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A VIDEO-BASED, MARKERLESS MOTION TRACKING SYSTEM FOR BIOMECHANICAL ANALYSIS IN AN ARBITRARY ENVIRONMENT

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INTRODUCTION

Current approaches for the study of human movement have provided valuable insight into the characteristics of normal and pathological patterns of locomotion. However, most methods are restricted to a laboratory environment where a subject must perform activities on a force plate while wearing reflective markers, wands or fixtures attached to limb segments. These laboratory conditions can encumber natural motion and produce results that don't represent normal movement. The influence of the laboratory environment is particularly important for studies where subtle variations in movement are important or for the study of athletic performance during an outdoor sporting event. Clearly, there is a need for a method to obtain both kinematic and kinetic quantities for human motion in an arbitrary setting without using markers or force plates. The purpose of this project was to design and develop a system for the study of the kinematics of human movement using a video based markerless approach.

METHODOLOGY

A method was developed to calculate the velocities and accelerations associated with human motion obtained from video data. A subject-specific 3-dimensional model is fit to recorded motion obtained from full frame video images. The system consists of two modules: an application for building 3-dimensional, subject-specific models, and a model-based visual tracking algorithm. Because the system is divided into these modules, alternative approaches to one module may be explored without modifying the other module, and other modules may be added in the future to expand the system's capabilities.

Model Builder

The model-building application consists of a graphical user interface (GUI) that allows the user to create a 3-dimensional subject-specific model by attaching body segments to one another with idealized joints. The three most important design criteria for the model builder are 1) a straightforward, easy-to-use GUI, 2) an elegantly designed data representation that has both the flexibility and the robustness to meet the needs of building human models of varying complexities, and 3) an ability to easily interact with the tracking module, by providing efficient joint constraint feedback. The latter two aspects are further discussed below.

Data Representation. Body segments are chosen from a library ranging in detail from weighted rods to geometric primitives to realistic segments reconstructed from human subjects (Fig. 1), then scaled and positioned to match a given subject. Inertial properties are associated with each segment, either by using a constant density assumption or by using heuristic values. Body joints enforce constraints on the relative positions of the connected segments, and range in complexity from a basic hinge joint to a joint that models the complexities of an articulating surface [1].

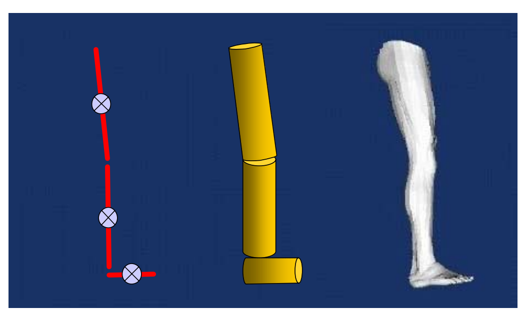

Figure 1. Three possible representations of a right leg.

Interaction With Other Modules. The output of the model builder is used by the model-based tracking algorithm to obtain kinematic data. The Image Tracker uses the model representation to construct synthetic images which are matched with the actual camera views [2]. It is possible to enforce joint range-of-motion constraints easily by only allowing synthetic images which are consistent with the joint constraints to be created.

Image Tracker

Although most studies will only be interested in kinetic data for one or a small subset of the joints, inverse dynamics calculations would necessitate tracking the motion of every segment of the body simultaneously. Therefore, markerless visual tracking techniques will be used to obtain kinematic data for the motion of all the body segments. After being initialized in the first frame by the operator, the image tracking algorithm will use the models created in the above model builder to match the model pose to multiple camera views in each subsequent frame.

Restrictions vs. Accuracy. The ideal solution for markerless tracking would have no restrictions on a subject's clothing. However, restricting the clothing can greatly improve the accuracy of visual tracking. Tight-fitting clothing allows the cameras to see the actual motion of the body segments, and controlling the color contrast and visual patterns allows the algorithm to quickly differentiate between segments and to isolate critical points for high-accuracy tracking.

Although it is necessary to track all body segments to perform inverse dynamics calculations, as mentioned above, a distinction can be made between critical body segments and non-critical body segments. The calculation of forces and moments at the joint of interest is very sensitive to kinematic errors in the critical segments, while it is not nearly as sensitive to kinematic errors in the non-critical segments. Therefore, this system utilizes different strategies for tracking these different types of segments—a color-based strategy and a point-cluster based strategy.

Color-Based Strategy. A special form-fitting garment has been constructed which applies a different color to each of the non-critical segments (Fig. 2, center). Segmenting each of these colored body segments is straightforward (Fig. 2, right) [3]. Once each segment is identified in multiple views, the optimal pose of the three-dimensional model at each time step is calculated consistent with these views. This optimization is done using an annealed particle-filtering algorithm, similar to [2], where the optimization criterion being minimized is the difference between actual color segmentation results and synthetic images of the 3-D model in different poses. This strategy does not yield reliable data for internal/external (IE) rotation of the segments, but for these non-critical segments the assumption of negligible IE rotation would not create significant errors in the kinetic calculations for the joints of interest.

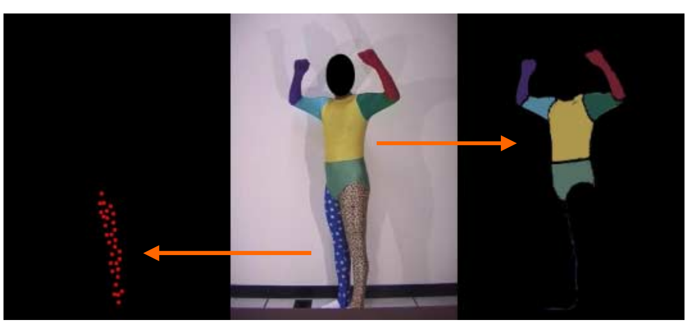

Figure 2. The raw image (center), the color-based strategy (right), and the point-cluster based strategy (left).

Point-Cluster Strategy. For the critical segments, individual points (Fig. 2, left) are tracked in three dimensions, and the point-cluster technique (PCT) [4] is used to determine the kinematics of the segments from this point-track data. While the PCT as previously described used markers as the points to track, the same algorithm can be applied to any set of points on a deformable object. To acquire these points, printed patterns are used on the critical segments of the form-fitting garment. Using the Shi-Tomasi algorithm for finding good points to track [5], the best points that correspond between views are chosen and tracked for input into the PCT algorithm.

RESULTS

Figure 2 shows segmentation results for the color-based and point-cluster strategies in one view at one instant in time. As can be seen in Figure 3, the color-based segmentation algorithm is successful at isolating non-critical segments through an image sequence.

Figure 3. Color segmentation of an image sequence.

DISCUSSION

The system described above gives kinematic information for the entire body. Because it does not rely on the specialized cameras or accurately placed markers like conventional motion analysis systems, it can potentially be used anywhere, greatly increasing the power of biomechanical analysis to improve our understanding of many different activities, including those which can not be properly performed in a laboratory. While this system only calculates kinematic data, it should be possible in the future to use its results along with assumptions about inertial properties and muscle firing patterns to calculate kinetic information as well. Inverse dynamics methods alone will probably be inadequate to do these calculations [6]. However, it may be possible to leverage advances in forward dynamics simulations [7] to improve accuracy or calculate forces which inverse dynamics alone cannot predict, such as ligament or individual muscle forces.

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