Real-Time Musculoskeletal Model for Injury Simulation on 3D Human Characters

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Abstract. We describe a real-time musculoskeletal model created for the purpose of simulating localized injuries on animated 3D human characters. The baseline experiment will include projectile injuries that are compared and validated against experimental data from the science of ballistics. The research will also include an injury assessment model suitable for motion editing purposes that looks at the total combined injury from separate biological layers such as bone, muscle, and fat tissues.

Keywords: musculoskeletal model, injury simulation, human character, OpenSim

1 Introduction

Human character animation affected by musculoskeletal injuries in real-time might be considered a next step for interactive media such as video games. It adds one extra layer of realism to the expected behavior of the human character while interacting with its virtual environment. For instance, assessment of an injury would influence the amount of DOFs that a character is able to perform. Because our injury assessment model focuses mostly on the geometrical component, it could be added on top of biologically-based locomotion controllers such as [1] thereby increasing the realism of the dynamic computations to better reflect the character's current physical circumstance.

The first goal is to design a technique that can be used to simulate a musculoskeletal model that is prone to damage by external forces and how such interactions can be accomplished in real-time. The methods used in this technique will be validated through comparison with experimental data from other areas including ballistics. The second goal would be to create a combined injury assessment model that could be used for motion editing purposes in the future. For instance, looking at the amount of injuries sustained at the muscle layer would determine the amount of torque that can be generated at relevant joint angles within the newly injured configuration.

2 The Musculoskeletal Model

As input for the musculoskeletal model, biomechanical data was chosen from the pivotal work of [2] that includes physical properties such as optimal fiber lengths for each muscle and muscle origin and insertion points relative to parent joints. For the rigid skeletal meshes, these were borrowed from [3] that were created for the OpenSim software and includes models for both upper and lower extremities of the musculoskeletal system. However, only the lower extremity is currently used as a first tryout. The soft muscle meshes are currently constructed from simple cylinders during run-time, similar to the work of [4]. Currently, each muscle consists of up to four cross sections, each section is divided into six patches of two triangles each. The area specified on each cross section can be varied resulting in the fusiform shapes seen in Figure 1. Therefore, modifying the vertices at each cross section gives the possibility to modify the volume in real-time.

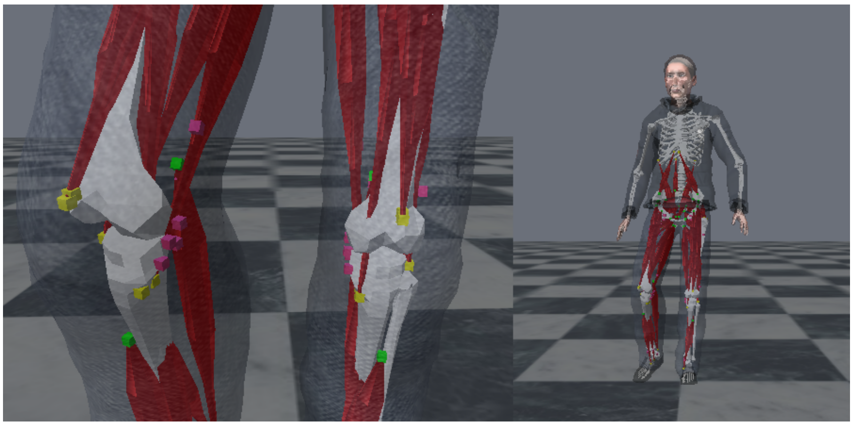

Fig. 1. Screenshot of preliminary musculoskeletal model including data from [3].

3 Muscle Shape Dynamics and Injury Simulation

Within the active musculoskeletal system, muscles would have to deform in real-time with physical constraints such as volume preservation. Model constraints defined by via points that are present in [3] would also have to be taken into account. Furthermore, penetration with the skeleton, other muscles, and character mesh should be avoided to maintain a realistic anatomical configuration fit for injury simulation.

Except for the skeletal system, the human muscular system comprises of mostly elastic material. This elastic property requires the use of techniques that can simulate soft-body dynamics. The most popular method, the finite element method suffers from high computational costs due to the computational complexity of its solver [5]. Several advances have been made on this regard, such as [6], [7], and [8]. However, other methods such as the boundary element method or a more simpler spring-mass model such as the one given in [9] could be adapted for this model.

With respect to injury simulation, as of this writing the baseline experiment will consist of projectile based injuries i.e. bullet wounds. This is due to experimental data that is available from the ballistic research that allows for validation of the technique through comparison with experiments such as the ones carried out on calibrated gelatin models. To give an example, ballistic research from [10] explores the distinctive features of bullet wounds such as temporary and permanent cavities that are dependent on the design of the bullet, seen in Figure 2. This dependency will help in the validation of the technique by comparing the results of the simulation with several types of bullet designs. Furthermore, because each bullet type leaves behind a specific damage signature, a boundary can be obtained from experimental data that limits the volume that the simulation has to solve thereby increasing real-time performance.

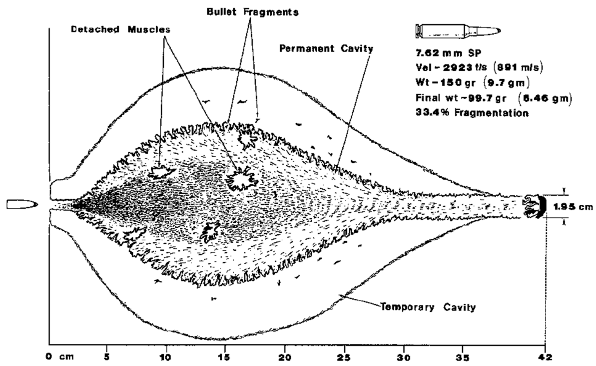

Fig. 2. Wound profile taken from [10] depicts the effects of a 7.62 NATO cartridge that is loaded with a soft-point hunting bullet. The profile illustrates among other things that the permanent cavity expands more than twice the diameter of the original bullet and that the bullet itself loses about one third of its mass due to fragmentation. A process where small pieces of the bullet gets separated due to deformation of the bullet upon impact.

Finally, an injury assessment method will be developed that looks at the combined inflicted damage on three separate layers, namely the fat, muscle, and skeletal layers. For the skeletal layer, the amount of bone tissue disruption could give an indication on the amount of force that cannot be transferred to other connected bone segments. Regarding the muscle layer, instead of trying to simulate bundles of muscle fibers in real-time, an approximation can be used which takes the angle between two vectors; the vector that defines the general direction of muscle fibers within a fiber bundle and another vector that defines the general direction of the passed projectile. This angle consequently indicates the amount of muscle fibers that have been damaged proportionally and could be used to account for the amount of force that cannot be exerted from the injured muscle. This angle is referred to in biomechanical literature as the *pennation angle*. With respect to fat tissue, more research is required from biomechanics to see whether a method could be created that links damage of fat tissue with a decrease in human movement performance. If no suitable link can be found, fat tissue will only serve as an added representation layer within the inner anatomy of the human character.

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