MOTION SIMULATION OF THE HIP JOINT USING AN OPZIMIZED MARKERS CONFIGURATION
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INTRODUCTION
Simulating joint motion is a prerequisite for any efficient surgical planning system. In this paper, we present a methodology that combines MRI and motion capture systems (Mocap) to simulate and visualize the hip joint motion with an optimized markers configuration. MR images are used to capture the subject’s anatomy as well as the trajectories of the skin markers that are attached to the subject. The anatomical models of the subject are reconstructed and the markers trajectories are computed from the images. The best markers configuration is selected based on the criteria of markers displacements due to skin artifacts. The optimized configuration is used for recording external movements with the Mocap system. The resulting animation is mapped onto the virtual body of the subject including internal bones and the joint motion is visualized.

METHODS
1. Anatomical models generation
Two healthy adult volunteers (a female and a male) have undergone MRI scanner. Four high-resolution MRI scans of T1-weighted spin echo images are obtained for bone and one series of T1-weighted gradient echo for cartilage. The in-plane resolution is 0.76mm x 0.76mm for bone sequences and 0.94mm x 0.94mm for the cartilage. The in-between plane resolution varies depending on the anatomical region. The highest resolution is performed in the hip joint region (2 mm).

On each MRI slice, an initial set of points is digitized along each articular curve with a coarse spacing of 1-2cm. An active contour is used to best fit the actual boundary [Yahia et al 03]. This provides an accurate location of the bone contour near the initialization curve (Figure 1).

The segmentation is validated by the medical experts before the reconstruction process to ensure 3D models’ accuracy.

To generate the iso-surfaces from the segmented volume, we use the Visual Toolkit\footnote{www.vtk.org} implementation of the Marching Cubes algorithm. The resultant polygonal surface is simplified with Schroeder decimation algorithm in order to decrease the total number of polygons while preserving intricate surface details.
The hip model is reconstructed with 42,944 vertices and 84,313 triangles, the femur model with 27,608 vertices and 53,534 triangles. Cartilage models are reconstructed with 5856 vertices and 11454 triangles for the acetabular cartilage and 10241 vertices and 20 360 triangles for the femoral cartilage (figure2).

2. Optimizing the optical markers configuration

Nine reflective markers are injected with a contrast agent and placed at specific anatomical locations on the right limb of the volunteer (Figure 3). The volunteer undergoes the MRI scanner; his/her right limb is constrained by a device and imaged by the scanner during each frame. The MR series are processed and the trajectories of the visible markers are calculated using an automatic tracking method developed by our team. Therefore, each marker $m_i$ is associated with an error $r_i$ corresponding to the sum of its displacements from frame to frame as follows:

For each marker $m_i$
  For each frame $f_i$
    Calculate the marker’s sum of displacements $\sum d_i$
    Assign to $m_i$ the error $r_i = \sum d_i$

For each triplet of marker $(m_i, m_j, m_k)$
  If (Check_colinearity($m_i, m_j, m_k$))
    Calculate the distance $d_{ijk} = d(m_i,m_j)+d(m_j,m_k)+d(m_k,m_i)$
    Calculate the error $r_{ijk} = r_i+r_j+r_k$

Check_colinearity ($m_i, m_j, m_k$): returns yes if the three markers $m_i$, $m_j$, and $m_k$ are non-collinear and no otherwise.

The best three markers $m_i$, $m_j$, $m_k$ are the most distant ones (maximum value of the sum of the markers inter-distances $d_{ijk}$) with the less relative motion (minimum value of the sum of the markers displacements $r_{ijk}$). Thus, each triplet of markers is assigned two weights: $r_{ijk}$ and $d_{ijk}$. To determine the best three markers, we need to minimize the quantity $r_{ijk}$ and maximize the quantity $d_{ijk}$. In other words, we seek for the triplet that maximizes the fraction $d_{ijk}/r_{ijk}$. An exhaustive search is used and the best triplet is selected (Figure 4).
The procedure is applied to three motion patterns recommended by our medical partner as being the movements used to determine the range of motion of the patient: (hip abduction, flexion and rotation).

3. **Creation of the virtual body of the subject**
The reconstructed bone surfaces are inserted in a virtual human skin mesh generated from adaptation of a generic model according to manual measurements of the subject’s segments [Seo et al. 03]. The same surfaces are used to evaluate the hip joint centre position using a functional method detailed in [Kang et al. 03]. This hip joint centre (HJC) is set on the subject’s technical skeleton model. This step ensures that the model’s HJC matches the precisely evaluated HJC therefore providing realistic animation visualization. As a result we obtain a visualization model composed of fairly accurate hip joints with bones within an approximated subject’s body deformable envelope (Figure 5).

One key interest of our approach lies in the fact that the visualization model corresponds to the subject’s real anatomy in the focus area (e.g. hip joint). The visualization of the motion that is as well recorded from the subject herself/himself is therefore closer to the real situation. That way, we removed the mapping on a subject-unrelated model bottleneck that gives little confidence in the visualization process given the variability in anatomy among different subjects.

4. **External movements recording**
We use a VICON system with 8 video cameras to record the subject external movements. The reflective skin markers are placed on anatomical landmarks of the subject according to the optimized configuration. The recorded markers trajectories are converted into the joint space parameters of the subject’s model. The converter technique [Molet et al. 99] takes into account the geometry of the skeleton model, motivating further the process of accurately matching the subject to the model. A record of the subject in stand-up calibration posture is used as a subject/model posture mapping reference. The model posture can be fine tuned with respects to the subject’s recorded posture before converting the trajectories into animation. This is done in practice by visualization of the markers position in the stand-up posture and adjusting the model pose, thus creating an offset posture (Figure 6). This offset posture is then used in place of the model’s default pose in the process.

We record hip abduction/adduction (Figures 7, 8), rotation, flexion, and conical motion. The positions of optical markers are visualized at the same time as the virtual model during its animation; this serves as reference to assess the reliability of the animation mapping.
Although we are concerned primarily by the study of the hip joints, we believe that providing a more complete, yet less accurate, animated visualization of the rest of the body is desirable as it confers a panel of views from general to detail.

The real-time visualization application we have developed is based on the VHD++ middleware framework [Ponder et al 03]. For the purpose of this work, we integrated the management of optical markers animation and enhanced the virtual human production pipeline to satisfy the constraints of anatomical accuracy.

CONCLUSION
We presented a methodology to overcome Mocap systems limitations in visualizing and analyzing joint motions. Visual comparisons with classical animation based on common markers positions and standard animation skeleton showed an improvement in the animation realism. In the future, we plan to improve the results by investigating methods to reduce the markers displacements due to skin motion using medical imaging modalities.

REFERENCES


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