the steps of computing assist torques of the augmentation device, based on simulated kinematic data and computing torques based on the simulated kinematic data, desired kinematic data of the segments and the assist torques. The method further comprises the steps of checking and adjusting the computed torques and computing the simulated kinematic data of the segments based on the computed torques at the joints.

[0013] According to another aspect of the invention, a computer readable medium containing a program for simulating a combined musculoskeletal and augmentation device system including segments and joints connecting the segments, is provided. The program comprises instructions of computing assist torques of the augmentation device, based on simulated kinematic data and of computing torques based on the simulated kinematic data, desired kinematic data of the segments, and the assist torques. The program further comprises instructions of checking and adjusting the computed torques and of computing the simulated kinematic data of the segments based on computed torques at the joints.

[0014] According to an embodiment of the invention, muscle forces are deduced from the computed torques, compared with maximum force limits and adjusted if the muscle forces exceed limits, to obtain feasible torques.

[0015] According to another embodiment of the invention, muscle forces with and without the assist torques are compared in order to asses whether the assist torque control helps or hinders motion and if the assist torque control hinders motion the muscle forces are adjusted and feasible joint torques are computed.

[0016] According to another embodiment of the invention, muscle forces with and without the assist torques are compared in order to asses whether the assist torque control helps or hinders motion and if the assist torque control hinders motion the assist torque control law is adjusted to ensure that feasible joint torques are computed.

[0017] According to another embodiment of the invention, muscle forces are deduced based on a static optimization criterion in which a sum of muscle activation squared is minimized.

[0018] According to another embodiment of the invention, modified accelerations of kinematic data are obtained through non-linear position and velocity feedback from the simulated kinematic data.

[0019] According to another embodiment of the invention, the kinematic data include position data, velocity data and acceleration data and estimates of kinematic data are computed, through non-linear feedback based on desired acceleration data, error between simulated position data and desired position data and error between simulated velocity data and desired velocity data.

[0020] According to another embodiment of the invention, the kinematic data include position data, velocity data and acceleration data and estimates of kinematic data are computed, through non-linear feedback based on error between simulated position data and desired position data and/or error between simulated velocity data and desired velocity data.

[0021] According to another embodiment of the invention, computed reaction forces under the segments contacting the ground are obtained based on the feasible computed torques and the simulated kinematic data.

[0022] According to another embodiment of the invention, gravity compensation control algorithm is employed, in which the assist torques are obtained to reduce the computed muscle force by artificially compensating for the forces due to gravity.

[0023] According to another embodiment of the invention, change in the computed torques, due to compensation for gravity is obtained, using coordinates of the center of the mass of the segments.

[0024] According to another embodiment of the invention, the coordinates of the center of the mass of the segments, are obtained from measurements of joint angles and segment lengths.

[0025] According to another embodiment of the invention, change in the computed torques, due to compensation for gravity, is obtained using measured reaction forces under the feet.

[0026] According to another embodiment of the invention, the feedback gains are selected to produce the fastest possible non-oscillatory response.

DESCRIPTION OF THE DRAWINGS

[0027] **FIG. 1 a** biped system having five degrees of freedom in the sagittal plane with intermittent ground contact during double support, single support, and air-born phase;

[0028] **FIG. 2** is a system model description with intermittent contact of left and right feet with the ground;

[0029] **FIG. 3** is an inverse dynamics controller with position and velocity feedback for calculation of torques that when applied to a system model, will track and reproduce the desired kinematic data;

[0030] **FIG. 4** is a muscle force and muscle capacity module;

[0031] **FIG. 5** is a block-diagram of the integrated simulation system;

[0032] **FIG. 6** is a flowchart illustrating a simulation process according to an aspect of the present invention;

[0033] **FIG. 7** is a simulation of the joint angles during a squatting maneuver without employing the desired accelerations (a=0), in which nearly perfect tracking of desired kinematic trajectories is illustrated;

[0034] **FIG. 8** is a simulation of the joint torques during a squatting maneuver without employing the desired accelerations (a=0), in which the proposed method using nonlinear feedback (NLF) produces nearly identical joint torque estimates as compared to the ground truth (ideal) joint torques obtained by a noise free inverse dynamics computation; and

[0035] **FIG. 9** is a simulation of the horizontal and vertical ground reaction forces during a squatting maneuver without employing the desired accelerations (a=0), in which the proposed method using nonlinear feedback (NLF) produces