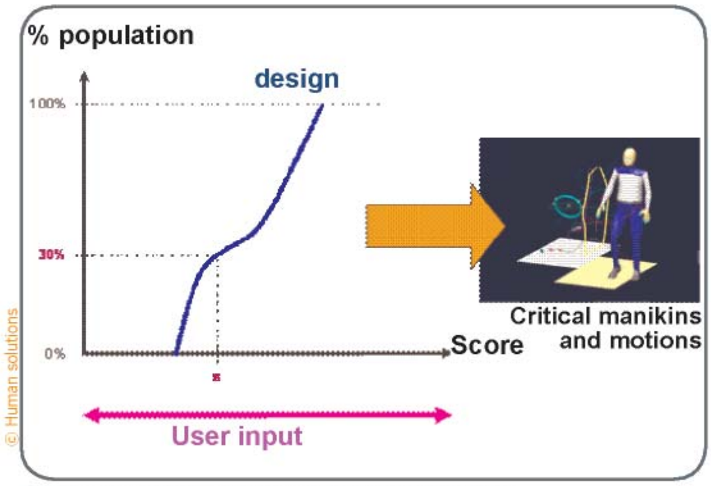

Figure 16 Critical manikin identification feature

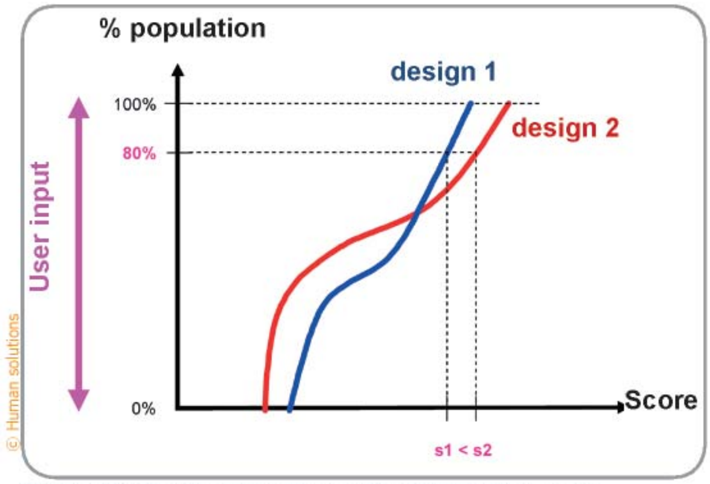

Figure 17 Design comparison and optimization feature

DHErgo Benefits for the End Users

In the field of Ergonomics, digital Humans are well established within the automotive product development process. Of course the demands are growing with their successful application. At the beginning of the DHErgo project, end user requirements were defined by Renault, PCA and BMW. These can be structured as demands concerning the definition of manikins, digital mockup, motion simulation and evaluation of functionalities. Comparing these end user requirements with the project results by taking the experience with the pre-released Demonstrator and the forecast for the final Demonstrator into account, it can be stated that most of the requirements are or will be achieved.

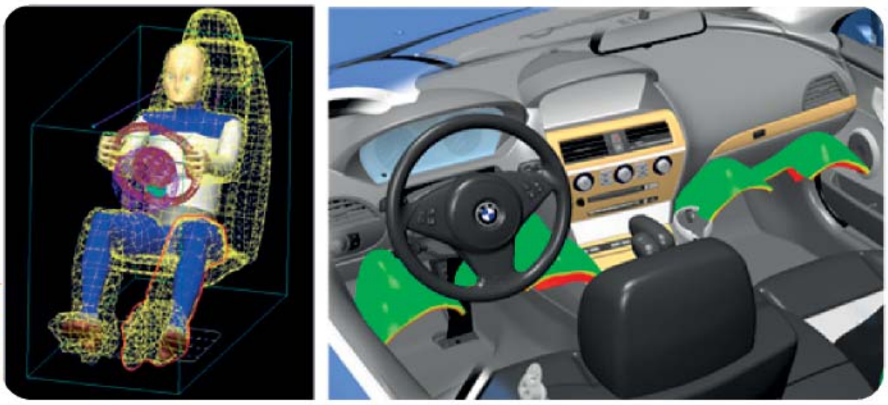

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Figure 18. Improvement of user demands regarding the clearance space (right side) defined with the tool "motion silhouette" by the DHErgo Demonstrator (left side).

Within the DHErgo Demonstrator it is now possible to create manikins based on experimentally measured anatomical landmarks. Besides other improvements - e.g. the calculation of joint centers - this approach is very welcome because it simplifies the experimental workflow and increases the reliability of all calculated parameters based on anatomical issues. Of course, the definition of manikins by the means of an anthropometric database is also offered within the DHErgo Demonstrator, and in the final version, the database will include parameters for anthropometrics, range of motion (RoM), strength and age. Furthermore, with this database the generation of a user -defined population will be possible. This function is very appreciated since a specific customer group containing a huge number of different manikins can be created and used for the design evaluation instead of only some extreme percentiles.

The product development process of vehicles mainly takes places in virtual reality. Hence the integration of an interface for importing CAD data into the DHErgo Demonstrator was indispensable. The disadvantage of this approach is that the importing process has to be repeated by the end user every time the vehicle geometry changes. As a solution, the DHErgo Demonstrator offers another tool which is called "Parametric Scene". The end user needs to define relevant dimensions for the task to be evaluated, e.g. pedal position and travel length. Once these dimensions are defined, the virtual mockup can be adjusted easily by just changing the values for the relevant dimensions and this makes the work with the tool quite efficient.

A main topic of the DHErgo project is the dynamic motion simulation including different motion strategies. Since the Demonstrator currently provided to the end users only includes the movement of the clutch pedal operation and some improvements have yet to be implemented, the accuracy and reliability of this functionality is unknown. But it is obvious that the motion simulation leads to a better implementation of user demands, e.g. regarding the clearance between the manikin and the geometry done with a 3D motion silhouette (Figure 18) or taking pedal resistance forces and their effect on muscular activity into account.

by Raphael Bichler [BMW Group]

Find out more on facts and activities of DHErgo project, visit our website on
www.dhergo.org

OUR PROJECT IN BRIEF

2008

Currently available digital human models used for ergonomic design of products are still far from the designer's expectations. They must be able not only to have a realistic visual representation of human body and movement but also to evaluate the muscular efforts associated with a task for a better understanding of human performance and perceived discomfort.

The project mainly focuses on the following scientific issues:

- Development of multi-body dynamic motion reconstruction methods in order to estimate joint motion and joint forces
- Development of a hybrid optimisation/data based complex motion simulation method
- Development of a generic motion-based biomechanical discomfort criterion
- The effects of aging on movement and perceived discomfort

PROJECT COORDINATION

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KEY DATA

2009

Acronym: DHErgo
Name of proposal: Digital Humans for Ergonomic Design of Products
Grant Agreement N°: 218525
Instrument: Collaborative Project (Small of medium-scale focused research project)

10 Partners

Academic: CEIT (ES), IFSTTAR (FR), TUM (DE), ULB (BE)
Software editors: ESI (FR), Human Solution (DE)
End Users: BMW (DE), PCSA (FR), Renault (FR)

Budget

Total cost: 4 903 504 €
EU contribution: 3 572 227€
Call: FP7-SST-2007-RTD-1
Starting date: 01/09/2008
Ending date: 31/08/2011

Duration: 36 months
Objective: Safety & Security
Research domain: Ergonomics & Biomechanics
Website: http://www.dhergo.org

MAIN DISSEMINATION ACTIVITIES

DHM2011, June 2011, Lyon - France.
140 participants from 13 different countries
Several DHErgo presentations including:
1 AWARD: Ilaria Pasciuto from CEIT and Tecnun (University of Navarra) was awarded for her presentation

2010

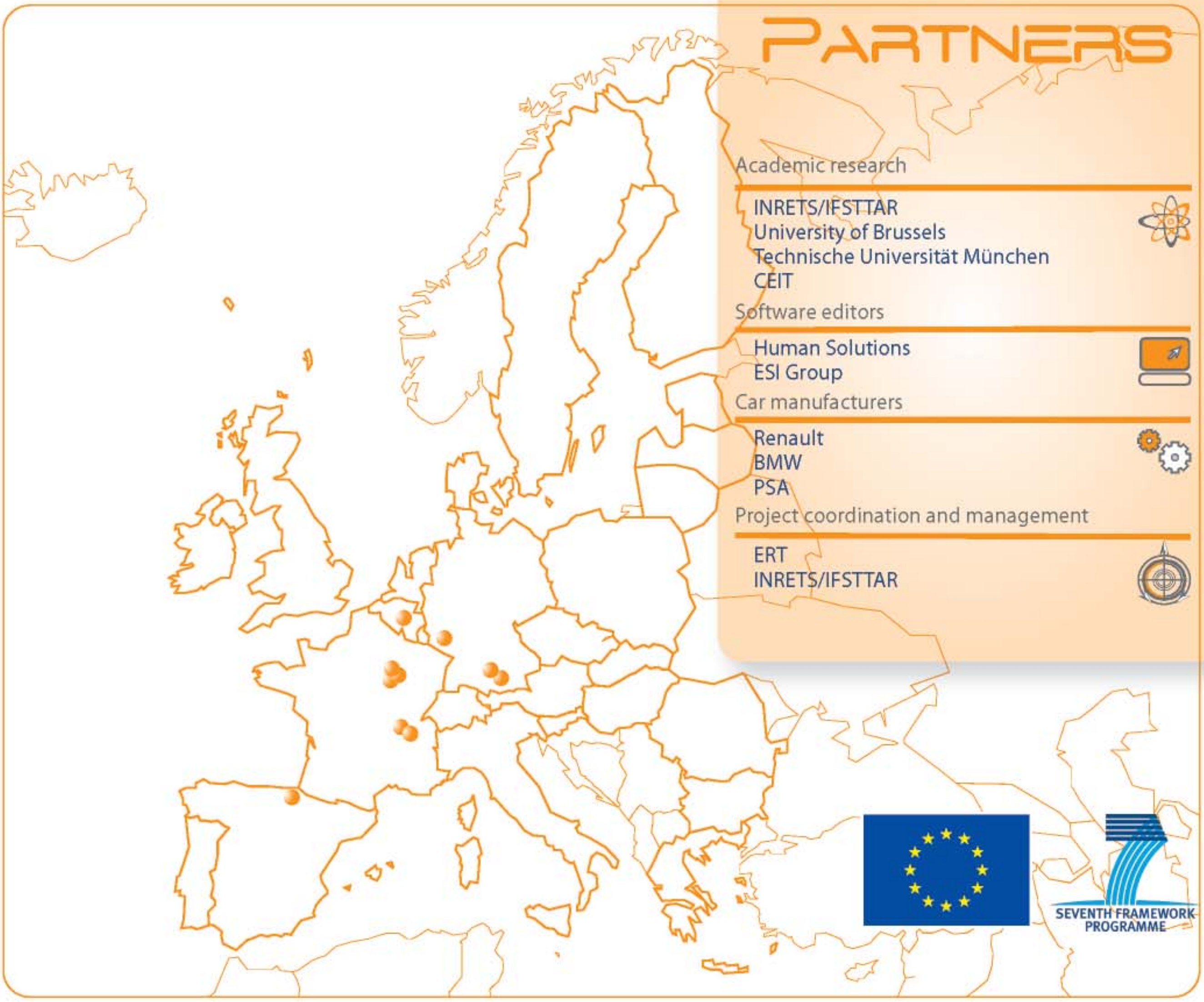
- 'A hybrid dynamic motion prediction method with collision detection'

AND ALSO...

- Dozens of publications and articles, 14 conferences, 11 consortium meetings, etc.

A number of printed copies of certain DHErgo publications are available on the Project website: http://www.dhergo.org

2011



Partners

Academic research

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- University of Brussels
- Technische Universität München
- CEIT

Software editors

- Human Solutions
- ESI Group

Car manufacturers

- Renault
- BMW
- PSA

Project coordination and management

- ERT
- INRETS/IFSTTAR

SEVENTH FRAMEWORK PROGRAMME

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