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VIRTUAL HUMAN MODELS FOR INDUSTRY

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Abstract: *The paper aims towards the development of virtual biomechanical human models as a support for design and optimization of not only passive and active safety systems used in various modes of transport. The simple usually multi-body system based models as well as the detailed finite element models are mentioned and a special hybrid model that benefit of both approaches is described. Scaling and personalisation is described as an important issue making the virtual human body models advantageous comparing to physical dummies. Finally special group of the active models including muscle tone and other activities as a challenge for future is presented.*

Keywords: *transport, biomechanics, virtual, model, safety*

1. INTRODUCTION

The traffic accidents cause one of the highest numbers of severe injuries. The numbers of deaths or fatally injured citizens prove that the traffic accidents and their consequences are still a serious problem to be solved. The statistics show the decreasing number of accidents in the past years [9], but the decrease is still necessary to be speeded up regarding also the socioeconomic aspects of the problem [3]. A lot of effort is devoted to both passive and active safety systems development. The transportation standards usually define safety requirements by regulations (e.g. ECE-R94, 96/79/EC and ECE-R95, 96/27/EC in Europe) with specific dummies (e.g. Hybrid III 50% and Eurosid II). The dummies include sensors for monitoring accelerations, loads and other signals and each dummy is developed for a specific scenario but there are limitations of these dummies like only specific body size (5%, 50% and 95%) or calibration just for a specific test. Taking into account that the consequence of the traffic accident is highly influenced by the stature of the body, the virtual human body models start to play significant role regarding the possibility of scaling and personalisation. Virtual human body models also become powerful tool for supporting development of human-friendly and safe vehicles by the numerical approach using computer simulation. Using virtual prototyping approach, a lot of structural designs, technical solutions and impact scenarios might be analysed before getting into physical prototyping. The virtual human models contribute not only to the safety systems development but also to the virtual prototyping as a complex development approach to reduce the production process costs and to protect the living environment.

2. VIRTUAL HUMAN MODELS

Contemporary mathematical methods enable extensive analyses of technical problems by numerical approach. Many industry fields apply virtual prototyping towards new product development including virtual testing, where the whole process is modelled by computer software. Regarding biomechanics, where human body modelling belongs, there open promising possibilities not only in the field of safety system virtual prototyping but also in the field of virtual certification of new vehicles. Other fields like ergonomy, clinical applications or forensic applications are due. All the above mentioned fields consider specific and biofidelic human body models to be developed and validated [1]. Based on the injury description implemented in the virtual human models, they might predict the human body response and injuries just by cost of computational time. Whilst some applications can be based on simple human body models, other applications might demand detailed ones. The complexity also plays an important role in the human body model development because it influences directly the quality of results, that the model is able provide, and also the development and later on computational costs of the model. Let us describe step by step several approaches to human body modelling and its use in the industrial applications.

2.1. Full 3D or just single dimension?

This question seems to be absurd, but it is shown in [2] that a simple 1D driver model can be fully used for development of an appropriate vehicle seat and for estimating the forces and motions being transmitted within the body under specific vibration. Furthermore, the model can predict the driver vibration exposure level and the ability of the seat to eliminate negative vibrations.

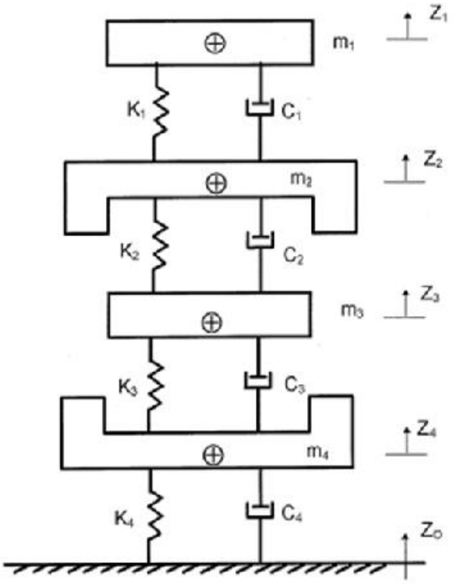

Figure 1: 1D driver model designed in [2]

Figure 1 shows the scheme of such 1D driver model. Increasing the number of dimensions, 2D models can be also very useful, because 2D human body kinematics and simple dynamical response caused by external impact can be analysed [5].

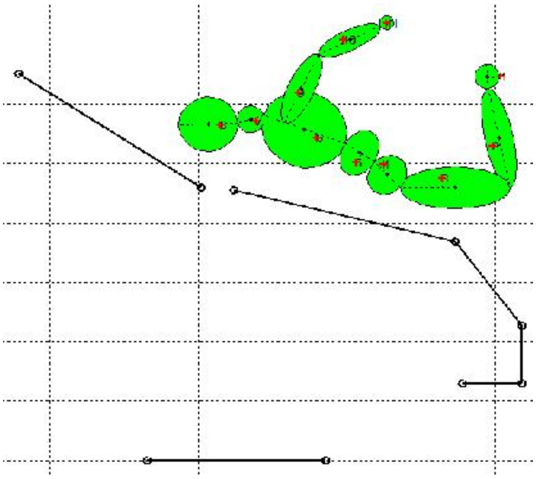

Figure 2: 2D pedestrian model under vehicle impact loading [5]

Figure 2 shows the developed 2D pedestrian model. Both models mentioned above are based on multi-body approach. On the contrary to the dynamical models implemented in the time domain, the model for vibration analysis is investigated in the frequency domain. Multi-body approach benefits from simple mathematical formulations implying fast computational runs. The only deformable elements are the joints connecting neighbouring rigid bodies in the open-tree multi-body system. The correct biofidelic response of such simple models is tuned using nonlinear springs and dampers in the joints and also in the contact interfaces that play a crucial role for the impact loading.

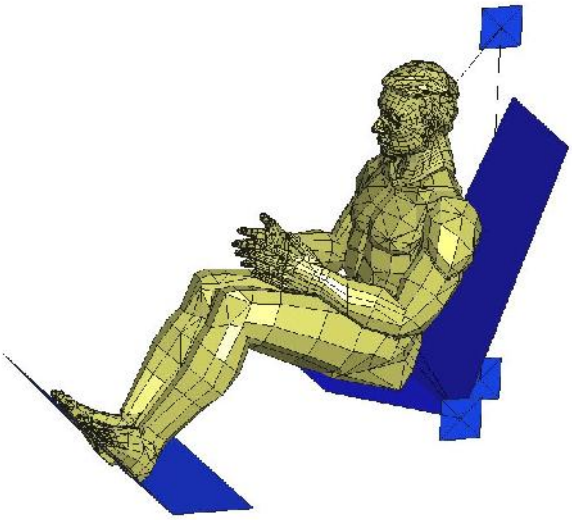

Figure 3: ROBBY articulated rigid body model [4]

The phenomena described in many industrial fields are usually fully spatial and the use of less-dimensional models than three is usually very limited. However in full 3D space a simple approach based on the multi-body system can be also advantageously exploited. Such models, often called ARB (articulated rigid body), have been already developed in various computational environments, e.g. PAM-CRASH or MADYMO. Using further features of the specialised software, like advanced seat materials or airbag and belt models, those models can predict basic biomechanical response concerning accelerations or external and internal loads. Based on the injury criteria implemented, the models are the first and fast step towards safety system performance analysis. The significant advantage of ARB model is their simple positioning and setting tests configurations.

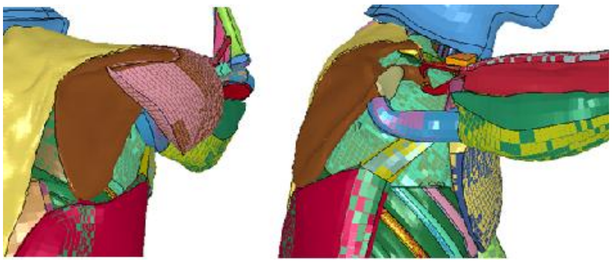

Figure 4: Detailed GHBMC thorax model (courtesy of GHBMC)

2.2. Deformable models

For really detailed analysis, it is possible to use already developed virtual human models based on finite element (FE) method, like GHBM, H-Model, THUMS or JAMA model. The models are usually developed by support of European projects (FP6 projects HUMOS and APROSYS) or by investment of special consortia focused on the automotive industry (Global Human Body Model Consortium and FP7 project THOMO). Figure 4 shows really detailed FE model of human thorax developed by the Global Human Body Model Consortium (GHBMC) via the Thorax Center of Expertise at the University of Virginia (COE) further upgraded and validated by the THOMO project. Further important issue making the human body models preferential before physical dummies is the possibility to be scaled or personalised. Whilst the scaling considers that the original 50% model can be scaled into 5% and 95% specimen, the personalisation means that the model can reflect particular human subject based on defined external body landmarks. The personalisation also concerns cortical rib bone thickness as an important factor influencing the model behaviour.

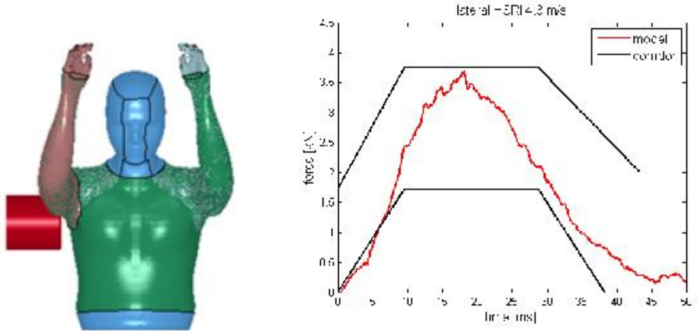

Figure 5: Validation of the GHBMC model in lateral impact:
test setup (left) and comparison to experimental corridors (right)

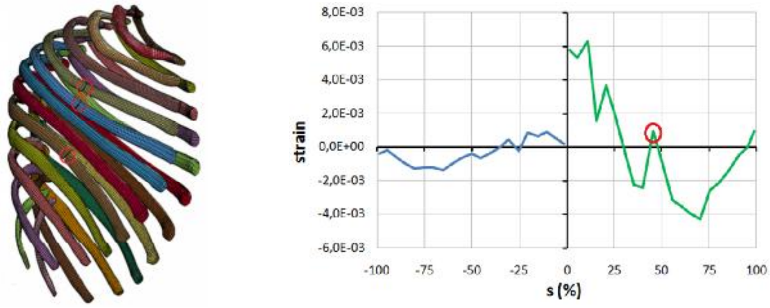

Figure 6: Performance of the personalised GHBMC model in oblique impact:
rib fractures (left) and the 4th rib costal ring strain profile (right)

The advantage of the detailed FE model consists in really detailed analysis of biomechanical behaviour. Besides the basic dynamical data like acceleration and forces, the models can directly predict injuries, e.g. rib strain distribution, rib fractures or tissue ruptures. Whilst Figure 5 shows the test setup and validation for lateral impact, Figure 6 shows rib fractures and rib strain profile in oblique impact.

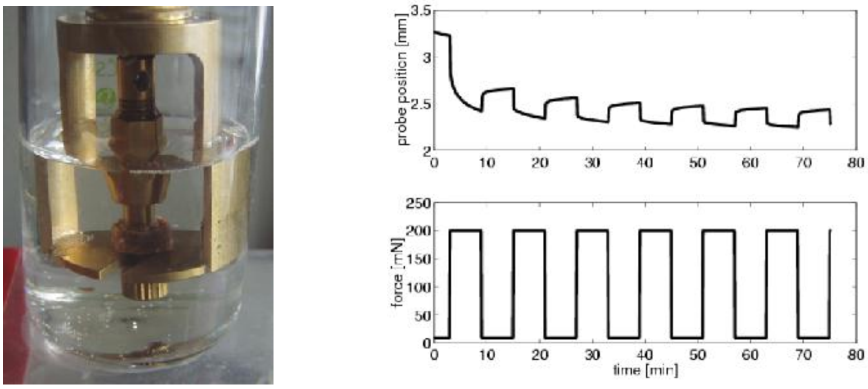

Figure 7: Viscoelastic treatment of a liver specimen:cylindrical liver tissue specimen between the holders of
Perkin-Elmer DMA 7e measuring apparatus (left) and viscoelastic response (right) [8]

The problem of implementation of such models is their complexity, i.e. positioning and setting test configuration is very difficult. Last but not least the time consumption for the calculation is considerably higher comparing to the ARB models. The development of the model is also really challenging because not only joints but also deformable segments composed of advanced material models must be well designed and validated. Material data measurement and cadaver testing in order to validate the models is an issue here. Special treatment including all ethical issues is highly considered. Figure 7 shows an example of tissue measurement.

2.3. Hybrid models

Whilst the multi-body based models bring only limited analysis for a really fast computational time, the detailed FE model can simulate the process as it is in physiological reality, i.e. fracturing ribs or rupturing soft tissues, but the cost relating to the model development and computational time consumption is considerably higher. The so called hybrid models benefit from both approaches combining them in appropriate manner. The basic structure of the model is the multi-body structure that carries deformable segments along its surface. The deformable segments are divided into sub-segments that are proposed in order to perform the correct deformation of the whole segment caused by external loading. The sub-segments are fixed to the basic multi-body structure by nonlinear springs and dampers. An example of such model is model VIRTHUMAN being currently developed by support of the Technology Agency of the Czech Republic. The model is designed as a multi-purpose model to be used in various modes of transport (road, rail and air). As all other models, the model is validated in various impact scenarios, for particular segments and also for the full-body model.

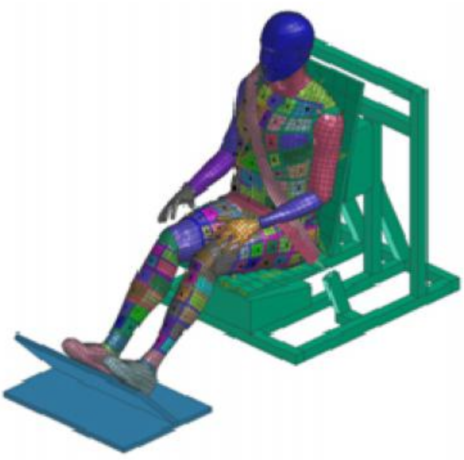

Figure 8: Model VIRTHUMAN

Figure 8 shows the 50% hybrid model VIRTHUMAN in the sled test environment. The advantage of the hybrid approach is that the model, although deformable, is simply fully articulated and the calculation time is very short. In other words, the model can be comfortably articulated and the value of the results is high.

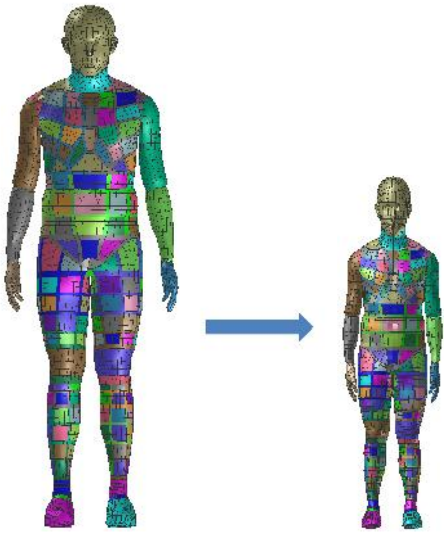

Figure 9: Scaling process of the VIRTHUMAN model into 6 years old child model

The developed model is also scalable towards the population. The scaling algorithm does not take particular human subject landmarks into account in order to develop his or her direct reflection but it accommodates the general statistical population data like body height, body mass, particular segments dimensions and their percentiles. Thanks to this algorithm, the model can be scaled into various groups of people (see a scaled child model in Figure 9).

3. FUTURE CHALLENGES

The description of the human body models above concerned only passive models, i.e. the models do not perform any activity and they are passively reacting on the impact just by the validated response included in the sophisticated parameters inside their material models. It is proved that for high speed impacts, which traffic accidents usually are, the activity of the human body is a negligible issue regarding the high external forces or the short duration (milliseconds) of the phenomenon – the body is not able to react. In many scenarios, where human comes into contact with external environment, the activity of the body must be considered. Particularly in pre-crash situations, the occupant's muscle tonus, bracing, and muscle reflexes have a large impact on the occupant kinematics. Such models further deal with other applications in ergonomy, where the physiological muscle tone plays also an important role, but it shall be considered also in safety for so called low-g impacts. The low-g impacts like usually vehicle rear impacts at traffic signs or low velocity impacts cause generally no fatal injuries or deaths, but the consequence injuries like neck pain implying work disability bring high socioeconomic costs. These aspects of the transport are impossible to be described by physical dummies at all. Current human body models have limited abilities to model the active human response that determines such effects, although there are some attempts to use active control of the human segments like neck, spine or arms (e.g. MADYMO). Several projects investing into this issue are currently investigated (e.g. Active Human Body Model project by Chalmers University wants to incorporate the active muscle response to a FE human full-body model in order to predict pre-crash kinematics and restraint interactions as well as injury due to crash loading).

4. CONCLUSION

The paper summarized up-to-date knowledge in development of virtual human body models. Cheap multi-body based models performing in fast calculation times but with very limited application fields were presented as well as detailed finite element models that might predict very detailed level of behaviour including real fractures or ruptures occurring in the human body after external impact. Multi-purpose hybrid model benefiting of both approaches based on deformable segments linked together as a multi-body system is further described with the advantage of full articulation and very short calculation time. For the particular types of model, the scaling and personalisation is described as an important issue making the virtual human body models advantageous comparing to physical dummies. Finally special group of the active models including muscle tone and other activities is presented.

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