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(54) Title: WEARABLE MATERIAL HANDLING SYSTEM

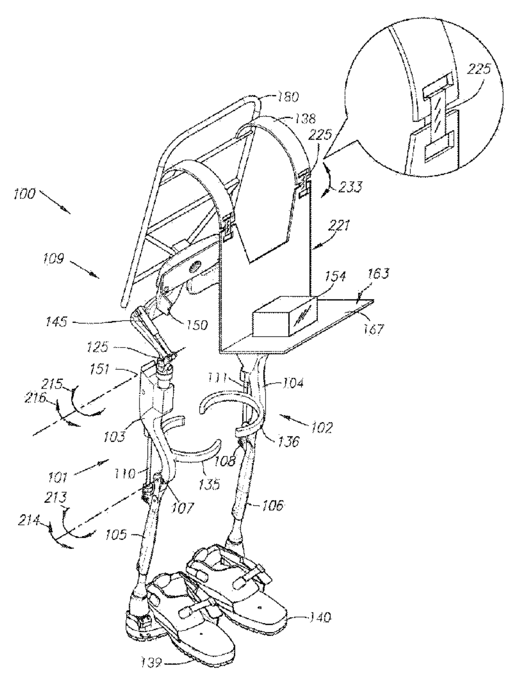

Fig. 4

(57) Abstract: An exoskeleton (100) configured to be coupled to a person (187) includes an exoskeleton trunk (109) and leg supports (101, 102) adapted to contact the ground. Hip torque generators (145, 146) extend between the exoskeleton trunk (109) and respective leg supports (101, 102). A load holding mechanism (221) is rotatably coupled to the exoskeleton trunk (109), preferably via over-shoulder members (138) configured to support a load (154) in front of the person (187). In use, hip torque generators (145, 146) create torque between the exoskeleton trunk (109) and respective leg supports (101, 102) in the stance phase, wherein at least one torque generator (145 or 146) is configured to create a first torque between the exoskeleton trunk (109) and one of the first and second leg supports (101, 102) in the stance phase opposing a second torque generated on the exoskeleton (100) by a weight of the load (154). Load bearing sensors (236, 303) may be utilized to determine the torque generated by the load (154) and communicate with a controller (137) to control power to the torque generators (145, 146).

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AMENDED CLAIMS
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1. An exoskeleton, configurable to be coupled to a person, said exoskeleton comprising:

first and second leg supports configurable to be coupled to a person's lower limbs and rest on a support surface during a stance phase, wherein each leg support includes a thigh link and a shank link;

first and second knee joints connecting the thigh links and shank links of the respective first and second leg supports to allow flexion and extension between respective shank and thigh links;

an exoskeleton trunk configurable to be coupled to a person's upper body and rotatably connected to the thigh link of each of the first and second leg supports to allow for flexion and extension between the first and second leg supports and the exoskeleton trunk;

at least one hip torque generator configured to create torque between said exoskeleton trunk and one of the first and second thigh links; and

a load holding mechanism rotatably coupled to said exoskeleton trunk for selective movement of the load holding mechanism relative to the exoskeleton trunk, the load holding mechanism configured to provide hands-free support of at least a portion of a weight of a load located in front of a person coupled to the exoskeleton, independent of upper limbs of a person coupled to the exoskeleton, wherein when said exoskeleton is worn by a person, the at least one torque generator creates a first torque between said exoskeleton trunk and the one of the first and second thigh links in the stance phase, opposing a second torque generated on the exoskeleton by the weight of the load.

2. The exoskeleton of claim 1, wherein the load holding mechanism is connected to the exoskeleton trunk through at least one over-shoulder member.

3. The exoskeleton of claim 1, wherein said at least one torque generator is a spring.

4. The exoskeleton of claim 1, wherein said at least one torque generator is an actuator.

5. The exoskeleton of claim 1, wherein at least one torque generator constitutes an actuator selected from the group consisting of hydraulic actuators, hydraulic rotary actuators, hydraulic cylinders, electric motors, pneumatic actuators and combinations thereof.

6. The exoskeleton of claim 2, wherein said load holding mechanism is coupled to said at least one over-shoulder member via a hinge.

7. The exoskeleton of claim 6, wherein said hinge is spring loaded.

8. The exoskeleton of claim 6, wherein the hinge is a flexible hinge member comprises an element selected from the group consisting of leather, fabric, elastomer, rubber, cloth, plastic and combinations thereof.

9. The exoskeleton of claim 6, wherein said hinge is located in front of a person coupled to the exoskeleton.

10. The exoskeleton of claim 2, wherein said over-shoulder member is coupled to said exoskeleton trunk via a hinge allowing for rotation of said load holding mechanism relative to said exoskeleton trunk.

11. The exoskeleton of claim 10, wherein said rotation is in the sagittal plane.

12. The exoskeleton of claim 10, wherein said hinge is located behind a person coupled to the exoskeleton.

13. Cancelled

14. The exoskeleton of claim 10, wherein said over-shoulder member is a U-shaped component capable of rotation relative to said exoskeleton trunk in a sagittal plane via the hinge.

15. The exoskeleton of claim 2, wherein said load holding mechanism includes a load holding member located in front of a person coupled to the exoskeleton to support said load in front of a person coupled to the exoskeleton.

16. The exoskeleton of claim 15, wherein said load holding member is rotatably connected to a portion of the load holding mechanism such that the load holding member moves relative to the portion of the load holding mechanism.

17. The exoskeleton of claim 15, wherein said load holding member includes a plate situated generally horizontally.

18. The exoskeleton of claim 2, wherein said load holding mechanism further includes a multi-degree of freedom mechanism that allows for controlled movement of the load with respect to the exoskeleton.

19. The exoskeleton of claim 18, wherein said load holding mechanism is coupled to the over-shoulder member in front of a person coupled to the exoskeleton.

20. The exoskeleton of claim 18, wherein said multi-degree of freedom mechanism further includes a serial link mechanism comprising a series of links serially connected to each other.

21. The exoskeleton of claim 18, wherein said multi-degree of freedom mechanism further includes a parallel link mechanism comprising a series of links connected to each other in a parallel form.

22. The exoskeleton of claim 18, wherein at least one link of said multi-degree of freedom mechanism is spring loaded.

23. The exoskeleton of claim 18, wherein at least one link of said multi-degree of freedom mechanism is spring-loaded to generally keep said load afloat.

24. The exoskeleton of claim 2, wherein said load holding mechanism is coupled to said over-shoulder member via a suspension mechanism capable of attenuating oscillations from said exoskeleton trunk and a person coupled to the exoskeleton to said load.

25. The exoskeleton of claim 24, wherein said suspension mechanism includes a spring.

26. The exoskeleton of claim 24, wherein said suspension mechanism includes a damper.

27. The exoskeleton of claim 2, further comprising:

a power unit in communication with the at least one hip torque generator for selectively supplying torque to the at least one hip torque generator; and

at least one load sensor in communication with the power unit for sensing a torque applied to said load holding mechanism by said load, wherein said power unit is adapted to control the at least one hip torque generator based on a signal from said load sensor.

28. The exoskeleton of claim 27, further comprising:

first and second feet connected to respective first and second shank links, wherein the at least one load sensor comprises first and second load sensors connected to the respective first and second feet.

29. The exoskeleton of claim 2, further comprising:

a power unit in communication with the at least one hip torque generator for selectively supplying torque to the at least one hip torque generator;

a signal processor in communication with the power unit; and

a sensor adapted to estimate a forward velocity of the exoskeleton in communication with the signal processor.

30. A method for supporting an object using an exoskeleton configurable to be coupled to a person and including: first and second leg supports configurable to be coupled to a person's lower limbs and rest on a support surface during a stance phase, wherein each leg support includes a thigh link and a shank link; first and second knee joints connecting the thigh links and shank links of the respective first and second leg supports to allow flexion and extension between respective shank and thigh links; an exoskeleton trunk configurable to be coupled to a person's upper body and rotatably connected to the thigh link of each of the first and second leg supports to allow for flexion and extension between the first and second leg supports and the exoskeleton

trunk; a load holding mechanism coupled to said exoskeleton trunk and configurable to provide hands-free support of at least a portion of a weight of the object located in front of a person coupled to the exoskeleton, independent of upper limbs of a person coupled to the exoskeleton, and at least one hip torque generator configured to create torque between the exoskeleton trunk and one of the first and second thigh links in a stance phase, the method comprising:

coupling the object to said load holding mechanism; and

creating a first torque with the at least one torque generator between said exoskeleton trunk and the one of the first and second thigh links in the stance phase opposing a second torque generated on the exoskeleton by the weight of the object.

31. The method claim of 29, further comprising:

generating a load signal, wherein said load signal represents a portion of a force or a torque applied by said object onto said exoskeleton and said the torque applied by the at least one torque generator is a function of said load signal.

32. The method claim of 30, wherein said load signal is generated manually by a person.

33. The method claim of 30, wherein said load signal is generated by a load sensor.

34. The method claim of 33, wherein said load sensor is located between said exoskeleton trunk and said load holding mechanism.

35. The method claim of 33, wherein said load sensor is located in said first and second leg supports.

36. The method of claim 33, wherein said exoskeleton further comprises first and second exoskeleton feet connected to respective shank links, and said load sensor comprises a load sensor located in each of the first and second exoskeleton feet, and wherein generating the load signal comprises generating a load signal based on a load sensed by at least one of the load sensors located in each of the first and second exoskeleton feet.

37. The method claim of 33, wherein said load sensor is a force measuring device generating a load signal wherein said load signal represents a portion of a force or a torque applied by said object onto said exoskeleton.

38. The method claim of 30, wherein said object comprises an element or combination of elements selected from the group consisting of a box, a camera, a battery, a monitor and a projectile.

39. The method of claim 30, further comprising:

moving the object from a first location to a second location using the exoskeleton by walking with the exoskeleton from the first location to the second location; and

disengaging the object from the load holding mechanism at the second location.

40. The method of claim 30, wherein the at least one torque generator constitutes first and second hip torque actuators configured to create torque between the exoskeleton trunk and respective first and second leg supports, and wherein the step of creating the first torque with the at least one torque generator between the exoskeleton trunk and the one of the first and second thigh links in the stance phase comprises:

sensing a force between a user's first foot and a first exoskeleton foot;

sensing a force between a user's second foot and a second exoskeleton foot;

determining a user's intended load distribution for the first foot;

determining a user's intended load distribution for the second foot;

applying a torque to the first hip actuator, wherein the torque applied by the first hip actuator is calculated to oppose the torque created by the load on the first foot based on the intended load distribution for the first foot; and

applying a torque to the second hip actuator, wherein the torque applied by the second hip actuator is calculated to oppose the torque created by the load on the first foot based on the intended load distribution for the first foot.

41. The method of claim 40, further comprising:

estimating a forward velocity of the exoskeleton;

determining when a walking event has started;

calculating a total torque required by the first and second hip actuators to cancel the torque imposed on the exoskeleton by the load;

adding the total torque to the torque applied to one or both of the first and second hip actuators when the one or both of the first and second hip actuators are determined to be in a stance phase.

42. A method for controlling an exoskeleton configurable to be coupled to a person, said exoskeleton, among other components, comprising first and second leg supports configurable to be coupled to a person's lower limbs and configured to rest on the ground during a stance phase, an exoskeleton trunk rotatably connectable to said first and second leg supports, at least one hip torque generator configured to create torque between said exoskeleton trunk and one of the first and second leg supports in the stance phase, a power unit in communication with the at least one hip torque generator for generating a torque to the at least one hip torque generator, and a load holding mechanism coupled to said exoskeleton trunk and configurable to provide hands-free support of at least a portion of a weight of the object located in front of a person

coupled to the exoskeleton, independent of upper limbs of a person coupled to the exoskeleton, said method comprising:

sensing a torque applied to said load holding mechanism by a load sensor;

generating a signal representative of the torque applied to said load holding mechanism;

processing a signal from the load sensor using said power unit; and

applying a torque to the at least one hip torque generator to cancel at least a portion of the torque applied to the load holding mechanism.