generation of assistive technology for both healthy and disabled people. For many physical tasks, human performance is limited by muscle strength. In addition, muscle weakness is the primary cause of disability for most people with neuromuscular diseases, including stroke, spinal cord injury, muscular dystrophies, and other neuro-degenerative disorders. In contrast to this strength limitation, humans possess specialized and complex algorithms for control of movement, involving higher and lower neural centers, that enable them to perform very complicated tasks such as locomotion and arm movement, while at the same time avoiding object collisions. In contrast, robotic manipulators can be designed to perform tasks requiring large forces or moments, depending on their structure and on the power of their actuators. However the control algorithms which govern their dynamics lack the flexibility to perform in a wide rage of conditions while preserving the same quality of performance as humans. Combining these two entities, the human and the robot into one integrated system under the control of the human, can benefit from the advantages offered by each subsystem. The mechanical power of the machine, integrated with the inherent human control system, could allow efficient performance of tasks requiring higher forces than the human could otherwise produce.

[0040] The HMI can be set at the neuromuscular level using processed sEMG signals initiated by the human's central nervous system to contract the human's own actuators—the muscles, as the primary control signal to the exoskeleton. As opposed to neural prostheses that provide control using EMG signals as simple on/off switches, with assistance from visual feedback, the exoskeleton device incorporates more complex control algorithm. This provides a more natural operation of the device, due to the high level of synergism resulting from the operator arm being in full contact with the exoskeleton.

[0041] The present subject matter enables prediction of the force generated by the muscle solely based on processed EMG signals. Such predictions are made in an isometric condition (static conditions). In dynamic conditions where the muscle is changing length and velocity, the situation is different.

[0042] The present subject matter leaves the EMG signal in its original domain as a neural signal. Using a signal processing algorithm, the neural activation of the muscle is predicted from the raw EMG signals. In addition to the neural activation levels, the myoprocessor takes into account the joint's kinematics to predict the muscle force and the moment applied on the joint. The myprocessor prediction is essentially the command signal to the hard core control system.

I. PRELIMINARIES

Performance

[0043] A quantitative measure of system performance is bandwidth. Systems having a higher bandwidth are controllable under higher frequency command signals. Limited by the system's lowest natural frequency, the bandwidth is a measure of how success as to the trade-offs between weight and stiffness.

[0044] In one example of the present subject matter, the bandwidth is 10 Hz based on actual weights of 3.5 kg and 6.3 kg for link 1 and links 2-7, respectively.

[0045] In various examples of the present subject matter, the exoskeleton is controlled based on a level of the human machine interface (HMI) between the exoskeleton robot and the human operator described as: (I) kinematic; (II) dynamic; (III) neuromuscular, e.g., surface electromyography (sEMG); (IV) brain, e.g., noninvasive electroencephalogram (EEG) or invasive action potential signal measured directly from the motor cortex.

[0046] At the neuromuscular level, the body's own neural command signals are used as command signals of the exoskeleton. By establishing the interface at the neuromuscular level, the effects of muscle contractions can be estimated before these effects can be directly measured using other means (e.g., kinematic and dynamic interfaces). An electro-(chemical)-mechanical delay (EMD) inherently exists in the musculoskeletal system and this time delay refers to the interval between the time when the neural system activates the muscular system and the time when the muscles and the associated soft tissues contract mechanically and generate moments around the joints. EMD values vary considerably depending on the muscle, the person, and the experimental technique used for the measurements and can be assumed to be in the range of 26-131 ms with values for some upper limb muscles in the middle-lower part of this interval.

[0047] A. Physical (Mechanical) Human-Machine Interface(s)

[0048] The physical components that mechanically couples the human arm and the exoskeleton structure, and enable force transmission between them are referred to as the mechanical HMI (mHMI). The mHMI can be tailored to different users based on the level of muscular and functional impairment or other factors.

[0049] B. Safety Considerations

[0050] In various examples, safety precautions are implemented at the mechanical, electrical, and software levels.

[0051] At the mechanical (hardware) level, physical stops prevent segments from excessive excursions that could hyperextend or hyperflex individual joints of the user. Also, pulleys in some joints are driven purely by friction. This allows the transmission to slip if the force between user and device exceeds a set limit. In one example, brakes are provided on all actuators. Electromechanical brakes are used with all servo actuators. The brakes are design to overcome the maximal mechanical torques generated by the actuators. Engaging the brakes stop the movements of all the servo system at once, regardless of the inputs provided to the servo system. As a result the system freezes and maintains the arm position in space.

[0052] One example includes physical joint limits. As such, the Exoskeleton mechanism includes physical joint limits constraining the range of motion of each joint to the physiological/anatomical range of motion. These physical stops prevent any potential joint dislocation.

[0053] At the electrical level, the system is equipped with three emergency shutoff switches: an enable button that terminates the motor command signal upon release, a large e-stop button for complete power shutoff by the observer, and a similar e-stop foot switch for the user.