[0025] FIG. 13B illustrates rendered workspace of the upper limb with a limited range of motion of the joints.

[0026] FIG. 14 illustrates a block diagram of a system according to one example.

[0027] FIGS. 15A and 15B illustrate perspective views of a model human wearing an exoskeleton.

[0028] FIGS. 16A and 16B illustrate perspective views of an exoskeleton.

DETAILED DESCRIPTION

[0029] The following detailed description includes references to the accompanying drawings, which form a part of the detailed description. The drawings show, by way of illustration, specific embodiments in which the invention may be practiced. These embodiments are also referred to herein as "examples." The embodiments may be combined, other embodiments may be utilized, or structural, logical and electrical changes may be made without departing from the scope of the present invention. The following detailed description is, therefore, not to be taken in a limiting sense, and the scope of the present invention is defined by the appended claims and their equivalents.

[0030] In this document, the terms "a" or "an" are used, as is common in patent documents, to include one or more than one, independent of any other usages of "at least one" or "one or more." In this document, the term "or" is used to refer to a nonexclusive or, such that "A or B" includes "A but not B,""B but not A," and "A and B," unless otherwise indicated. Furthermore, all publications, patents, and patent documents referred to in this document are incorporated by reference herein in their entirety, as though individually incorporated by reference. In the event of inconsistent usages between this document and those documents so incorporated by reference, the usage in the incorporated reference(s) should be considered supplementary to that of this document; for irreconcilable inconsistencies, the usage in this document controls.

Introduction

[0031] In one example, the human-machine interface (HMI) is positioned at the neuromuscular level, a relatively high level of human physiological (neurological) system hierarchy, in order to reduce the effects of the electro-chemical-mechanical delay. The electro-chemical-mechanical delay, usually referred as the electro-mechanical delay (EMD), 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 mechanically contract and generate moments around the joints. By establishing the interface at the neuromuscular level, the present subject matter can estimate the forces that will be generated by the muscles, using a muscle model, before the muscle contraction actually occurs. As a result, the reaction time of the human/machine system is reduced, resulting in a more natural control of the task. In line with this concept, an exoskeleton is disclosed in which the HMI is set at the human neuromuscular junction.

[0032] The HMI of the present subject matter is positioned at the neuromuscular level and uses processed surface electromyographic (sEMG) signals as a command signal of the system as shown in FIG. 1. These signals are the same signals initiated by the human's central nervous system to contract the human's own actuators (the muscles). As such, this example uses a myoprocessor to control the structure.

[0033] FIG. 1 illustrates a block diagram of one example of the present subject matter. In system 100 illustrated in the figure, the input includes EMG signals 102 and joint kinematic data 104. The user's musculature system 106 and the exoskeleton 108 are in parallel alignment and coupled by mechanical link 110. The load 112 is shared by the parallel elements.

[0034] During the EMD, the system gathers information regarding the physiological muscle's neural activation level based on processed EMG signals, the joint position, and angular velocity. This information is provided to the myoprocessor which in turn predicts the moment that will be developed by the physiological muscle relative to the joint. The predicted moment is provided to the exoskeleton system such that, by the time the physiological muscle contracts, the exoskeleton amplifies the joint moment by a preselected gain factor. Part of the time gained by using these predicted muscle moments is employed by the electromechanical subsystems of the powered exoskeleton to compensate for their own inherent reaction time.

[0035] The upper limb includes segments linked by articulations with multiple degrees of freedom and is able to perform tasks involving both power and precision of movement. A lower limb exoskeleton system may also include control for balance and dynamic components of gait to allow standing and walking.

[0036] An electromechanical system may be fully portable or stationary. A portable system may be limited by the power to weight ratio of the power source. For the human upper limb, the exoskeleton system can be part of a stationary working station or fixed to the frame of a powered wheelchair and powered by the wheelchair battery or other power supply.

[0037] Setting the HMI at the neuro-muscular level may lead to seamless integration and intuitive control of the exoskeleton arm as a natural extension of the human body. One component of the exoskeleton HMI includes a model of the human muscle, the myoprocessor, running in real-time and in parallel to the physiological muscle, that predicts joint torques as a function of the joint kinematics and neural activation levels. One example of the present subject matter includes one or more myoprocessors for the upper limb based on the Hill phenomenological muscle model. In one example, a genetic algorithm is used to configure the internal parameters of the myoprocessors utilizing an experimental database that provides inputs to the model and allows for performance assessment.

[0038] Previous exoskeleton designs have primarily utilized internal-external rotation joints and prono-supination joints that fully enclose the arm, requiring the user to enter the exoskeleton from the device shoulder and slide his/her arm axially down the length of the device through the closed circular bearings. This can be a difficult and even uncomfortable task for users depending on the severity of impairment. In the current exoskeleton, the use of open mHMI's for both upper and lower arm segments eliminates this difficulty.

[0039] Integrating human and robotic-machines into one system offers multiple opportunities for creating a new