ADVANCED HUMAN BODY MODELLING FOR HUMAN CENTRED DESIGN: TRENDS AND SOLUTIONS

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The research for human body modelling for application in the shape design of artefacts for physical interaction is calling for technologies of increasing power. Three main aspects for research were recognized: geometric modelling, the modelling of physical-physiological behaviour, and the implementation in the design of the shape of the contact area. First research in this field is mentioned.

Introduction

The massive amount of publications on modelling human bodies or body parts shows a strong need for human body models. Most of the reported models are conventional ones supporting for instance ergonomics, industrial design, medicine and animation (Dirken, 1997). Each field puts its specific requirements for the models. In the field of physical ergonomics efforts were made to develop human body models for capturing complex relationships between external loads and physiological effects. It has given impetus to the research in advanced human body modelling, which tries to capture complex body characteristics, such as assemblies of tissues, uncertainty of a shapes (Carter and Heath, 1990), effects of dynamic loads on stress and deformation (Levine et al., 1990; Goossens, 1994), the relationships with the human body type (Kernozek et al., 2000), structural changes in person-artefact interaction, biophysical changes of body parts and tissues (Dahlin et al., 1986), and complex constitutive behaviour (Malinauskas et al., 1989; Zhang et al., 1997). Although several authors expressed the wish to have all-embracing body models covering all these kinds of characteristics, due to the complexity of problems, lack of data, and processing power they had to apply and accept certain simplifications (Hubbard et al., 1993).

What has been achieved related to these characteristics? Only a few characteristics have been seriously considered for investigation and incorporation in conventional body models, for instance geometric aspects (Zajac et al., 1986; Zhu et al., 1998) and the constitutive behaviour (Vannah and Childress, 1996) of the anatomical tissues. Currently the nominal shape of the tissues can be reproduced by geometric models (Ramirez, 1992; Todd and Wang, 1996), but generic rules are still missing. Models to simulate the constitutive behaviour are still based on purely elastic behaviour that have been developed for rubber materials (Moes, 2002), although there are publications on multi-phase modelling (Oomens et al., 1987). It is also a problem that conventional body models show a lack of compatibility due to differences in dimensionality, geometric simplifications, and ability to handle large deformations. The majority of these models were based on the finite elements technology, see, for instance, (Todd et al., 1990; Chen and Zeltzer, 1992; Bidar et al., 2000; Lemos et al., 2001; Moes and Horváth, 2002).

Trends

Due to the ever increasing achievements of hardware and software a trend is recognized to develop support for human centred design with knowledge intensive computational human body models. If a sufficient amount of knowledge seems to exist regarding physiological processes, functional anatomy, biomechanics, biophysics, continuum mechanics and finite elements methods, why does the development of advanced human body models then lag behind? As far as we can see, the main barriers for the knowledge synthesis are (i) the incompatibility of available knowledge and model requirements, (ii) the inconsistency of the developed constitutive models, (iii) the lack of generic methods to handle the variability of humans and circumstances of using artefacts. Based on our literature survey we came to the conclusion that the development of an advanced human body model needs the following fields of investigation: (i) modelling the geometry and the assembly, (ii) modelling the mechanical and physiological behaviour of tissues under external load, and (iii) implementation of the assembled model in the shape design process.

Geometry

The geometry of a human body model can be developed in different levels of simplification, figure 1. The ideal solution is an assembly of (i) the micro structures (for instance contractive muscle fibres as active force elements, or blood vessels inside the tissues) into tissues (meso structures), (ii) the tissues and their geometrical relationships into body parts (macro structure), and (iii) the body parts into a complete body (holonic level). In the holonic level different postures can be implemented. Because of the uncertainty and the incompleteness of measured shape data, and the natural anatomical variability of the shape, the tissues must be represented by vague expressions (Moes et al., 2001). The mathematical fundamentals for the assembly and the contact conditions of vaguely defined tissues have been elaborated in (Rusák, 2003).

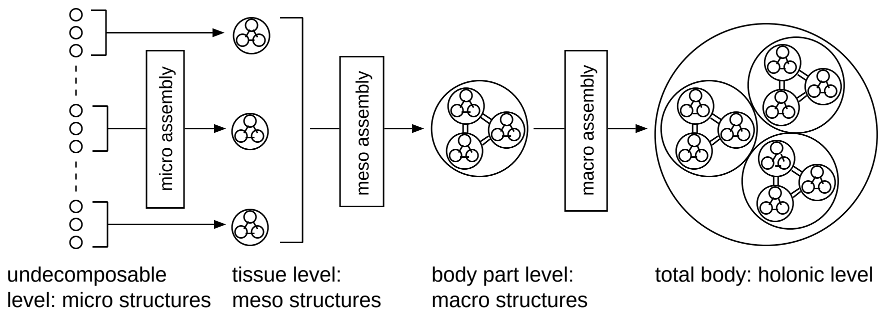

Figure 1. Micro, meso and macro assembly.

To enable the adequate description of the characteristics of the tissues for application in advanced human body models such elaboration requires a specific organization of applied anthropometric, anatomical and physiological research, and the support by descriptive statistics and the vague discrete interval modelling (Rusák, 2003). This needs the knowledge of the unloaded shape and the spatial orientation, and the influence of gravity, muscle activation, passive elongation, and the contact properties of tissues. To enable the generic character of such vague modelling the measured shape must be related to anthropometric quantities (e.g., linear measures of distances circumferences), physiological quantities (e.g., the amount of subcutaneous fat), and the overall characteristics (somatotype, gender) of the individual (Moes et al., 2001). Two additional investigations are needed for the generic model: the validation of the geometric model and the expansion for a wider stratification and application.

Behaviour

Modelling the behaviour of the tissues and the body under load needs a geometric model, the knowledge of the loads, the physiological tissue properties that can be influenced by mechanical loads, and the mechanical characteristics of the tissues.The synthesis of geometry, behaviour and external loads enables the computation of the effects on physiological processes such as the flow of fluids (blood, interstitial fluid). Figure 2 gives a schematic view of this process.

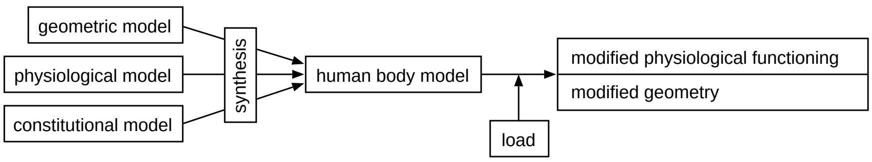

Figure 2. The synthesis of the constituents of the human body model and the modification by loads.

Constitutive modelling

Since the deformation of tissues during artefact usage can be extremely high the constitutive behaviour of tissues must be adequately modelled by highly non-linear formulas. Current elastic models describe the material behaviour unsufficiently. Even the rheologic models, implemented in state of the art FE software, were not developed to simulate the total complexity of the mechanical behaviour of organic tissues. To advance for this level the following investigations seem required: (i) getting insight in the complex material behaviour of tissues under various types of mechanical loads, (ii) the development of adequate constitutive models to represent this complex behaviour, (iii) modelling the kinematic and kinetic behaviour (biomechanics) of the meso and the holonic assemblies to enable the integral mechanical behaviour of the body, (iv) the constructive validation of the models for the tissues or the body in the natural, functional context, (Moes, 2002).

Effects of internal loads on physiological functioning

The assessment of the relationships between internal loads and the physiological effects of these loads requires the investigations of (i) the effects of the hydraulic pressure on physiological processes such as the flow of the interstitial fluid, (ii) the effect of forces and pressures on the transportation systems, such as blood vessels, which includes the forces exerted by the smooth muscles of the vessel walls and the pressure exerted by the surrounding tissues, (iii) the effect of pressure on the blood supply of tissues, and (iv) possible tissue damage from mechanical load.

Implementation in the design process

Assuming that a human body model is build and validated, then it must be applied in the shape design process. Figure 3 shows the implementation modelled as a optimization process. Based on posture and personal characteristics a body model is generated (Moes and Horváth, 2002b). The result of the external load is an internal stress and strain distribution. The effects on the physiological functioning of the tissues is evaluated by the testing for criteria, for which purpose an ergonomics optimization functional must be defined (Moes and Horváth, 2002a). The algorithm for the shape optimization is based on an iterative improvement of the fulfilment to the criteria, see figure 3.

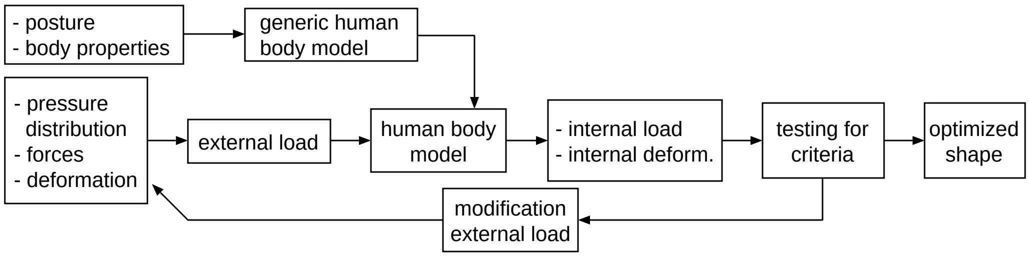

Figure 3. The implementation of the body model in the shape generation process.

Relationships between external measures and internal loads

An important research aspect is to find the relationships of external load and the internal load. This knowledge is of primary importance in e.g., the field of decubitus research and the research of designing prostheses, where the external load can be measured without too much difficulty, but where it has also generally been accepted that the possible tissue damage occurs as a result of processes inside the body (flow of fluids) and not at the body surface (pressure distribution in the contact area). Within the field of sitting research the effects of the pressure exerted by a particular shape of a seat has been expressed in terms of the distribution of internal tissue deformations, compressive and shear stresses, but a systematic, quantified correlation has not yet been found (Moes, 2003).

Conclusions

A need exists for advanced human body modelling. Although much knowledge is available, it is not yet sufficient and consistent for application in such modelling. Research in the fields of geometry, physiology, mechanical modelling and optimization is needed for the further development and the implementation. Currently, basic research has been set up in our department to investigate the fundamentals for possible solutions. The feasibility of certain aspects of the conceptual solution has been demonstrated in several publications, see above. The foreseen perspectives are the development of human body modelling of increasing complexity, validity and applicability, including the physical and eventually the psycho-physical influences on physiological functioning.

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