GENERAL TO SPECIFIC – A NEW MODELING PARADIGM IN HUMAN SIMULATION

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This paper introduces a novel human modeling system utilizing the ADAMS (Mechanical Dynamics Inc.) multi-body simulation program. The FIGURE Human Modeling system is a plug-in to ADAMS which provides users with the capability to generate human models of various levels of detail and fidelity, permitting simulations ranging from passive response (crash, falls, etc.) to active participation (sports performance, task simulation). The paper introduces the modeling paradigm of FIGURE and provides an example of direct dynamics simulation based on data from a newly introduced motion capture device.

KEY WORDS: biomechanics, simulation, functional anatomy, computer graphics

INTRODUCTION: Currently, software tools, which address the computer simulation of the human being, target specific application areas. In considering the variety of human simulation programs available today, the application target areas can be divided into the areas of crash simulation (vehicular occupant injury), slips/falls (environmental injury), orthopedics (joint and tissue mechanics), gait simulation (rehabilitation), task simulation (virtual factory) and sports performance simulation.

Figure 1 - Human simulation using FIGURE.

The approach of targeting a specific application area has resulted in specialized software solutions with a high degree of biofidelity for the appropriate task. However, this specialized solution approach represents significant challenges in the academic and industrial sectors. Most challenges relate to the complications of selecting the appropriate tool for the specific task as well as the burden on students/professionals in becoming proficient with the tool(s).
Perhaps an alternative solution in the university sector would be to have available a generalized program which would address a broad application space. This approach would provide students with exposure to the various application areas of biomechanics requiring the student to master one software tool instead of numerous specialized tools.
This was the intention of the FIGURE Human Modeler (Figure 1). This software tool was developed via consortium of over 30 leading sports equipment manufacturers, orthopedics companies, vehicle manufacturers, universities, research institutions and government agencies. In order to address the challenges from a community with a wide range of needs, FIGURE evolved into a broad-based application in the biomechanics arena.
The intent of the product offering was to provide a single tool to easily create human models with a level of sophistication ranging from simple to very complex. In order to address the needs of each member of the consortium, the human models would be appropriate for a wide range of applications from sports performance to injury evaluation, from gait simulation to vehicle ride comfort.

Human modeling paradigm: The basic model building paradigm in FIGURE is to start with a base human model representation and refined it to the appropriate fidelity depending on the application.

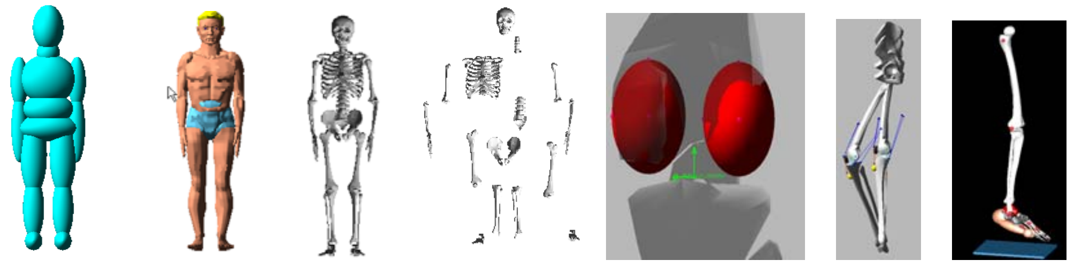

Figure 2 - Base human model discretization.

Figure 2 depicts the modeling progression for a detailed leg/foot model. Starting from a base representation, created from an anthropometrics database, each joint is refined to the specific level of biofidelity necessary for the specific simulation. The base model is a 15-segment model of the large portions of the body with the bones grouped into each segment. The grouping may be broken up into individual bones or individual segments for more detailed modeling of various body parts. For example in gait simulation, it may be appropriate to model as individual parts, the talus, calcaneaus, metatarsals and the mid-bones in the foot as separate segments in order to maintain balance, while maintaining the relative coarse discretization in the rest of the body.

The default joints in the base human model are tri-axis hinge joints created at anatomical locations. As with the segment discretization, the joint may be refined from its original basic representation. The joint tri-axis hinge arrangement may be replaced with force sets or other constraint arrangements. For example in Figure 2, the knee joint is modeled as a force-based joint consisting of the tibio-femoral contact forces and the patello-femoral contact forces, all stabilized with ligaments and actuated with muscles.

Forces acting across the joints may be of the passive or active type. Passive simulation involves the human body's response to the physics of the environment. The applications in this area include crash, falls, impact, etc. The human models created for these events have the segment mass properties and dimensions, joint stiffness, damping friction and limits consistent with the Hybrid III crash dummy used by many automotive companies to evaluate safety potential of automotive equipment. Data received from these simulations include segment contact force, displacement, velocity and acceleration, joint force and torques, and may be compared against injury norms for evaluation of the potential harm of a physical event. For an active simulation, a forward dynamics approach may be used. Here, the user describes the angulation history of the particular degree-of-freedom and generates a torque using the automatically generated proportional-derivative (PD) controller. This angulation history may be imported from a data table or generated using an inverse-dynamics approach. If muscle forces are used, muscle elongation histories or muscle activation values may be used to drive the model using elongation histories generated from an inverse-dynamics simulation (Figure 3).

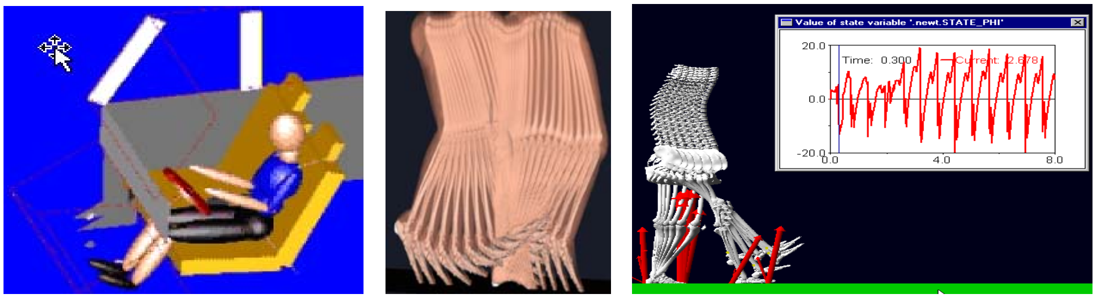

Figure 3 - Passive and active simulation.

Motion capture (MOCAP) data may be used to drive the direct dynamics simulation where data splines are automatically created. The user then places "motion agents" at the locations in the model, which correspond to the marker locations on the subject. A simulation is performed where the motion agents are moved based on the motion capture data, moving the body segment with it. During the simulation, the angulations at all degrees-of-freedom in the joints are recorded as well as the muscle elongation histories. It is this recorded angulation history or muscle elongation history, that may be used for a subsequent forward dynamics simulation where the model is driven exclusively with torques produced by the PD controllers or forces from the muscles.

Simulation example: The purpose of this section is to introduce a new body motion data acquisition technology and incorporate the function with a sophisticated computer model of the human neck built using the FIGURE Human Modeler. The ultrasonic device captures the changing of the length of the skin between sets of sensors during movement. By strategically placing the sensors on the human body, the skin motion can be equated to body segment motion through a calibration procedure or by applying the data to actuators in a computer model of the human neck. The computer model of the neck can provide insights into the biomechanical behavior of the cervical spinal column by producing data on disk pressure during certain activities.

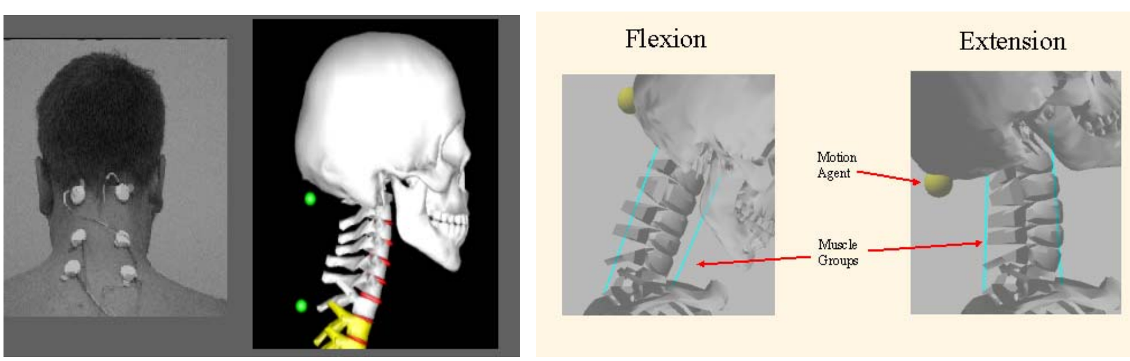

Figure 4 - Sensors on test subject, and motion agents on model.

The data collection device (Orthoson), which is portable and attached to the subject's waist, assesses body movements with an ultrasonic measurement method. Each sensor pair records the skin dilation between the two and can calibrate it to a distance measurement. These distance measurements, when placed strategically on the body can be used to capture and record body segment motion (i.e., joint rotation). Figure 4 displays the arrangement of the sensors on the back of the neck and the head.
The base model is created for the human subject based on the height and weight. The base model is refined to represent the cervical spine with 9 parts: C1-7, the skull, and the upper torso.

The parts are modeled as rigid bodies and coupled together with hinge joints since the motion is strictly in the sagittal plane for this flexion/extension example. For this present study, the ligament forces are represented as spring/damper elements to deny bone impingement. Rotational spring/damper elements are used at the hinge joints to represent the composite stiffness of the stabilizing musculature in the neck. Data for these forces were derived from (Kelps, 1988). Contact forces at the anterior side of the vertebrae provide the compliance properties of the disks using force/deflection data from (Matyjewski, 1995).

To drive the dynamic model using data from the ultrasonic device, motion agents are added to the model. A motion agent consists of two parts: one, which moves via the motion reported from the ultrasonic sensors, and one, which is connected to the local bone. The two parts themselves are connected together by a 6 DOF spring. This arrangement allows for error between data collection and the model by constraining the motion produced by the data to the physics of the model. A simulation is then performed to capture the muscle elongation history of the flexion/extension muscle groups. After this simulation is performed, the motion agents are stripped from the model and PD controllers are automatically installed to create the muscle forces. The PD controller provides muscle tension force based on tracking the elongation history from the previous simulation (Figure 5). Data retrieved from the simulation includes cervical joint kinematics, contact forces and disk pressures for the flexion/extension motion of the neck. This data was in agreement with the general profiles reported in (Begeman, 1973).

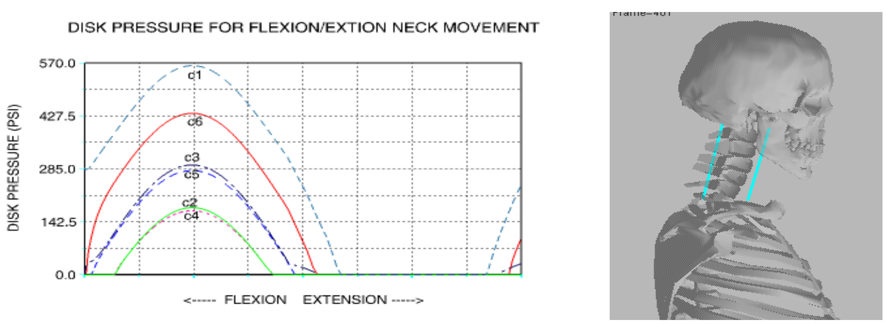

Figure 5 - Animation and results from simulation.

CONCLUSION: This study was intended to provide the reader with an exposure to the modeling paradigm of the FIGURE Human Modeler by developing a methodology to generate the internal reactions of the neck based on skin deformation data from the newly introduced Orthoson device. The near-term practical utility of this work is to study neck motion and loading during a severe sports activity such as American football.

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