Simulating Pathological Gait using the Angular Momentum Inducing Inverted Pendulum Model

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INTRODUCTION

In this study, we propose a new method to simulate human gait motion when muscles are weakened. The method is based on the enhanced version of 3D linear inverted pendulum model that is used for generation of gait in robotics. After the normal gait motion is generated by setting the initial posture and the parameters that decide the trajectories of the center of mass and angular momentum, the muscle to be weakened is specified. By minimizing an objective function based on the force exerted by the specified muscle during the motion, the set of parameters that represent the pathological gait was calculated. By using our method, it is possible to find out the general idea how an impairment of a muscle can affect biped gait. By doing further concise modeling of the musculoskeletal and development of techniques to import parameters from individual humans, it will be possible to use the proposed method for analysis, diagnosis, and rehabilitation training of patients with impairments at the muscles. The effects of weakening the gluteus medialis were analyzed. Important similarities were noted when comparing the predicted pendulum motion with data obtained from an actual patient

METHODS

The 3D Linear Inverted Pendulum Mode [1], a method to plan biped locomotion of robots, was enhanced so that angular momentum can be generated around the center of mass. Since angular momentum is consistently generated around the center of mass when human perform gait motion, this function is essential to generate gait motion similar to humans. This model is called Angular Momentum inducing inverted Pendulum Model (AMPM). Using AMPM, the human gait was modeled. We then introduce a method to combine using the musculoskeletal model with AMPM. A musculoskeletal model based on Delp's data [2] was prepared to estimate the muscle force by using static optimization [3]. The gait motion was first modeled using AMPM, and then the motion was tuned by changing the parameters that define the behavior of AMPM by optimizing a criteria based on the musculoskeletal dynamics.

RESULTS AND DISCUSSION

To examine the validity of the method proposed in this paper, we have generated normal and pathological human gait motion using our method, and compared the kinematical and dynamical data with those by humans. A set of AMPM parameters that produce a gait motion with a step length of 0.6 m and velocity of 1 m/s were used. By minimizing an objective function based on muscle dynamic, the effects of weakening the gluteus medialis, was simulated. As the optimization proceeds, features known as lateral trunk bending appears in the motion. The trunk swings from one side to the other, producing a gait pattern known as waddling. During the double support phase, the trunk is generally upright, but as soon as the single support phase begins, the trunk leans over the support leg, returning to the upright attitude again at the beginning of the next double support phase.

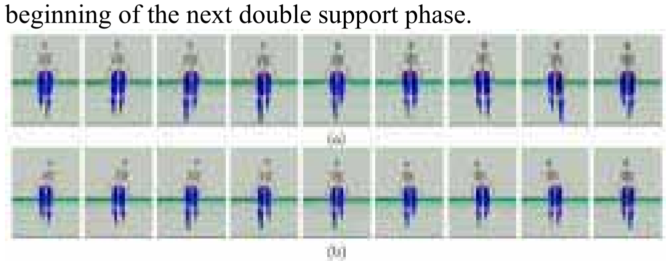

Figure 1 The trajectory of the AMPM-generated motion before (a) and after (b) the optimizing an objective function based on gluteus medialis.

The method proposed in this study has the following advantages compared with previous methods:

- Since the gait motion is described by the AMPM parameters, there is no need to specify all the input parameters of the muscles. As a result, the computational cost for the optimization is much less than previous methods.
- As the balance of the human body model is explicitly kept by using the AMPM model, the optimizer only needs to search for the optimal set of parameters in terms of muscle force, and hence does not need to go through a large number of trials to generate the balanced motion.

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