JointViewer – an interactive system for exploring orthopedic data

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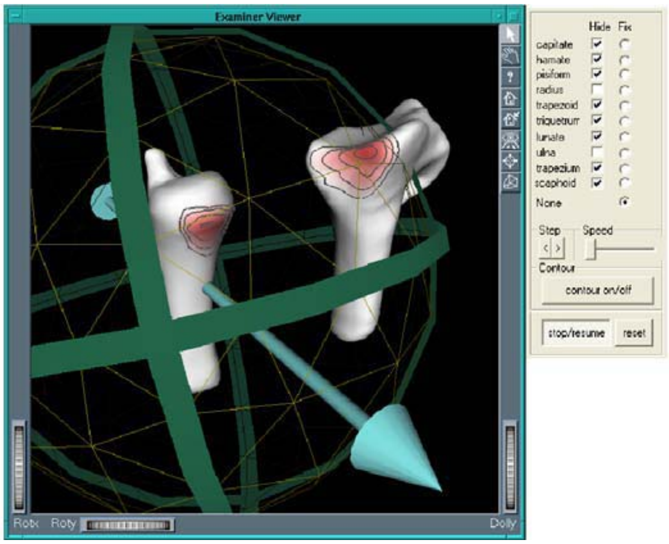

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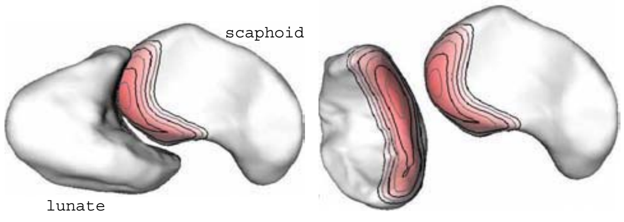
Figure 1: Screenshot of JointViewer (forearm joint uploaded). Inter-bone distance values are mapped to varying saturations of color. Darker regions are closer. The user is maneuvering a bone to better observe the location of dark areas.

Overview

We present JointViewer, a software tool to aid orthopedics researchers in exploring complex, *in-vivo* joint kinematics. Given bone-geometry data and bone-motion information, JointViewer models and visualizes bone inter-spacing in the joint. Next, it proposes and displays plausible ligament paths which connect bones together. Both types of models are constructed through a distance-field approach. Users can maneuver the bones in a joint for better viewing, see motion relative to a specific bone, or remove bones from a joint.

We demonstrate JointViewer's effectiveness in three applications: examining normal human wrist kinematics, capturing the effect of injury on forearm kinematics, and exploring the kinematic constraints imposed by ligaments in a pigeon shoulder. In all applications, the system effectively highlights subtle yet important relationships among bones and soft-tissue that in previous standard joint visualizations had gone unnoticed.



(a) (b)

Figure 2: Two articulated bones in the wrist joint. The saturation of color on bone surfaces represents the distance to the nearest point on the opposite bone. (a) Bones in their correct anatomical context. (b) Bones rotated to show articulated surfaces more clearly. Users can track bone-spacing changes induced by joint motion.

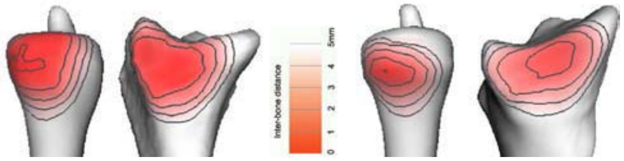
Methods

Data Acquisition and Bone Modeling

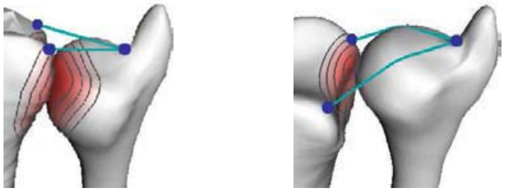
3D joint structures were acquired using CT technology. Each joint was imaged in multiple poses, and kinematic information was recovered by registering the bones across CT image sequences. Within our system, bones are modeled both implicitly (as scalar distance fields [1]) and parametrically (as NURBS surfaces). Signed distance fields are computed from the parametrical bone model through a level-set based method [2].

Inter-bone Spacing and Ligament Path Calculation

We compute the surface on each bone where the inter-bone distance is less than a user-specified threshold. Using the distance field representation we find distances from every vertex in the surface model of each bone to every other neighboring bone. These



(a) Uninjured (b) Injured (mirrored)



(c) Uninjured (d) Injured

Figure 3: Inter-bone spacing (top) and ligament paths (bottom) in the uninjured and injured forearm of the same subject (both forearms in neutral pose). The dark area is significantly decreased and shifted downwards in the injured case. Ligament paths also wrap around the head of the bone in the injured case, indicating soft-tissue involvement in altered kinematics.

distance values are updated for each frame of animation based on the joint kinematics. Iso-contours are computed on the contact area. Each contour shows the points where the distance map is equal to a constant distance.

We evaluate potential soft-tissue constraints in the joint by constructing minimum length paths between ligament insertion points (points where the ligament anchors to the bone). The insertion points are identified manually by the user, and the minimum paths are constrained to avoid bone penetration. These paths are generated through a sequential quadratic programming approach [3].

Visualization

We visualize inter-bone spacing by using color mapping and contouring. Ligament paths as visualized as streamtubes. Color maps are generated for each bone so that distance values of surface points are mapped to varying saturations of color. Saturation increases as distance decreases. Contouring becomes very useful for grouping distances and, in this sense, complements the color mapping technique. Distances beyond the user-specified threshold value are neither colored nor contoured. They are shown as a white surface.

Results

We present results from three applications. In the first application, we model and visualize the inter-bone spacing in a human wrist (two bones from the wrist shown in Fig. 2). The users — orthopedics researchers — were for the first time able to confirm a 1940 theory on the increase of inter-bone spacing with specific types of wrist motion (flexion-extension).

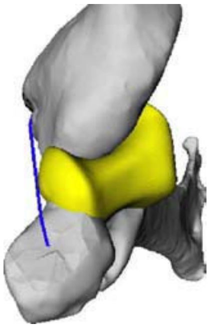


Figure 4: The interplay between the ligament (blue), bones (white), and cartilage (yellow) in a pigeon shoulder joint, as revealed by JointViewer. The users hypothesized ligament-cartilage collision was responsible for the previously observed constrained wing motion. The above visualization suggests otherwise.

In the second application, we model the inter-bone spacing and ligaments in two forearm joints (one normal, one injured). Figure 3 shows that motion limitation in the injured case was not due to bone collisions, as previously thought in the hand-surgery community, but more likely to ligament–bone collision. Wider inter-bone spacing in the injured case indicates bones are actually farther, not closer post injury, and hence not colliding. Curved, bone-colliding ligament paths, correlated with a downwards shift in the location of the red area, indicate that a subtle change in the joint geometry stretches abnormally the ligaments in the injured case. Based on these findings, hand-surgeon users of JointViewer shifted their focus from bones to soft-tissues.

In the third application, we model the ligament connecting two bones in a pigeon shoulder joint (Fig. 4). In this case, the users — evolutionary biology researchers — hypothesized ligament–cartilage collision during flight was responsible for the observed constrained wing motion. Based on the visualization produced by JointViewer, they rejected this hypothesis.

Conclusion

JointViewer can be used as a tool to explore hidden structures and subtle kinematics of joints. Results show that our system can be useful in the study of both normal and pathological anatomy and kinematics of complex joints. The techniques developed may have applications to the study of joint disorders such as rheumatoid arthritis, ligament tear attenuation, and carpal-tunnel syndrome.

Acknowledgments

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References

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