ACTIVE ANKLE FOOT ORTHOSIS

BACKGROUND OF THE INVENTION

[0001] Individuals may suffer from a variety of ankle foot gait pathologies, such as muscle weakness in the anterior and/or posterior compartments of the leg, which severely inhibit locomotory function. For example, drop foot gait is the inability of an individual to lift or dorsiflex their foot because of reduced or no muscular activity, typically in the anterior compartment of the leg around their ankle. The major causes of drop foot include stroke, cerebral palsy, multiple sclerosis, and neurological trauma from accident or surgical complication. The two major complications of drop foot are slapping of the foot after heel strike (foot slap) and dragging of the toe during swing (toe drag). At heel strike, the foot generally falls uncontrolled to the ground, producing a distinctive slapping noise (foot slap). During mid-swing, toe drag prevents proper limb advancement and increases the risk of tripping.

[0002] A conventional approach to the treatment of drop foot gait is a mechanical brace called an Ankle Foot Orthosis (AFO), which has increased in popularity over the last several years. Although AFO's offer some biomechanical benefits, disadvantages still remain. For example, AFO's do not improve gait velocity or stride length in children with cerebral palsy. Further, although a constant stiffness AFO is able to provide safe toe clearance in drop foot patients, the device does not reduce the occurrence of slap foot at all walking speeds.

SUMMARY OF THE INVENTION

[0003] Increasingly, robotic technology is employed in the treatment of individuals suffering from physical disability, either for the advancement of therapy tools or permanent assistive devices. Initial research has focused primarily on devices that provide therapy to the arms of stroke patients. However, lower extremity robotic devices have recently been developed. When used for permanent assistance, adaptive orthoses enables disabled persons to walk with greater ease and less kinematic difference when compared to normals. Active leg prostheses also show promise. Preliminary studies report that the Otto Bock C-Leg, a microprocessor-controlled artificial knee, provides amputees with an increased independence compared with passive knee prostheses.

[0004] In one embodiment, a variable-impedance Active Ankle-Foot Orthosis (AAFO) is provided to treat ankle foot gait pathologies, such as drop foot gait.

[0005] Another embodiment for the treatment of ankle foot gait pathologies, such as drop foot gait, includes functional electrical stimulation (FES). Short bursts of electrical pulses can be applied to elicit muscle contractions. FES can be used as a permanent assistance device, and the technology can be customized to the individual using trial-and-error methods and qualitative measurements.

[0006] Neither AFOs nor conventional FES systems adapt to the gait of the user, adapt to step-to-step changes in gait pattern due to speed or terrain, or adapt to long-term gait changes due to changes in muscle function. In one embodiment, a computer-controlled Active Ankle Foot Orthosis (AAFO) is provided where joint impedance is varied in response to walking phase and step-to-step gait variations. The AAFO includes an actuator, such as a force-controllable Series Elastic Actuator (SEA) capable of controlling orthotic joint stiffness and damping for plantar and dorsiflexion ankle rotations.

[0007] A variable-impedance orthosis has certain clinical benefits for the treatment of drop foot gait compared to both unassisted gait and conventional AFO's that include constant impedance joint behaviors. For example, the major complications of drop foot gait, namely foot slap and toe drag, can be reduced by actively controlling orthotic joint impedance in response to walking phase and step-to-step gait variations. Recent investigations have shown that for the healthy ankle-foot complex, ankle function during controlled plantar flexion closely resembles a linear torsional spring where ankle moment is proportional to ankle position. Thus, by adjusting the stiffness of a virtual linear torsional spring acting about the orthotic joint, forefoot collisions can be minimized and the slap foot complication alleviated, not only at a single speed but at every forward walking speed. Furthermore, during swing, a spring-damper (PD) control can be applied to the orthotic joint, with gains that vary with gait speed, to dorsiflex the ankle through a greater angular range to provide sufficient clearance at variable walking speeds. For individuals suffering from unilateral drop foot gait, changing orthotic joint impedance results in a more symmetric gait between affected and unaffected legs.

BRIEF DESCRIPTION OF THE DRAWINGS

[0008] The foregoing and other objects, features and advantages of the invention will be apparent from the following more particular description of various embodiments of the invention, as illustrated in the accompanying drawings in which like reference characters refer to the same parts throughout the different views. The drawings are not necessarily to scale, emphasis instead being placed upon illustrating the principles of the invention.

[0009] **FIG. 1** is a side view of an embodiment of an Active Foot Orthosis (AAFO).

[0010] **FIG. 2** illustrates individual states for a finite machine.

[0011] **FIG. 3** illustrates triggers for the finite machine of **FIG. 2**.

[0012] **FIG. 4A** is a representative forefoot ground reaction force from a drop foot participant.

[0013] **FIG. 4B** is a representative forefoot ground reaction force from a normal participant.

[0014] **FIG. 5** illustrates orthotic joint stiffness plotted against the number of steps taken by a participant starting from an initial default impedance value of zero.

[0015] **FIG. 6** illustrates slap foot occurrences per 5 steps (n=5) measured on two drop foot subjects walking at slow, self-selected, and fast speeds.

[0016] **FIG. 7** is a plot of the amount of swing dorsiflexion for normal (n=3) and drop foot (n=2) participants.

[0017] **FIG. 8** illustrates the amount of powered plantar flexion for normal (n=3) and drop foot (n=2) participants.