Exploring Human Adaptation using New Data Collection Techniques and Optimized, Dynamic Human Models

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INTRODUCTION

Classic inverse/dynamics methods fall short in providing a methodology which allows the human model to adapt to a change in environment or equipment. This paper introduces a dynamic human model with joint torques governed by coupled feedback controllers and optimized to a specific objective to allow for a structured approach in human adaptation simulation.

REVIEW AND THEORY

Inverse/dynamics methods for human simulation include methods of calculating the joint torques necessary for the human model to emulate the recorded motion [Allard 1995]. One problem analysts using these methods often encounter is in replicating the recorded motion with a high degree of accuracy [Li 1993]. This is in part due to the fact that various motions in the joints of the multi-segment chain representing the human, may be highly non-linear and discontinuous, resulting in high torque spikes which do not translate to exactly emulating the recorded motion. This is combined with the fact that the motion data is not acutely accurate to begin with, due to unwanted movement of the motion targets attached to the skin of the human subject. Using standard methods, these models are also unable to adapt to changes in environment or equipment.

This paper introduces a method of accurately replicating the recorded motion with a dynamic human model. It also accounts for data error of the motion targets and introduces an adaptation scheme for adjusting the torques to allow for the human to accommodate small changes in the environment.

PROCEDURES

Motion data from a data collection source (i.e., video, sensors, etc.) consists of 3D position histories of markers placed at various locations on the human subject. One such method involves new device employing an ultrasonic measurement method to capture body movements. The device is completely self-contained and carried on the human body. It consists of a small central unit and sensors which are applied at specific locations on the skin. The changes in the distance between any pair of sensors are reported with an accuracy of a millimeter. The key advantage of the ultrasonic sensory system is that the device and the sensors are quite small and unobtrusive to the patient, permitting the patient to wear it for long periods of time and allowing for the recording of large amounts of data. With this capability the devices is well suited to perform data intensive studies such as human fatigue.

By tracking the relative distances between markers through time, the data from this device can be used to drive a dynamic human model to simulate any human activity. This approach can be used to model the full body with large joint motion as in figure 1, or a specific limb with small articulations as in figure 2 [McGuan 1994].

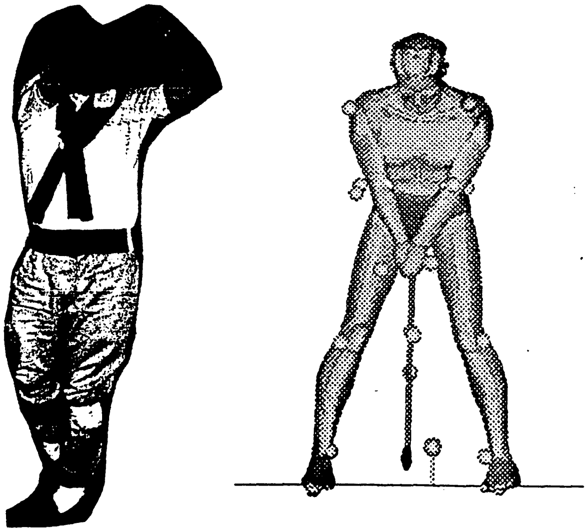

Fig. 1 Data Collection and Simulation for Full Body Motion.

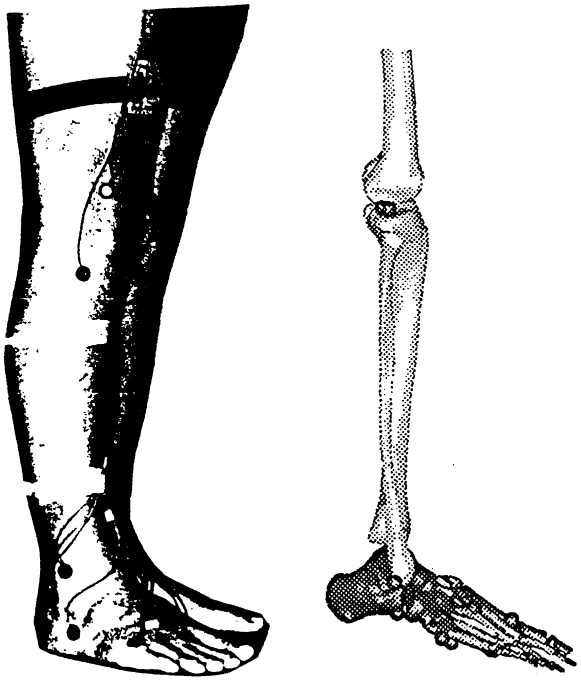

Fig. 2 Data Collection and Simulation for Partial Body Simulation.

The ADAMS® (Mechanical Dynamics Inc.) mechanical simulation system is used to process these data into a dynamic human model. The process begins by positioning "motion agents" on the multi-segmented human model at the same relative locations as in the experiment. The motion agents, displayed as spheres (figures 1 and 2), are driven with the experiment motion data. The agents are physically attached to the corresponding human segment using a 6 degree-of-freedom (DOF) spring elements (bushings). The stiffness of this connection is normalized to the relative accuracy rating of the specific target marker in the experiment (available from the motion analysis equipment/software). This allows for the marker with a higher degree of accuracy to contribute more to the motion in the model changing the nature of the motion data to motion <u>influencing</u> rather that motion <u>governing</u>.

A kinematic analysis is performed with this arrangement to retrieve the joint rotation histories for the human model emulating the motion. In the case of the model in figure 1, the joint motion is retrieved for the major joints in the body, in figure 2 it is for the equivalent joints throughout the articulating foot.

Adaptable, Dynamic Human Simulation

To perform a dynamic simulation with this model the motion agents are removed and torque elements are positioned at each DOF. The joint torque functions are implemented using the rotations from the proceeding kinematic analysis in a feedback controller of the form displayed in figure 3.

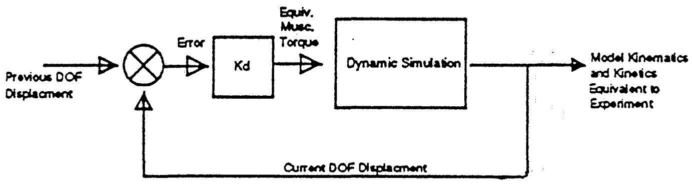

Fig. 3 Feedback Controller for Torque Functions in the Dynamic Human Model.

This controller produces the torques necessary for the human model to follow the motion from the proceeding kinematic analysis. The controller gains, K_d, for each DOF may be coupled with the gains from other areas in the body in such a way to systematically adjust the motion tracking ability of the dynamic human model. By adjusting these coupled coefficients, the human model will track the motion differently. By introducing an optimization scheme to adjust these coupled coefficients to achieve a specified goal, the human model can, in a sense, react to changes in the environment.

RESULTS

Motion data was collected for the golfer in figure 1. The simulation was performed using a dynamic human model and a golf club with a flexible shaft (Young's modulus = 2.68 x 10^6 N/cm^2). The procedure outlined above was used for the dynamic simulation of the golf swing. This resulted in an acceptable swing with a loft (face-angle with the vertical) of 9.7° and a club head velocity of 59.8 m/s at impact [Jorgensen 1994].

A second simulation was performed to display the effects of a change in equipment to the human model without any adaptation. For this test, the golf club shaft stiffness was increased by 30%. Without any adaptation, the human model swings the club using the same force as if it were the club from the proceeding analysis. With the differing mechanical characteristics of the club the human model's timing will be off. During the swing, the club is still bent backwards at contact and the loft is decreased to -6.6° and a club head velocity of 39.8 m/s at impact, indicating that the shaft has not fully straightened out.

Adaptation was then implemented in the model with the goal being to adjust the timing of the swing action to utilize the energy of the stiffer club. The optimization process [Pike 1986] consists of maximizing an objective function by iterating on variables under some system constraint. The objective in this golf simulation was the club head speed at ball contact. The constraints were the limits for the head face and loft angle at contact, and the variables were the controller gains for the torque functions. Coupling was introduced to the gains, grouping the arms, trunk, and legs into 5 variables, decreasing the number of gains from 34 and the greatly speed up the optimization process.

The results of the adaptation simulation yield a respectable 8.5° loft and a head speed of 51.8 m/s. Figure 3 displays a comparison between the three simulations.

DISCUSSION

The next step in this research is to simulate the golf swings (or other activities) of several subjects with clubs of variable stiffness. From this sampling, trends may be identified to aid in the K_d coupling, bounding and heuristics to allow for statistically viable human models with a higher degree of biofidelic adaptation. This system promises much utility in muscle control and coordination research, as well as practical applications of sports simulations, gait analysis, etc.

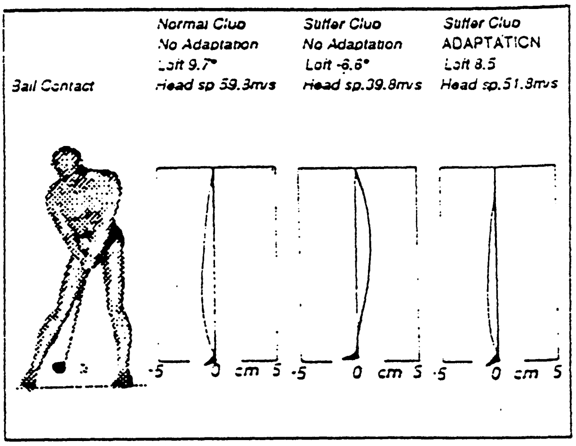

Fig. 3 Results: 1. Normal club, 2. Stiffer Club 3. Stiffer Club (Adaptation).

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