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[0059] The computed muscle forces are then compared with physiological capacity of the muscle in the muscle capacity module **420**. The maximum force limits can be ascertained from the well-studied force-length-velocity relationship of muscle (Zajac 1989, cited above). In addition, the muscle forces with and without the assist torque are compared in order to assess whether the assist torque control has helped (improved efficiency) or hindered the motion. If the assist torque control hinders motion, the muscle forces are adjusted and feasible joint torques are computed (modules **430** and **440** in **FIG. 4**). A poorly designed assist control would then result in $D\tau' \neq D\tau$, producing a simulated response that would not track the desired response. If the assist torques are well designed, $D\tau' = D\tau$ and the resulting motion would track the desired motion.

[0060] Augmentation Device Controller

[0061] The inputs to the human augmentation device may include the sensed state variables q_s and/or $\dot{q}_s$, which can be directly measured or estimated. These inputs, denoted by $(q_s, \dot{q}_s)$ represent a subset of the total number of state variables $(q, \dot{q})$ in our human model. In addition to the sensed state variables, measurements may also be used as input to the augmentation device controller. The augmentation device controller output represents the assist torque τ_a, which is then input to the inverse model.

[0062] Different control strategies may be used by the human augmentation device controller. For example, gravity compensation control can be used for tasks requiring an increase in potential energy of the total system (human and exoskeleton). Such tasks would include lifting objects, carrying loads, climbing stairs, rising from a chair, etc. A different control strategy, or hybrid control strategies, may be suitable for other tasks such as walking or running. Here, we will present the gravity compensation control algorithm.

[0063] By using the Lagrangian, we can assess the total potential energy of the musculoskeletal system. Let U denote the total potential energy stored in the system,

$$U = \sum_{i-1}^{n} m_j g^T X_1 \tag{12}$$

[0064] The torque at joint i due to gravity can be computed by taking the partial derivative of U with respect to q_i,

$$D\tau_{gr} = \frac{\partial U}{\partial q_i} = \sum_{j=1}^{n} m_j g^T \frac{\partial X_j}{\partial q_i} \tag{13}$$

[0065] where g^T represents the gravitational acceleration vector, and X_j represents the coordinates of the center of mass of segment j. Suppose the knee joint between segment **1** and segment **2** is actuated by an augmentation device and the angle corresponding to q_2 (represents $q_s \subset q$) is measurable. The following control law may be used as one algorithm for the augmentation device controller

$$D\tau_a = D\tau_{gr} = \frac{\partial U}{\partial q_2} = \sum_{j=1}^{n} m_j g^T \frac{\partial X_j}{\partial q_2} \tag{4}$$

[0066] Note that the above control algorithm requires the center of mass positions of all the link segments (denoted by X_j). Although X_j can be derived from measurement of joint angles and segment lengths, it may not be feasible to measure all joint angles and all segment lengths. Alternatively, if the vertical component of the ground reaction force under each foot can be measured or estimated, it is possible to derive an iterative "ground up" gravity compensation algorithm which would eliminate the need for access to center of mass of every segment.

[0067] Integration of Modules

[0068] The block-diagram of the integrated modules as has been presented in the description is shown in **FIG. 5**. The Augmentation device controller is presumed to have as inputs the sensed states and output the assist torques. The overall framework is very general and enables flexible design of the augmentation device control signals. The details of such designs are easily made by those skilled in the art.

[0069] **FIG. 6** shows a flowchart illustrating a simulation process according to an embodiment of the present invention. At step **S605**, time t is set to 0. At step **S610**, desired kinematic data for the combined musculoskeletal and augmentation device system are obtained. The desired kinematic data may be obtained from motion capture data.

[0070] At step **S612**, the simulated kinematic data is fed back to obtain tracking error.

[0071] At step **S615**, modified accelerations $\ddot{q}^*$ are computed using Equation 6.

[0072] At step **617**, the sensed kinematic data is fed back.

[0073] At step **S620**, assist torques $D\tau_a$ are computed using the augmentation device controller **500**.

[0074] At step **S625**, torques $D\tau'$ are computed using Equation 5 (inverse model **300**).

[0075] At step **S630**, muscle forces are checked and adjusted to modify the corresponding torques (muscle force and capacity module **400**).

[0076] At step **S635**, the induced accelerations $\ddot{q}$ are computed using Equations 3 and 4 and the simulated kinematic data q and $\dot{q}$ are obtained by numerical integration (modules **200**, **210** and **220**).

[0077] At step **S640**, time t is incremented and at step **S645**, whether t is less than t_c or not is determined. If t is less than t_c, the process returns to step **S610**. If t is equal to or greater than t_c, the process ends.