ANGULAR MOMENTUM CONTROL OF FORWARD DYNAMIC WALKING

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INTRODUCTION

Stable walking, in particular the balance and postural stability during gait, has been widely studied in robotics. However, only a few studies have used angular momentum about the center of mass (CoM) to create stable bipedal gait (Goswami 2004). Popovic(2004a) demonstrated the regulation of angular moment of the full body around its CoM and presented a control strategy where the system angular momentum was explicitly controlled (2004b). This strategy was however only presented for the single support phase of walking.

In this present study, we demonstrate the feasibility of stable walking simulations using angular momentum about the CoM as a control. Subject-specific human models were run in forward dynamics mode by applying controlled torques. Proportional and Derivative (PD) gain at each joint minimized the errors between individual segment's desired and simulated angular momentum about the CoM. Simulations included the determination of the ground reaction forces using a developed contact model between the foot and the floor.

METHODS

Clinical gait kinematics of 3 test subjects without history of lower extremity pathology were used to develop/validate the patient specific models. All kinematics were collected using Vicon motion analysis system (Oxford, UK).

From this data the angular momentum about the CoM for each body segment was calculated and averaged for each subject. This data was used to populate the 19xN angular momentum matrix [A] where N is the number of data points over a gait cycle.

For each subject, a full body model was created in MSC.Adams (MSC.Software) using LifeMod (Biomechanics Research Group, Inc). Models were made patient-specific using subject anthropometric data. The models were composed of 19 segments and 16 joints representing a full body in three dimensions though motion was constrained to the sagittal plane for these simulations. A contact model (foot/floor interaction) is used to compute the ground reaction force when the foot is in contact with the floor and Coulomb friction is applied between the foot geometries and the floor. Contact parameters (i.e. stiffness and damping) were optimized for better match to measured ground reaction force if experimental force plate data was available for one trial. However, this optimization process is not mandatory.

Forward dynamic simulations were run using the angular momentum about the CoM of each segment, [A], as a negative feedback control. At each subsequent time point, 1,2,…N, in the gait cycle standard proportional and differential (PD) feedback gain were used to determine individual joint torques applied during the simulation to minimized error between desired and simulated angular momentum.

RESULTS/VALIDATION

Forward dynamic simulations were successfully completed using the subject-specific human model, foot/floor contact model, and PD control for both the single and double support phases of gait. Figure 1 shows agreement between the clinically measured joint angles and the forward dynamic solution for a single subject. Figure 2 shows the degree of agreement between measured and computed ground reaction forces for the same subject. Results for the other subjects were similar.

Analysis also found that angular momentum computed from the kinematics data collected experimentally show invariance with walking speed. These results are consistent with the ones published by Popovic(2004b) and should allow computation of different walking speeds with the same angular momentum control.

CONCLUSIONS

Stable walking patterns are simulated using angular momentum about the full body CoM as high level control. The trajectories produced using PD controllers (tracking reference angular momenta) correlate with the reference trajectories.

The subject specific models make no assumptions with regard to symmetry and the entire gait cycle is computed. Thus this methodology is applicable to subjects with gait pathology. Our research has found that children with cerebral palsy have angular momentums with patterns similar to a typical walker. Extension of this work to pathologic gait is underway.

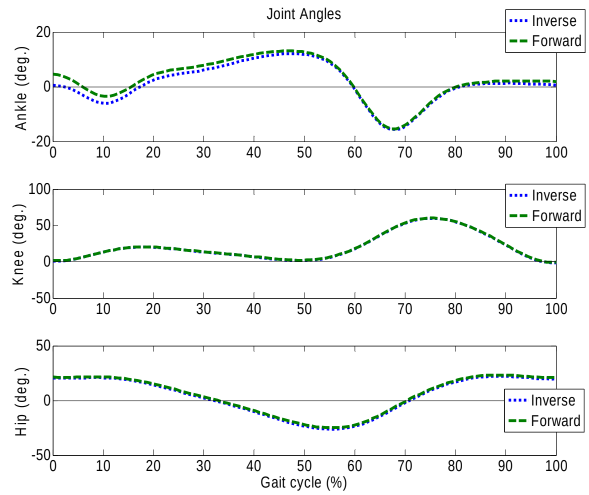

Figure 1: Ankle, knee, and hip angles during inverse and forward simulation.

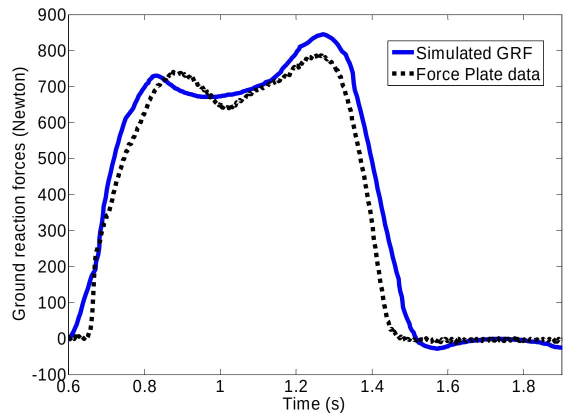

Figure 2: Simulated and experimental ground reaction forces.

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