PREDICTION OF HUMAN WALKING BASED ON SIMPLE GAIT DESCRIPTORS

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INTRODUCTION

Gait prediction has many potential applications including the investigation of: motor control objectives in gait; the impact of musculoskeletal structure and injury on movement coordination; and the effect of assistive devices on locomotion performance [1]. Dynamic optimisation combined with the forward dynamics method offers a possible solution, however, it leads to very large computational burdens [2]. The inverse dynamics method, with its high computational efficiency, may provide an alternative means of gait prediction [3].

In this study, an inverse dynamics multi-segment model was combined with optimisation techniques to simulate normal human walking in the sagittal plane on level ground. Walking is formulated as an optimal motor task, subject to multiple constraints, with minimisation of mechanical energy consumption being the performance criterion. All segmental motions and ground reactions were predicted from only two simple gait descriptors: walking velocity and cycle period.

METHODS

The human body is modelled as a dynamic coupled multi-segment system containing seven segments: the right and left thighs, shanks, and feet together with a HAT segment (head, arms and trunk). The segments are connected by frictionless hinge joints, and the model accounts only for segmental motions in the sagittal plane. The foot is modelled as a rigid body with a curved surface rolling on the ground without slipping.

A set of kinematic variables (segmental angles) are used to define the motion of the model. During walking, the motion of the stance ankle can be determined by the shape of the plantar surface of the stance foot and its orientation. Thereafter, the motion of each body segment can be derived based on the topology of the model, the segmental angles and the stance ankle motions.

An inverse dynamics method is employed to calculate the joint kinetics and mechanical energy expenditure during walking. As the ground reactions are initially unknown, the inverse dynamics algorithm is based only on segmental motions [4], where a linear transfer assumption is used to solve the indeterminacy problem during the double support phase [4].

In this study, the gait prediction problem is formulated as an optimisation problem, which can be described as: find segment trajectories that achieve the specified gait parameters, whilst minimizing energy cost, and satisfying the constraints associated with a walking gait. Multiple constraints are implemented in the optimisation, which can be broadly categorized as: task constraints, biomechanical constraints and environmental constraints.

RESULTS AND DISCUSSION

The optimisation scheme was implemented in the MATLAB (Mathworks, MA, USA) programming environment using the SQP (Sequential Quadratic Programming) optimisation algorithm. The two input gait descriptors (walking velocity and cycle period) were obtained from the gait measurement data of one subject (age: 38years, weight: 101.7kg, height: 178cm), where the averaged values from four repeated normal walking trials were used.

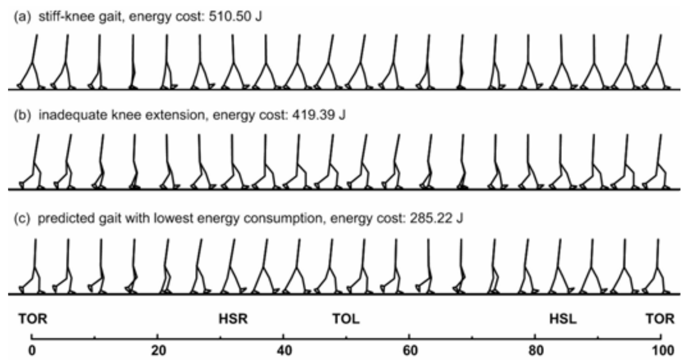

Figure 1: Some typical gait patterns (local minima) found during the random optimisation runs. The model (weight, 101.7 kg) walked at 1.50 m/s, with a cycle period of 1.0 s.

To find optimal solutions (local minima), the minimization was repeated with different random initial values. Due to the high non-linearity of human walking, several local minima were obtained (Figure 1). It was found that the solution with the lowest energy consumption (Figure 1(c)) yields the most realistic gait pattern.

Quantitative comparisons of the predicted ground reactions and segmental motions with gait measurements show that the model reproduced the significant characteristics of normal gait in the sagittal plane. The simulation results suggest that minimising energy expenditure is a primary control objective in normal walking. However, there is also some evidence for the existence of multiple concurrent performance objectives.

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