[0054] One example uses redundant position sensing. The joint position of each DOF is sensed by two sensors: a shaft encoder located on the actuator and potentiometer located on the exoskeleton joint. This redundant setup of sensors allows triggering an E-stop in any case that a discrepancy between the readout of the two sensors will be identified. Such a discrepancy may occur whenever one of the sensors fails or any damage to the structure element takes place such as mechanical cable breakout or mechanical deformation of the link.

[0055] One example uses an emergency stop or "E-stop." An E-stop is a state of the system that can be triggered both by hardware and software. One example of the system includes three E-stop buttons that can be activated by the user, the exoskeleton operator or the therapist. Upon pressing the E-stop button, the power to the servo amplifiers is disconnected and the brakes are engaged. In addition software based E-stop triggers the same response to the hardware trigger base on sensors' discrepancy and internal logic that is incorporated into the system (e.g. position sensors miss-match, exceeding operational envelop).

[0056] At the software level, one example of the system includes redundant position sensors (potentiometer—Midori, Fullerton; shaft encoder—HP), with one sensor each at either end of the power train to monitor both joint motion and motor position. Redundant position sensing enables the software to monitor power transmission integrity; any slip occurring between the motors and end-effector will result in a position discrepancy and lead to immediate system shutdown. Software limits are also implemented on commanded motor currents, (for example, motor torques).

[0057] One example includes position/velocity/acceleration limits. These thresholds on the position, velocity and acceleration of the joints are implemented into the control software. These limits gradually increase over time based on the operator conditions up to values associated with a controlled movement of a normal subject. The system will freeze (e-stop) if the operational value will reach a safeguard margin of 5% of the selected limits.

[0058] One example includes force limits. Force limits are thresholds on the interaction forces between the exoskeleton and the operator that are implemented into the control software. High interaction forces may develop if the exoskeleton moves to the opposite direction of the operator or when the movement exceeds the workspace of the operator. These limits will gradually increase based on the operator conditions up to values associated with controlled movements of a normal subject. The system will freeze (e-stop) if the operational value will reach a safeguard margin of 5% of the selected limits.

[0059] One example includes virtual fixtures. These are thresholds on the range of motion of each joint which are smaller than the normal range of motion implemented in software. The exoskeleton will stop once the joint angle reaches its limit. Any application of force as an attempt to exceed this limit will trigger the force limit and will result in an e-stop. The joint range of motion will be gradually increased based on the operator conditions up to the maximal physical joint limits that are incorporated into the hardware of the system.

[0060] One example includes gravity compensation. Gravity compensation is the ability of the system to support its own weight as well as the weight of the operator's arm and hand. The gravitational compensation implementation emulates arm and hand movements in a zero gravity environment. The joint torque for compensating the gravitational loads are calculated base on a dynamical model running in real time. This algorithm calculates the required joint torques base on the joint position and the anthropometrical information of the patient arm. Based on this calculation a set of commands is sent to the exoskeleton actuators (servo DC motors) utilizing a feed-forward control. In one example, the joint torques generated by the 7 actuators always supports the gravitational loads that are generated by the exoskeleton arm itself however the extent in which the patient's arm is supported can be adoptive based on the experimental protocol and recovery of the subject. The present subject matter enables adapting the gravitational field for different circumstances. Gravity compensation as a mode of operation can affect treatment in a therapeutic application. The gravitational field can be gradually introduced as the treatment is progressing by gradually decreasing the compensation. However, gravity compensation can also be used as a safety precaution allowing the patient with limited muscle strength to explore the entire reachable workspace without exposure to gravitational loads which often exceed the muscle strength of the disabled operator and cause pain in proximal joints.

[0061] C. Modeling the Human

[0062] Anthropomorphic joint approximations can be modeled at varying degrees of accuracy and complexity. The level of complexity for a suitable representation depends on the desired tasks to be performed and replicated using the model. Shoulder motion, for example, including a glenohumeral (G-H), acromioclavicular, and sternoclavicular articulations, can be represented largely by the G-H joint for a variety of arm activities involving up to 90 degrees of arm elevation. With minimal activity exceeding this range, a simplified model of the shoulder may be appropriate. The G-H movement can further be simplified to a ball and socket joint having three orthogonal axes intersecting at the center of the humeral head, although the true center of rotation may vary with arm orientation. Rotations about these orthogonal axes can be treated as Euler rotations. The order of flexion-extension and abduction-adduction about the first two axes is arbitrary but should be noted, while the third rotation corresponds to internal-external rotation.

[0063] The elbow can be represented as a single-axis hinge joint where the hinge rests at an oblique angle with respect to both upper and lower arm segments under full arm extension as shown in FIGS. **2**A, **2**B, and **2**C.

[0064] FIG. **2** illustrates angular variations between elbow flexion-extension and pronosupination axes resulting in different elbow flexion kinematics. FIG. **2**A illustrates a Type I elbow having a symmetric axis with respect to both upper and lower arm segments. FIG. **2**B and FIG. **2**C illustrate less common examples.

[0065] Of the three elbow types, Type I (shown in FIG. **2**A) is relatively common and is used in one example. The hinge offset accounts for lateral deviation of the forearm during supinated activities. Under full elbow extension and forearm supination, angular differences, β, of up to 10 degrees exist between the midlines of the upper and lower arm segments, and decrease with pronation. In one example,