[006] Passive systems typically suppress tremors by absorbing or dissipating the vibration energy. In 1998, Kotovsky et. al created Viscous Beam, the first passive device for vibration suppression, which limits wrist rotation by applying viscous damping to the flexion & extension of the wrist joint. Nicolas Philip Fromme et. al created a lightweight passive orthosis that uses an airbag to reduce wrist vibration. These passive systems can be very lightweight (minimum weight only at 33 g) compared to active and semi-active systems. However, the damping forces or torques provided by passive systems are typically very small, making it difficult to suppress the tremor effectively. Although Sreekanth Rudraraju et. al proposed a mass-spring-damper system that reduced tremor by 70% to 80%, such a system can only suppress the tremor in one direction.

[007] Semi-active systems typically measure vibration amplitudes using embedded sensors and then adjust the damping force to suppress tremors. To generate damping force, the semi-active systems generally employ magnetorheological fluid, electromagnetic brake, pneumatic cylinder, etc. Among them, magnetorheological fluid is the most effective solution. The viscosity of a magnetorheological fluid can be continuously controlled with an applied magnetic field. It is typically lighter than the active system (approximately 200 g to 700 g) and eliminates the need for driving components such as motors, hence is better suited to the human wrist. However, the existing magnetic fluid-based flexible wrist exoskeleton mechanism can only provide about 10 N damping force in general, making it difficult to meet the practical needs.

[008] A need therefore exists to provide a semi-active exoskeleton system that seeks to overcome or at least minimize the above-mentioned problems. In this regard, the present application provides exoskeletons that are not only lightweight but also able to produce a sufficient damping force that can effectively suppress tremors in multiple directions simultaneously, and methods of controlling thereof. Also provided is a tremor simulator device that can be used to simulate tremors in various directions that facilitate to, e.g. investigate effectiveness of the exoskeletons as disclosed herein.

SUMMARY

[009] According to an embodiment, there is provided an exoskeleton. The exoskeleton comprises a first support; a second support; a joint structure rotatably connecting the first support and the second support; a vacuum pump; and a controller. The second support comprises: a first anchor component connecting to the joint structure, a second anchor component, and a sensor coupled to the controller, wherein the first anchor component and the second anchor component are connected by a variable stiffness unit coupled to the controller, the variable stiffness unit being made of a chain mail-like structured fabric, and wherein

the variable stiffness unit is configured to provide a variable damping force determined by the controller to reduce an amplitude of a tremor sensed by the sensor. In response to detection of a tremor signal received by the controller from the sensor upon sensing the tremor, the controller is configured to control the vacuum pump to activate the variable stiffness unit to provide the variable damping force. Furthermore, the chain mail-like structured fabric comprises a plurality of interlocking particles that conform to a wearer of the exoskeleton in an unjammed state when no pressure is applied to the fabric. The plurality of interlocking particles are configured to undergo a granular jamming transition to provide the variable damping force upon activation by the controller in response to the tremor sensed by the sensor

[0010] According to another embodiment, there is provided a method of controlling an exoskeleton, the exoskeleton comprising a first support, a second support, a joint structure rotatably connecting the first support and the second support, a vacuum pump, and a controller, wherein the second support comprises a first anchor component connecting to the joint structure, a second anchor component, and a sensor coupled to the controller, and wherein the first anchor component and the second anchor component are connected by a variable stiffness unit coupled to the controller, the variable stiffness unit being made of a chain mail-like structured fabric. The chain mail-like structured fabric comprises a plurality of interlocking particles that conform to a wearer of the exoskeleton in an unjammed state when no pressure is applied to the fabric. The method comprises: sensing a tremor by the sensor, detecting a tremor signal by the controller, the tremor signal received from the sensor, determining a variable damping force by the controller in response to the sensed tremor, controlling the vacuum pump by the controller, to activate the variable stiffness unit, providing the variable damping force by the variable stiffness unit to reduce an amplitude of the tremor, and activating the plurality of interlocking particles by the controller, to undergo a a granular jamming transition to provide the variable damping force in response to the tremor sensed by the sensor.

[0011] According to the disclosure, there is provided a tremor simulator device. The tremor simulator device comprises a linkage mechanism; a drive motor; and a speed controller. The linkage mechanism comprises a first rod and second rod that are configured to rotate with respect to each other, and a third rod fixedly connected to the second rod, wherein the third rod is configured to make a linear reciprocal motion with respect to the second rod, and wherein the speed controller is configured to control the drive motor to drive the first rod and the second rod to rotate and the third rod to make the linear reciprocal motion so as to cause a shaking at an end of a limb coupled to the tremor simulator device.

BRIEF DESCRIPTION OF THE DRAWINGS

[0012] Embodiments and implementations are provided by way of example only, and will be better understood and readily apparent to one of ordinary skill in the art from the following written description, read in conjunction with the drawings, in which:

[0013] Figure 1 shows a schematic diagram of an exoskeleton 100, according to an embodiment.

[0014] Figure 2 shows a diagram 200 depicting another embodiment of an exoskeleton. In the embodiment, the exoskeleton is coupled to a wearer's arm and wrist. It is understandable to those skilled in the art that the exoskeleton can be coupled to other parts of the body of the wearer based on the practical needs.

[0015] Figure 3 shows a diagram 300 depicting another embodiment of an exoskeleton. In this embodiment, the exoskeleton further comprises a vacuum pump provided at the waist

Claims

1. An exoskeleton, comprising:

a first support;

a second support;

a joint structure rotatably connecting the first support and the second support;

a vacuum pump; and

a controller,

wherein the second support comprises:

a first anchor component connecting to the joint structure,

a second anchor component, and

a sensor coupled to the controller,

wherein the first anchor component and the second anchor component are connected by a variable stiffness unit coupled to the controller, the variable stiffness unit being made of a chain mail-like structured fabric,

wherein the variable stiffness unit is configured to provide a variable damping force determined by the controller to reduce an amplitude of a tremor sensed by the sensor,

wherein, in response to detection of a tremor signal received by the controller from the sensor upon sensing the tremor, the controller is configured to control the vacuum pump to activate the variable stiffness unit to provide the variable damping force,

wherein the chain mail-like structured fabric comprises a plurality of interlocking particles that conform to a wearer of the exoskeleton in an unjammed state when no pressure is applied to the fabric, and

wherein the plurality of interlocking particles are configured to undergo a granular jamming transition to provide the variable damping force upon activation by the controller in response to the tremor sensed by the sensor.

2. The exoskeleton according to claim 1,

wherein the first support is couplable to an upper arm of a wearer of the exoskeleton,

wherein the first anchor component of the second support is couplable to a forearm of the wearer of the exoskeleton,

wherein the second anchor component of the second support is couplable to a hand of the wearer of the exoskeleton and the sensor is configured to be located on or proximate to the hand, and

wherein the variable stiffness unit is located at or proximate to a wrist of the wearer of the exoskeleton, spanning from the first anchor component to the second anchor component.

3. The exoskeleton according to claim 1 or 2,

wherein the tremor is sensed in one or more of extension and flexion directions, abduction and adduction directions, and pronation and supination directions, and

wherein the variable damping force is provided in a direction along the direction of the sensed tremor.

4. The exoskeleton according to any one of the preceding claims,

wherein the chain mail-like structured fabric is 3D printed with a selective laser sintering (SLS) method from a high-strength lightweight nylon.

5. A method of controlling an exoskeleton, the exoskeleton comprising a first support, a second support, a joint structure rotatably connecting the first support and the second support, a vacuum pump, and a controller,

wherein the second support comprises a first anchor component connecting to the joint structure, a second anchor component, and a sensor coupled to the controller,

wherein the first anchor component and the second anchor component are connected by a variable stiffness unit coupled to the controller, the variable stiffness unit being made of a chain mail-like structured fabric, and

wherein the chain mail-like structured fabric comprises a plurality of interlocking particles that conform to a wearer of the exoskeleton in an unjammed state when no pressure is applied to the fabric,

wherein the method comprises:

sensing a tremor by the sensor,

detecting a tremor signal by the controller, the tremor signal received from the sensor,

determining a variable damping force by the controller in response to the sensed tremor,

controlling the vacuum pump by the controller, to activate the variable stiffness unit,

providing the variable damping force by the variable stiffness unit to reduce an amplitude of the tremor, and

activating the plurality of interlocking particles by the controller, to undergo a granular jamming transition to provide the variable damping force in response to the tremor sensed by the sensor.

6. The method according to claim 5, further comprising:

coupling the first support at an upper arm of a wearer of the exoskeleton;

coupling the first anchor component of the second support at a forearm of the wearer of the exoskeleton;

coupling the second anchor component of the second support at a hand of the wearer of the exoskeleton such that the sensor is located at or proximate to the hand; and

locating the variable stiffness unit at or proximate to a wrist of the wearer of the exoskeleton, spanning from the first anchor component to the second anchor component.

7. The method according to claim 5 or 6, further comprising:

in response to the sensor sensing the tremor in one or more of extension and flexion directions, abduction and adduction directions, and pronation and supination directions, providing, by the variable stiffness unit, the variable damping force in a direction along the direction where the tremor is sensed.