Dynamics Computation of Musculo-Skeletal Human Model Based on Efficient Algorithm for Closed Kinematic Chains

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1. Introduction

There are many researches on motion analysis and motion simulations of Musculo-Skeletal human model in the field of sports science and medicine. However, these researches uses simplified models or limited models, so they could not deal with whole body motions becasue of the high computational cost of whole body detailed human model. By applying the dynamics computation of closed kinematic chains, we enabled forward/inverse dynamics computation of the Musculo-Skeletal human model in a practical time.

2. Musculo-Skeletal Model

The detailed human model we designed is comprised of the skeleton and the musculotendon network. We produced polygon skeleton model by reconstructing CT cross-sections, and grouped bones under some simplification. Then we put muscles, tendons, and ligaments onto the skeleton model. We modeled most of muscles/tendons/ligaments as a wire which have a origin and an end. Some of the elements that have complex structure were modeled by introducing one or more via-points in between, or by putting virtual links.

3. Efficient Dynamics Computation of Musculo-Skeletal Human Model

Forward Dynamics computation is based on the following procedures:

1. Compute $\boldsymbol{J} \in \boldsymbol{R}^{N_l \times N_G}$, the Jacobian matrix of wire lengths with respect to the generalized coordinates.
2. Using the Jacobian matrix obtained above, transfer wire tensions into generalized force: in this case joint torques.
3. Compute the motion which will be generated from the joint torques using forward dynamics computation of kinematic chains.

Inverse Dynamics computation requires the following procedures:

1. Applying inverse dynamics computation of kinematic chains to the given motion data, and obtain joint torques $\boldsymbol{\tau}_G$.
2. Mapping of the joint torques to the wire tensions $\boldsymbol{f}$.

The mapping problem is difficult because the number of wires are quite larger than that of link joints. We used mathematical programming method to solve this redundancy problem.

4. Experimental Results

In forward dynamics experiment, we set all muscle force as zero, and simulated motion when we hang the head. Fig.1 shows the simulation result wich the body hanged down according to the gravitational pull.

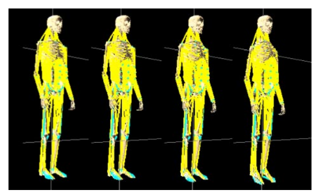

Figure 1: an Example of Forward Dynamics

In inverse dynamics experiment, we used motion captured data of "kicking" for the motion data and computed wire tensions from the data. We visualized the wire tensions by classifying the force by color. Fig.2 shows the result from the computation.

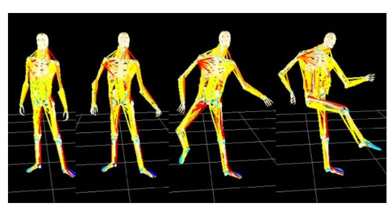

Figure 2: an Example of Inverse Dynamics

5. Conclusion

We proposed modeling methods for human dynamic system which the musculotendons are computable as kinematic chains, and we designed a detailed human model based on the modeling methods. We also developed computational algorithms for inverse/forward dynamics of wire-based human model. The computational algorithms were successfully implemented.