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MODELLING THE HUMAN BODY FOR ERGONOMIC CAD

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ABSTRACT

A recently completed Brite-Euram (European Community) research project was concerned with life-cycle aspects of car seating with Loughborough University being responsible for driver comfort assessment. This was achieved by road and laboratory trials, with the results to be incorporated within the SAMMIE computer-aided ergonomic design system. Driver comfort is in part determined by seat pressure distributions which lead to deformation of the human flesh and the seat and result in uncertainty in the position of important design locations such as the driver's eyepoint. Accommodation of these effects requires a realistic representation of the human body using surface rather than solid representations. Hence a shadow scanning technique was used to capture human body shape which was processed into the DUCT surface modelling system and via IGES files into SAMMIE. Finite element techniques were then used to predict deformations at the seat/driver interface. Having established an anthropometrically correct representation of body shape, current research is aimed at improving the kinematic and analytic capabilities of the human model by introducing a multi-segment spine that can respond to external and internal loadings. This spine model is intended for use in the evaluation of human working postures (such as car driving) where, although the loadings might be viewed as well within human capabilities, previous studies have shown that back pain or damage might result. The model described is based on an arch representation rather than the pin-jointed rigid link systems which are perhaps more usual, but which have been shown to be deficient in several respects.

KEYWORDS

Ergonomic Design, Human Modelling, Spine Modelling

1. INTRODUCTION

The evaluation of the ergonomic aspects of design by the use of computer-aided design techniques is a well-established methodology and many computer systems are available [l]. SAMMIE, System for Aiding Man-Machine Interaction Evaluation [2] is a long-established and typical example that has been used in a wide variety of applications [3] and forms the basis of the work described here. Human modellers are frequently similar to more general kinematic modellers used for the simulation and evaluation of mechanisms such as industrial robots. Thus the major articulation points of the body are represented by pin-joints constrained to maintain motion within the ranges of human joint extensions. The joints are connected by rigid links as an approximation to the long bones of the body, and these are enfleshed to give a visual representation of human shape. Figure 1 shows a typical example of SAMMIE used in the ergonomic evaluation of a tractor and illustrates the symbolic nature of the flesh representation. Anthropometric control through manipulation of the joint-to-joint dimensions and flesh shape and size is provided so that the model can be made representative of the product user population. The complexity and variability of the human body has dictated that an approximate representation of shape is used (by the use of primitives in a boundary representation solid modelling scheme). This results in a symbolic shape, which although useful for many applications, is inadequate where the human body is in close contact with the product being designed (as in the case of a car seat). A second limitation arises from the complexities of the human skeletal link structure with its many degrees of freedom and the resulting difficulties in driving the model to predict realistic postures. Human models are often limited to twenty or so joints/links with the major area of approximation being in modelling the spine as only one or two links. Again this is adequate for many applications, but is not sufficiently precise elsewhere (such as car driving, difficult postures in assembly or machining, load carrying, etc). A final concern with existing modellers is their relative weakness in assessing loads on the body. This is particularly important for the spinal column as it serves as a major load-carrying member and is susceptible to long-term damage with even relatively light loading. These three limitations form the basis of current research and progress to date is described in this paper.

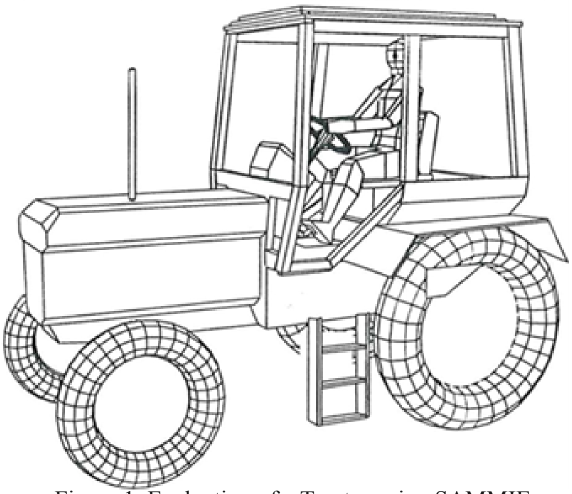


Figure 1. Evaluation of a Tractor using SAMMIE

2. MODELLING OF BODY SHAPE

The variety in human body shape and dimension makes it particularly difficulty to determine initial shape representations and to subsequently manipulate these to represent individuals or general populations. A shadow scanning technique (LASS, Loughborough Anthropometric Shadow Scanner) developed by the HUMAG (Human Measurement and Growth) Research Group in the Human Sciences Department of Loughborough University was used to capture shape information. The entire human body can be scanned in a matter of minutes and ordered coordinate information provided. This information has been processed for input into the DUCT surface modeller where some data reduction can take place before being output in the form of IGES B-Spline surfaces. These surfaces are then processed into a quadrilateral mesh representation that can be handled by the PHIGS functionality implemented within SAMMIE.

2.1 Scanning Body Data

The Loughborough Anthropometric Shadow Scanner (LASS) [4,5] has been used to capture human body shape in the form of three-dimensional coordinates describing the surface. The subject stands on a platform which rotates through 360 degrees in steps of approximately 2.3 degrees in about 3 minutes. Strips of light are projected onto the body and recorded by television cameras. This produces a 'raw' binary data file typically containing some 64,000 coordinates. This data is processed both to remove ‘noise’ created by stray reflections and to extrapolate for regions that are obscured during the scanning process (e.g. the part of the torso hidden by the arms).

2.2 Surface Modelling

Coordinate data from the body scanner is used to create a surface model in proprietary computer-aided design systems (both DUCT and Unigraphics have been used for this purpose). Using the full data from the scanner gives a very precise representation of human shape as can be seen in figure 2(a) which shows a full resolution plot in both its rendered and wireframe forms. In this case the model consists of 36 horizontal sections each of which is defined by 30 three-dimensional coordinate points.

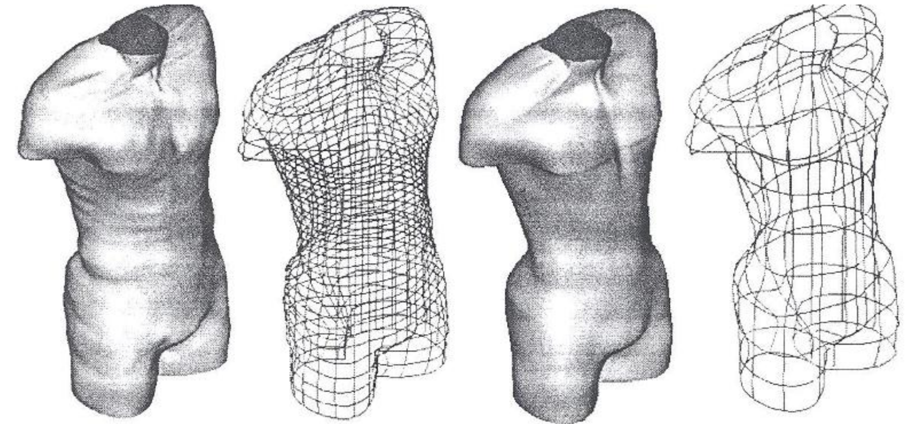


Figure 2(a). Male torso (36 sections, 30 points per section

Figure 2(b). Male torso (11 sections, 16 points per section)

The information can be reduced while maintaining the anthropometric shape integrity. A simple reduction of the data is achieved by the removal of appropriate horizontal sections and alternate points on each section. Figure 2(b) illustrates that these simple techniques are effective in achieving an eighty-five percent data reduction in data. In practice however the surface modeller is used to convert the coordinate information into surface representations where control over the level of detail in the model can be controlled by the normal means available in such modellers.

2.3 Anthropometric Modelling

Merely capturing images of particular subjects and using this information to generate a model does not meet the requirements of an anthropometric model where there is a need to be able to manipulate the model such that it represents a user population. i.e. algorithms based on large scale surveys are required so that anthropometrically correct large/small, fat/thin, etc models can be synthesized and used in design situations. This is the subject of current research proposals, but we are helped in this by knowledge of the relationship between scan sections and anthropometric landmarks. The scan data also needs to be modified to allow us to generate a model that has joint articulation. This requires some modification of the surface models in the regions where limbs connect with each other and the torso. Figure 3 illustrates the current status of this work with an 'armless' figure (we have yet to obtain arm scans). The figure also illustrates the particular application of car seat evaluation where composite car seats have been constructed from parametrically defined elements such as seatpan, backrest, headrest, side supports

2.4 Transfer to SAMMIE

SAMMIE is a boundary representation solid modelling system and its graphics is handled by a commercial implementation of the PHIGS international standard [6]. The transfer from DUCT to SAMMIE is achieved by an IGES file containing B-Splines that are readily convertible into a mesh representation which reduces the visual realism of the image but is suited to the next stage of the work which is to use finite element methods to investigate the compression between driver and seat.

2.5 Analysis of driver/seat interface

The creation of more realistic body shapes fulfils an overall objective of improving the performance of the SAMMIE system, but for our Brite contract we wished to investigate and produce algorithms for the way in which the flesh and car seat deform when in contact. The Patran finite element package was used for this using the geometric knowledge contained in the models described above. Information on the compressibility of the seats was available from earlier experimentation and, although the compressibility of human flesh is less easily determined, the HUMAG research group had determined these characteristics whilst creating physical manikins. Our own experimental work has determined pressure contours for a variety of driver/seat configurations and these were used in the validation of our modelling work.

Figure 3. Human Model combined with parametrically defined model of a car seat

The investigation of deformations at the seat/human body interface had the objectives of determining variability in location of important design points (principally the eyepoint and the H-point) as drivers of different size and weight sit on seats with variable seat cushion compressibility, and the production of pressure distribution maps.

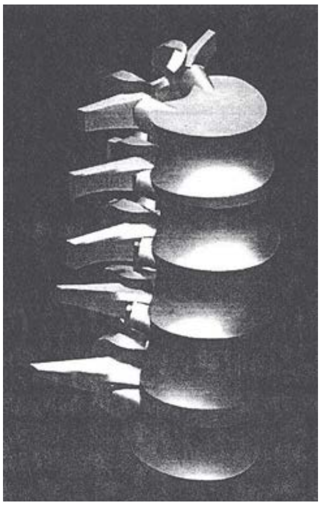
The pressure distribution maps were intended as a predictor of seating comfort - the hypothesis being that pressure distributions could be related to comfort and that this could be confirmed by our laboratory experiments. In the event this relationship proved to be difficult to find, so this aspect was not pursued. Subjective comparison of the experimentally and analytically obtained pressure maps has however provided us with a valuable confirmation of the validity of the analytical work.

Car seat evaluation is simply one example of an area where better representations of body shape are required, but there are many others. Any product that comes into direct contact with the body is a potential area of application of the technique - clothing, helmets, gloves and facemasks being typical examples. In other applications visual realism of the human figure itself is of importance. This is reflected in current research proposals to investigate and provide for the needs of virtual reality systems in this respect.

3. SPINE MODELLING

In addition to improving exterior shape representations, research is being undertaken that is aimed at developing parameterised spine models of sufficient geometric and kinematic complexity to provide a basis for analysing posture and loading. Eventual inclusion of this facility within the SAMMIE system will allow the evaluation of many of the complex comfort issues associated with a wide variety of human workplaces.

The creation of a geometric model of the spine is an essential precursor to the mathematical modelling work which is aimed at analysing loading conditions to predict discomfort or spinal damage. The geometric model [7] (produced using Unigraphics and illustrated in figure 4) describes the geometry of the spinal components (vertebrae and discs) and how these are spatially arranged (relative locations and orientations) to form the overall spine structure. A parametrically driven model is required to accommodate anthropometric variability between individual people.



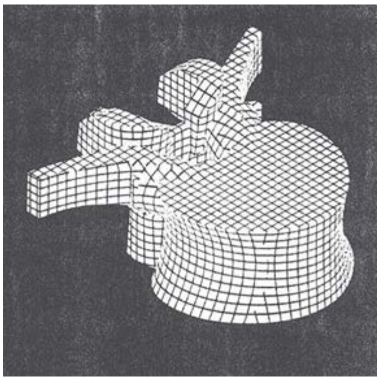


Figure 4. Model of a single Vertebra (above), and the assembled Lumbar Section of the spine (left)

The geometric model provides a starting point for the mathematical modelling of the spine. Study of the literature [8, 9] has established the range of methods available and in particular [10] provides a comparison between the conventional lever models and the arch model that we believe to be more appropriate for our work. The arch model draws an analogy between the human spine and masonry arches and it has been shown that in some circumstances it provides a more appropriate measure of internal loading at the vertebrae [11]. The purpose of our mathematical model is to predict the spinal component loads under fixed spine curvature conditions. Total spine loading occurs in three principal ways: (i) transmission of upper body forces due to gravity and external loads - this is represented as a force and torque vector applied to the cervical/thoracic spine; (ii) lumbar and thoracic gravity forces dependent on trunk size, shape and posture; and (iii) reaction forces on the spine due to muscles, ligament activity and intra-abdominal pressure.

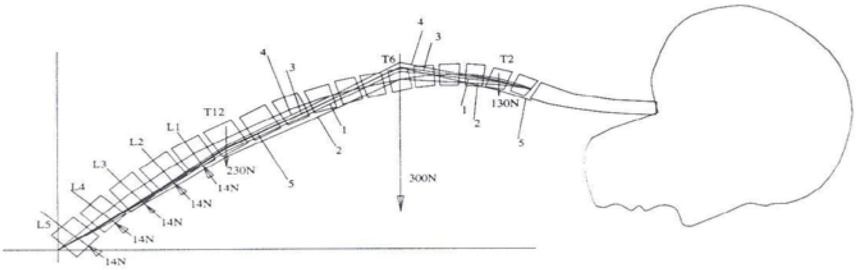


Figure 5. Spine Model showing load system and thrust line (stooped posture)

Prototype versions of the model have been constructed using techniques identified in the literature survey and combines aspects of both the lever and arch models. The ADAMS mechanism modeller is used to construct a hierarchical link model and to load it in the fashion indicated in figure 5. The first two loading conditions (external loads and trunk gravity forces) are those found in conventional lever models, while the arch model accommodates important aspects such as reaction forces due to muscular activity. This problem is statically indeterminate under these loading conditions and stability is determined by the application of well-known theories of the structural behaviour of arches [12]. Optimisation techniques are used to ensure that the thrust line is contained within the volume of the spine. The primary output of the model is the loading conditions at each of the vertebrae and discs which provide an indicator of the relative suitabilities of different postures, either by comparison with experimentally determined values or by further mathematical modelling using finite element methods. These aspects have not yet been tackled and constitute a significant part of our future work.

4. CONCLUSIONS

The work carried out to date and reported here has demonstrated the viability of the approach aimed at improving the capabilities of computer human models that are used for workplace design and evaluation. The more realistic flesh shape will not only improve visualisation, but will also open up many opportunities for a wider application of human modelling techniques. In particular, we are interested in products that have a direct interaction with the user (the car seat being a good example) and where there is potential for body and product shape to deform under normal loading conditions. The spine model with its considerably increased number of links will provide significantly improved posture representation and provides the basis upon which to evaluate the suitability of loading conditions and their relationships to potential discomfort and back injury.

5. ACKNOWLEDGEMENTS

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