functional virtual human arms that are linked to the motion to the exoskeleton. The exoskeleton and the virtual reality are linked such that any motion generated by a person wearing the exoskeleton is presented in the virtual environment. The view is reflected to a pair of virtual reality goggles or eyeglasses worn by the user. In addition, joint velocities and joint toques are represented as vectors that are linked to each joint of the arm. Any gain factor can be introduced between the actual joint angle of the arm and their virtual representation in order to enhance arm movements.

[0225] One example of the present subject matter can be used for rehabilitation treatment for hemiparetic upper limb of patients with chronic stroke. The treatment utilizes an exoskeleton incorporated into an immersive virtual environment that facilitates three-dimensional arm movements. The combined effect of gravity compensation as a perturbation field can be gradually introduced by the exoskeleton along with an active assistance implemented as an impedance control. A treatment strategy which involves a gradual increase of a gravitational field from a micro-gravity field (weightless motion—0G) to a full gravity field (1G) along with a gradual decrease in robotic assistance can improve the motor recovery process. The combination of gradual increases in gravitational effects with decreased assistance, introduced in a cyclic pattern over multiple treatment sessions, may result not only in improved motor recovery, but to an extent greater than that which is achievable through full (0G) gravity compensation alone. There may also be improved ability to perform self-care activities using the hemiparetic limb.

[0226] An example of the present subject matter can also provided a robot-assisted quantitative measurements of upper limb impairment. Dynamic motor tests that employ virtual reality can be conducted using patients with chronic stroke, along with a number of conventional (non-robot-assisted) measures of impairment and disability.

The Virtual Reality Environment

[0227] Virtual environment may enable better control and provide more flexibility in creating the environment with which the patient can interact, as compared to the real physical environment. This environment allows the patient to view and physically interact with virtually any object with any physical properties. In addition, it enables altering of gravitational fields as well as guiding of visual information as the user interacts with the virtual objects.

[0228] In one example, the user dons a set of head mounted displays (HMD). The HMD includes two separate screens (one for each eye) allowing for rendering of virtual reality scenes separately for each eye in order to provide 3D immersed environments, as in FIG. **13**A. A head-tracking sensor is incorporated into the HMD allowing the user to view the scene from different angles. As the user moves his head, the virtual scene is rendered accordingly providing a sense of immersed environment. FIG. **13**B illustrates a user with a limited range of motion of the arm. The gray volume represents a morphing of the range of motion based on the individual range of motion of each joint. A view corresponding to that of FIG. **13**B is presented to the user via the HMD. In one example, the scene is visually rendered and also haptically rendered, meaning that force feedback is provided to the user once he or she touches the virtual objects or follows a path with virtual constraints. All the physical properties of a virtual object such as weight, stiffness, viscosity, texture, etc. are generated by the exoskeleton and conveyed to the user through this device. The user will feel a force as he/she presses the virtual cylinders. Virtual reality as a graphical interface can be implemented using a software package, in a OpenGL, for example. Various virtual objects, movement paths, and gravitational force fields can be implemented into the system.

[0229] As discussed elsewhere in this document, various applications can be met with one or more implementations of the present subject matter.

[0230] A. Physiotherapy—a user wearing the exoskeleton can perform task-based occupational therapy or physical therapy in an active or passive mode.

[0231] B. Assistive Device (human amplifier)—a user wearing the exoskeleton can manipulate or interact with an object or the environment in which the actual load is shared between the exoskeleton and the user.

[0232] C. Haptic device—a user wearing the exoskeleton can physically interact with a virtual reality object or scene while the forces generated through this interaction are fed back to the user through the exoskeleton conveying the shape, stiffness, texture or other physical characteristics of the virtual object or scene.

[0233] D. Master Device—a user wearing the exoskeleton can control a second robot in a master-slave relationship. As such, the user (master) can control a remote (slave) robotic system in a teleoperation mode, where the exoskeleton reflects back to the user the forces generated as the slave robot interacts with the environment. In one example, more than one slave device is controlled by a master device.

V. OTHER EXAMPLES

[0234] In one example, the range of motion for each joint at the shoulder, elbow and wrist is approximately 180 degrees, however ranges above or below this value are also contemplated.

[0235] In one example, the exoskeleton uses internal-external rotation joints and pronosupination joints that fully enclose the arm. In this case, the user inserts their arm from one end and slides it axially down the length of the arm.

[0236] In one example, the exoskeleton includes open mHMI's for both upper and lower arm segments, thus allowing the user to don the structure more comfortably.

[0237] As a result of the placement of the shoulder singularity, as described elsewhere in this document, pure shoulder flexion is achieved through a combination of rotations about joints **1** and **2**. In addition, this placement moves the region of highest shoulder joint isotropy into the area of the workspace most often utilized during functional tasks.

[0238] In one example, the axes at the wrist are anthropometrically correct in that there is a slight offset between the flexion-extension and radial-ulnar deviation axes. In one example, this offset is omitted.

[0239] One example includes a spring or other energy storage device to provide the drive power to the actuators.