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Repositioning Methodology For FE-HBM Pelvis Flesh To Account For Upper Extremity Posture Change

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ABSTRACT

Many research groups are developing Human Body FE Models (FE-HBM) as a tool to be used in safety research. The FE-HBM's currently available are in certain fixed postures. Repositioning of model in alternate postures is needed for use in out of position (OOP) occupant simulations and different pedestrian posture simulations. Postural change in upper extremity can be split two processes, viz, repositioning of spinal vertebra and repositioning of the soft tissue associated with the spine. The objective of this study is to establish a methodology to regenerate pelvis flesh with change in spine/pelvis position. The outer profile of the pelvis flesh should ideally be parametrically described with respect to the associated hard tissues which is not the case in existing FE-HBM's. The affine invariant (Farin, 1990) property of cubic Bezier curves is used in this study. It is hence implied that applying affine mapping to either the control points or to the points on the curve itself yields the same result. Initially, for each pelvis flesh contour, four points are identified (end points and two other points of significant curvature) to define a cubic Bezier curve and identify the associated control points. The upper extremity posture changes are described with respect to hip, pelvis, and thorax angles. The end points defining the contour of the pelvis flesh are relocated by affine transformations. The new shape of the pelvis flesh contour is then obtained using the control points located earlier. Mesh morphing using Barycentric coordinates is proposed to be used for repositioning of the interior pelvis flesh. The paper presents a new method which employs inverse parameterization of Bezier curve to re-compute the shape of the pelvis flesh. These computer graphics techniques used are time efficient and do not involve active user intervention. Further, the element quality and time steps are not significantly affected, thus preserving computational efficiency of the FE model. The method has been demonstrated through repositioning of the pelvis flesh with change in posture of lower spine segment in this paper. It will be extended to repositioning the upper spine segment of FE-HBM with change in spinal/pelvic posture.

INTRODUCTION

Human Body FE Models are increasingly being used to investigate injuries due to impact. Both frontal and side airbags can inflict injuries, to upper extremities, if the body is within the envelope of airbag deployment (Good, 2004; Petit et al., 2003; Bass et al., 1999). In an effort to protect the out-of-position occupant from air bag injuries, the National Highway Traffic Safety Administration (NHTSA) amended Federal Motor Vehicle Safety Standard (FMVSS) 208 to include new standards for out-of-position protection in addition to frontal crash protection. Most of the situations of interest in the standard, with respect to the car occupant's upper extremity, are obtained by sagittal plane movement of the spine. Injuries in the upper extremity are reported to vary with position change (Ono et al., 1998, Prasad et al., 1997, Strother et al., 1994).

Torso side airbags and inflatable side curtains are reported to mitigate thoracic injuries and related trauma in nearside impact (Olsson et al.,1989, Haland and Pipkorn, 1996). Effect of occupant dynamics on OOP injury from side impact torso airbags through simulation based techniques is reported by Hallman et al., 2008. The MADYMO (MADYMO® R6.3, TNO-MADYMO, Livonia, MI) facet occupant model was used in the study and was subjected to OOP conditions using a rigid wall lateral impact apparatus. Single posture of the occupant model was used in the study. However, due to model unavailability affect of anatomical differences in different postures could not be captured.

Vezin et al., (2005), report that, the HUMOS2 has been equipped with posture change capability. Two methods have been described for repositioning the model. In the first approach a database of pre-calculated positions is being used and intermediate positions are obtained by linear interpolations between nearby positions. The second approach is based on interactive real-time calculations.

However, they do not provide enough information about the technique and the quality of the results obtained; it is thus not possible to judge the accuracy of the anatomical relation among the body segments, the time required for repositioning and the quality of the mesh obtained.

Commercially used FE-HBMs are available in standard postures. Repositioned model in other postures are needed to be obtained for OOP simulations. Primary concern in repositioning of upper extremity is spine repositioning as measurement and predication of the inter-vertebral movements of the lumbar spine is fraught with difficulties. This is primarily because the spine is rather inaccessible, and the nature of the movements is very complex (Sun et al., 2004). Appropriate measurement of the lumbar curvature is important for clinical decisions (Chen 1999) as well as for OOP simulations. Prediction of spinal posture using natural spline method is used in the current study of FE-HBM repositioning as it does not require pre-computed spinal postures (Marathe et al., 2010). However the soft tissues and outer flesh associated with spinal repositioning need newer and faster methods. The geometry of the FE model used was abstracted from a full human body FE model (The General Motors (GM) / University of Virginia (UVA) 50^{th} percentile male HBM (Untaroiu et al. (2005) and Kerrigan et al. (2008)).

SIMULATIONS BASED METHODS

Very few studies report repositioning techniques for human body FE models. Parihar (2004), repositioned the lower extremity of the THUMS model from an occupant posture to a standing (pedestrian) posture. Method for mesh modification of lower extremity using dynamic simulation is reported by Chawla et al., (2004). In this method, boundary conditions are applied to bones, which through contacts cause the soft tissues to reposition. They report that the simulation time is very long and requires a large number of iterations and user interventions. Similar issues are also expected while repositioning pelvis flesh.

Similar to the method proposed by Parihar (2004) repositioning of pelvis and associated soft tissues was attempted. The pelvis position was modified using a series of FE simulations. LS-Dyna explicit solver was used for the simulations. In each step pelvis was given a rotation of 5 – 6 degrees. It was found that the simulation took about 11 hrs for 60 degrees of flexion on a Intel P IV 2.4 GHz processor with 2 GB RAM and required a large number of iterations and interventions. Issues of mesh penetration and mesh quality were observed. Negative volume in soft tissues was also observed and needed to be corrected at each simulation stage.

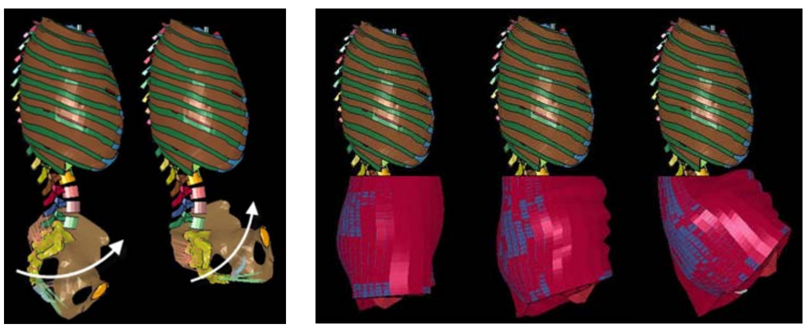

Figure 1 – (L-R) (a) Pelvis and upper extremity in erect posture; (b) Flexed posture

A faster method thus needs to be developed for changing the topology of pelvis flesh with change in posture of existing FE-HBM's without compromising their biofidelity or computational efficiency. The present study describes a computer graphics based repositioning technique. The computer graphics are proposed to be used in addition to morphing methods which are widely used for generating human body animations. Many researchers have used various morphing approaches to generate animations of human-like characters (Sheepers et a. 1997, Aubel 2001, Dong et al. 2002, Blemker et al. 2005 and Sun et al. 2000). Proposed method is compared with simulation based methods based on the time required for repositioning, control over the kinematics followed, anatomical correctness of the repositioned (with respect to the bone position) model and the level of user intervention needed.

The paper presents a new method which employs inverse method of parameterization of Bezier curve to estimate the shape of the pelvis flesh. The graphical techniques used facilitate repositioning the entire pelvis flesh of FE-HBM quickly and without much user intervention. The method developed was used to reposition the pelvis flesh during change in posture of the lower extremity. With the applied technique computational efficiency of the model is not compromised. It will be a key method in repositioning the upper extremity of FE-HBM for different spinal/pelvic postures.

MATERIAL

AM50 model has been used in the study as it represents a fairly large population of clinical studies. Repositioning of the FE-HBM using graphical techniques is done in two stages, viz, repositioning of rigid components (bones) and deformable components (soft tissues). In the current study posture change in bony structure is restricted only to change in the sagittal plane. Posture change (flexion/extension) of spine in sagittal plane is proposed to be predicated by the natural spline method (Marathe et. al., 2010) where inter vertebral movement of spine was predicted using cubic natural splines as shown in Figure 2 (a). Cubic interpolation was done between key-vertebral positions within a given posture, to achieve the postural change. Thus change in lumbar posture due to the sagittal movement of thorax was predicted. The method can be used in FE HBM as it does not require information from other postures.

Figure 2 –(L-R) (a) 30^o flexed posture of FE-HBM upper extremity about the lumbo sacral joint (Adapted from Marathe et. al., 2010) (b) Transformed mesh of upper extremity with change in spine posture. (c) Flexed posture of upper extremity along with initial mesh of pelvis flesh.

Outer profile of the pelvis flesh should ideally be parametrically described with respect to the associated hard tissue; however, this is not the case in existing FE-HBMs. Hence on change in posture of the upper extremity bone structure, associated soft tissues also need to be repositioned. In the exiting FE-HBM, flesh associated with the rib cage is assumed to transform along with the changed in upper extremity posture.

Changed posture of the upper extremity flesh is shown in Figure 2 (b). Change in lumbar shape from erect posture to either lordotic or kyphotic would cause change in shape of the pelvis flesh mesh. In Figure 2 (c) pelvis flesh is shown in the initial posture along with the flexed spine. As explained in the earlier section repositioned pelvis flesh could be obtained by simulation techniques. However to overcome the limitations of the simulation method a faster technique for repositioning is proposed in the current study.

METHODS

Repositioning of the outer flesh is broadly divided into two categories, viz, deriving the outer profile of pelvis flesh (skin) and morphing of associated solid mesh. In this paper graphical techniques are proposed for these steps. Bezier curves are proposed to be used for the skin repositioning while Delaunay Tetrahedralization based morphing technique (Dhaval et. al., 2009) is proposed to be used for inner flesh repositioning.

INVERSE PARAMETERIZATION OF BEZIER CURVE

In classical Bezier method, transformations of control points are used to obtain new spline shape. In the proposed method the property that Bezier curves are affine invariant (Farin, 1990) is used. It is hence implied that applying affine mapping to either the control points, or to the points on the curve itself yields the same result.

In the proposed method the original shape of pelvis profile is used as an input for repositioning the pelvis skin. The pelvis skin is subdivided into equally spaced longitudes termed as pelvis flesh contours. For each pelvis flesh contour, four points are identified (end points and two other points of significant curvature) so as to define a cubic Bezier curve that passes through these points and associated control points are identified as shown in Figure 3(a). The pseudo inverse technique is proposed to be applied to each contour in order to find the control points which correspond to the pelvis skin.

Initial position of the pelvis skin is shown in Figure 3(a). The set of four points, two end points and two intermediate points (on the curve with significant curvature) were identified. These identified points are shown by yellow dots in Figure 3(a). One pelvic contour along with the selected points (shown by red circles) is shown in Figure 3(b). By applying the inverse technique of curve characterization, two control points were calculated in addition to the end points (Figure 3(c)). Thus for a given contour four control points (including two end points) were calculated.

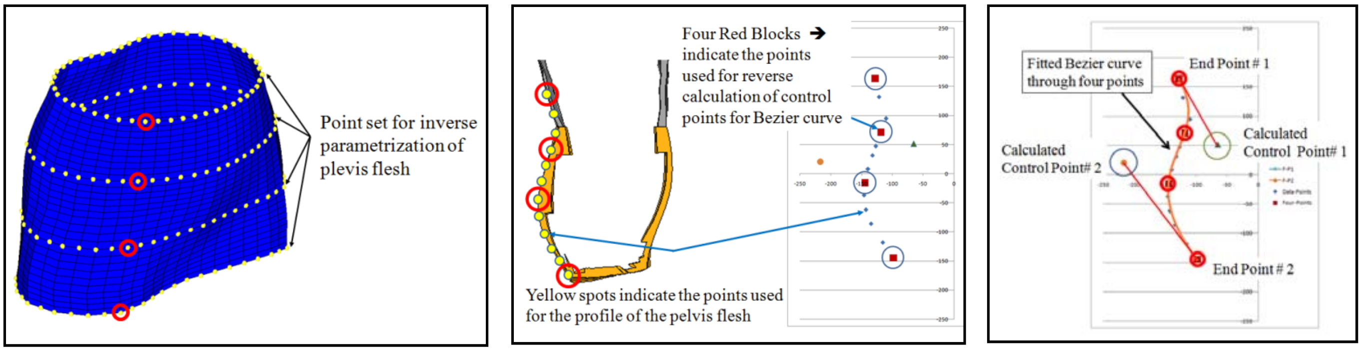

Figure 3 – (L-R) (a) Point set for inverse parameterization of pelvis flesh for FE-HBM in 3D. (b) Inverse calculation of control points from pelvis flesh of FE-HBM in 2D. (c) Calculated control points through fitted Bezier curve

MORPHING METHOD

After the repositioning of outer skin of pelvis flesh, the internal mesh between the skin and bones also needs to be repositioned. The internal mesh is proposed to be repositioned using a morphing like approach. In it barycentric co-ordinates and Delaunay triangularization (tetrahedralization) methods are used (Dhaval et. al., 2009). In the current work also, Delaunay triangularization is proposed to be used for mapping the inner volume mesh of the pelvis flesh. After mapping of the inner volume, barycentric coordinates will be used which will provide the a 1-1 mapping between the original and the repositioned tetrahedrons. This process minimizes the amount of mesh penetration during repositioning. However some mesh distortion and quality deterioration may be observed post morphing. These are planned to be eliminated by the use of mesh smoothing techniques.

RESULTS

With each point set defining a Bezier curve, control points for the Bezier curve definitions are calculated (shown with red in Figure 4 (a)). The control points on the curves are frozen and the end points defining the contour of the pelvis flesh are relocated by affine transformations of the thoracic region. Repositioning of the upper extremity is defined by change of hip, pelvis and thorax angles. The new shape of the pelvis flesh contour is then obtained using the repositioned control points as shown in Figure 4 (b).

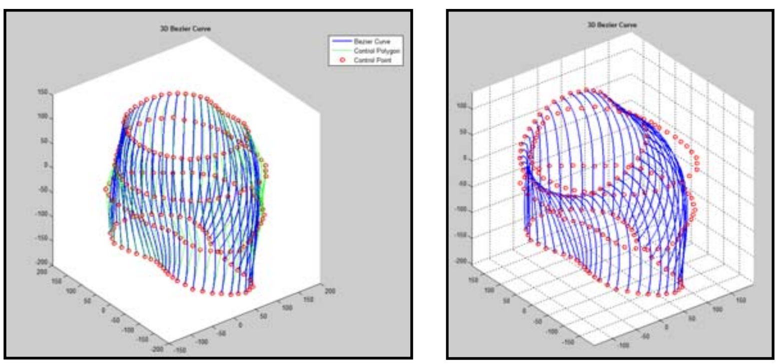

Figure 4 – (a) Points representing each Bezier curve along with the computed control points in standing posture. (b) Reconstructed Bezier profiles for 30^o flexion of upper extremity.

Output of the developed method for 30^o flexion and extension of thorax is shown in Figure 5. It can be seen from the figures that the pelvis flesh contour thus obtained from the program conforms to the repositioned lumbar and pelvis. OOP postures thus could be quickly computed without much user intervention.

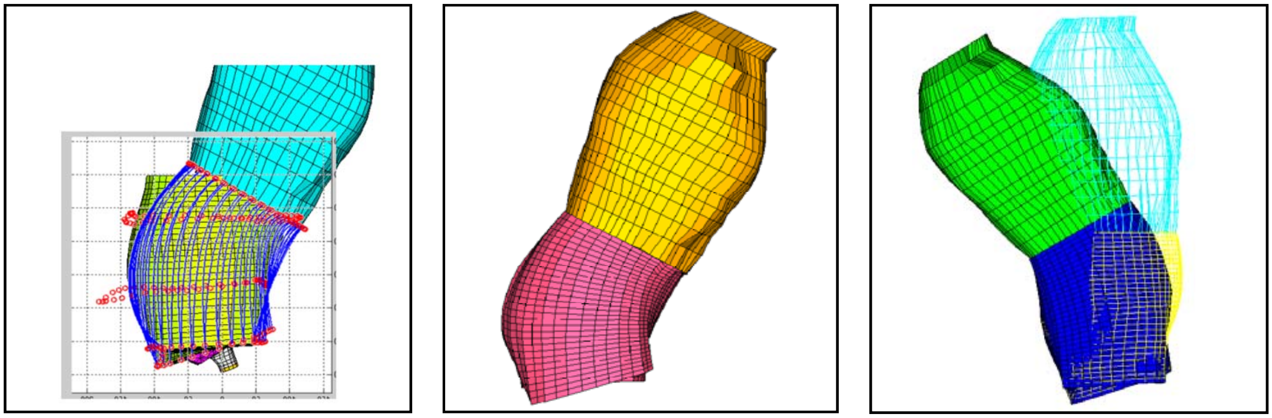

Figure 5 – (L-R) (a) Program generated output mapped over FE mesh of upper extremity. (b)Skin profile of pelvis flesh predicted as a result of 30^o flexion. (c) Skin profile of pelvis flesh predicted as a result of 30^o extension.

In changing from standing posture to walking posture, points connecting only the thigh could be transformed. This independent control over the flesh contour would be useful in postural change. Initial results of repositioning the model through graphical techniques are quite encouraging. The technique requires much lesser time compared to FE simulations. Moreover, it allows a much better control over the repositioned mesh being obtained. Some problems of distorted elements persist in this approach also but they are being taken care of by implementing mesh smoothing techniques.

DISCUSSION

The paper presents a new method for generating the pelvis flesh mesh for a new posture of the spine model. The model neither uses dynamic simulations nor a stored database of meshes in different configurations. The proposed technique has been incorporated in a program which takes as an input the initial posture of spine and angle of thorax flexion/extension and outputs the new pelvis and spine posture. Time required for the method is in the order of few minutes as compared a few hours required in simulations. User intervention in the proposed method is minimal as compared to simulation techniques. Control over mesh quality features like Jacobian, warpage and minimum element length is planned to be incorporated in the near future. These quality parameters are critical for controlling the solution time step and the stability of the simulations.

At this stage, this repositioning method does not incorporate pre-stressing of tissues in the final repositioned model. The work is also limited by the fact that it is assumed that there is no relative motion in the thoracic vertebra and hence the flesh covering thorax would not deform. The current work only deals with repositioning of the flesh in the lumbar region. These aspects are expected to be addressed in the future.

CONCLUSION

The problem of generating pelvis flesh postures that are anatomically consistent in unloaded, spinal configurations of a FE-HBM has been addressed. Bezier basis functions were used to define the pelvis contours, and the control points were obtained using an inverse method of curve definition. The Bezier functions were later used to re-create the shape of skin in the pelvis flesh. Once the skin is regenerated internal solid mesh is repositioned using Delaunay Tertrahedralization and Barycentric Coordinates. The algorithm has been successfully tested with MATLAB® and planned to be implemented in VC++ and OpenGL environment. Results indicate that repositioning of pelvis flesh in FE-HBM can be done accurately and quickly without resorting to manual remodelling tasks or FE simulations.

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DEFINITIONS/ABBREVIATIONS

FE-HBM	Human Body FE Models
HUMOS2	Human Model For Safety 2
FOM	Facet Occupant Model
FMVSS	Federal Motor Vehicle Safety Standard
NHTSA	National Highway Traffic Safety Administration
AM50	50^{th} Percentile Adult Male
OOP	Out of Position