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(54) **Title**: ERGONOMIC HANDLE FOR HAPTIC DEVICES

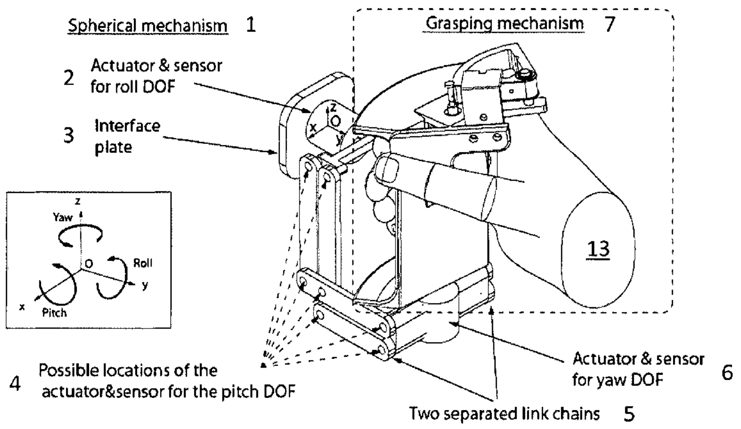

Figure 1 Represents the preferred embodiment with a hand model.

(57) **Abstract**: A ergonomic handle that can be added to existing haptic devices, composed by a spherical mechanism providing hand orientation and a grasping mechanism is shown. Both the proposed spherical mechanism and the handle have been ergonomically designed to avoid postures that could lead to physical discomfort or cumulative traumas such as carpal tunnel syndrome or tenosynovitis.

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ERGONOMIC HANDLE FOR HAPTIC DEVICES

CORRESPONDING APPLICATION

The present application claims the priority of US application N° 61/453,972 the content of which is incorporated in its entirety in the present application.

FIELD OF INVENTION

The present invention generally relates to the haptic devices field, and more specifically to an ergonomically optimized spherical wrist with at least gripping force feedback capabilities.

More specifically, the present invention concerns an ergonomic handle with a remote center of rotation and providing hand orientation and force feedback.

BACKGROUND OF THE INVENTION

A haptic device is an input/output interface that can interact with the user by sensing users movement (input) and generating a force (output) in response to this movement. The input and output information can be inverted if the device is impedance controlled (force/motion) or admittance controlled (motion/force).

These devices are increasingly been applied in teleoperation tasks in which haptic information can enhance user's performance and increase safety. The teleoperated robots can work in hazardous environments, perform distant surgical procedures, or work with objects in a totally different scale. In those applications a haptic device allows scaling the forces and the motion to perform bigger forces or more precise movements without loosing the haptic information involved in the manipulation.

Haptic device components are very similar to the ones of an industrial robot: actuators, transmissions and sensors, attached to a task specific mechanical structure. However, the dynamic physical interaction with a human operator imposes supplementary constraints with respect to other standard mechatronic devices. For instance, the motion and the force generated by the haptic interface should be free of parasite effects and thus the designed mechanisms should minimize inertia, friction, and backlash, and maximize stiffness, workspace and bandwidth. Since haptic devices will have to control the interaction force with the user, safety features and ergonomics are crucial factors.

Regarding the ergonomics specifications of this kind of devices, it has been proved (see references [7][2][10]) that forces applied by the fingers while grasping an object are highly related with wrist position, thus one of the specifications is to keep the user's wrist always close to the neutral position. In addition, fatigue must be taken into account during the device design since it might prevent the user to maintain the required force. The task duration represents an important risk factor as it plays a significant role in the development and onset of musculoskeletal injuries; longer tasks duration will definitely increase the risk of adverse effects produced by a poor ergonomic design. For instance, in a teleoperated surgical system, this is a safety rule that concerns both patient and surgeon, since this could lead to a lower performance during the procedure and thus, a worse result for the patient.

Even though robotic teleoperated systems have overcome many ergonomic drawbacks in tasks where the user had to work in uncomfortable postures such as minimal invasive surgical procedures or micromanipulation, there is still room for improvement. Recent studies showed that commercially available teleoperated surgical robots still present some sources of discomfort, specifically neck and back muscle hardening due to the long-last non-neutral back position (see references [3][4]) and tension on the fingers. The aforementioned reasons motivated the design of an ergonomically optimized user interface decreasing user's mental stress and the likeliness of work-related physical injuries.

BRIEF SUMARY OF INVENTION

It is an aim of the present invention to improve the known devices and methods. More specifically, it is an aim of the present invention to provide an ergonomically optimized handle for the use of haptic interfaces.

Additionally, it is an aim of the present invention to propose an ergonomic handle for haptic interfaces being used in teleoperation tasks or to interact with virtual reality.

A further aim of the present invention is to propose a handle that can be used in tasks requiring high dexterity and precision such as teleoperated surgery or virtual simulators for training or games.

Features of the device according to the present invention are defined in the appended independent claims.

Dependent claims define specific embodiments of the present invention.

An idea of the present invention is to provide an ergonomic handle for a haptic interface that acquires the orientation of the user's hand and provides force feedback in the gripping action and features safety brakes for the orientations.

Preferably, a DC motor is used to simulate the gripping force when gripping virtual or distal objects. Pneumatic brakes are preferably used to block the orientation of the user's hand if any problem occurs. Of course, other equivalent means are possible as well.

In addition, an ergonomic grasping mechanism with force feedback has been designed to distribute the force among all the fingers and combining both precision grip and a power grip finger postures see reference [5]. This design allows the operator to perform fine manipulation while maintaining the appropriate hand stiffness and force control.

The present invention concerns therefore an ergonomic handle comprising:

- a plurality of degrees of freedom of orientation in which at least one of them is accomplished by a double parallelogram;
- a remote center of rotation located inside the user's hand;

- an input sensor per DOF, to measure the user's hand orientation.

In an embodiment the handle comprises a grasping mechanism with an input sensor to measure the user's hand aperture.

In an embodiment the handle involves all fingers to grasp the device and the thumb to control the action.

In an embodiment the moving part of the grasping mechanism has the axis ergonomically located to follow the natural thumb movement.

In an embodiment the fixed part of the grasping mechanism has a curved shape to avoid finger tension.

In an embodiment the moving part is actuated to provide grasping feedback.

In an embodiment the handle further comprises brakes to block user's hand orientation.

In an embodiment the handle further comprises actuators to provide torque feedback.

In an embodiment the handle further comprises a contact sensor, to detect the presence of the user's hand.

In an embodiment the handle further comprises a safety feature that blocks user's hand movement when the user removes the hand from the handle.

In an embodiment the handle further comprises a safety feature that blocks user's hand movement when a safety issue arouses.

In an embodiment the double parallelogram is separated in two parallel link chains to increase the stiffness of the mechanism.

In an embodiment the handle further comprises split axis to increase the workspace of the mechanism.

In an embodiment, the handle is assembled on another input device providing extra DOF.

In an embodiment, the handle further comprises Peltier elements to provide temperature tactile sensations.

In an embodiment the handle further comprises actuators providing vibrations to recreate tactile sensations on the user's hand skin.

In an embodiment the handle further comprises a tactile display composed by an array of pins to display a tactile pattern by indenting the skin of fingertip.

In an embodiment the array of pins is actuated in a pulsated manner to simulate heartbeats.

In an embodiment a device, such as a haptic device, comprises a handle as defined herein.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 illustrates a preferred embodiment with a hand model;

Figure 2 illustrates simple and double parallelogram mechanisms;

Figure 3 illustrates extreme positions of the spherical for the roll DOF;

Figure 4 illustrates extreme positions of the spherical for the yaw DOF;

Figure 5 illustrates extreme positions of the spherical for the pitch DOF;

Figure 6 illustrates a detailed view of the grasping feedback system;

Figure 7 illustrates a grasping DOF;

Figure 8 illustrates a detailed view of the cable transmission;

Figure 9 illustrates tactile cues;

Figure 10 illustrates a detailed view of the pneumatic transmission system.

DETAILED DESCRIPTION OF THE INVENTION

Figure 1 illustrates an illustrative embodiment with a hand model.

Spherical mechanism 1

The proposed spherical mechanism 1 has been ergonomically designed so that the user will mainly control the device with postures that slightly differ from the neutral position of the wrist.

The spherical mechanism 1 is based on a double parallelogram structure 11 with a remote center of rotation 12.

Fully decoupled 2-DOF or 3-DOF spherical mechanisms 1 can be synthesized based on elementary motion generators. A parallelogram 10 (Figure 2(a)) can be used to displace the pointing motion in parallel to the actuated link. Each point of the bottom link of the pantograph 10 performs a circular displacement, however the link remains aligned parallel to the top link. The rotation is thus created by a 2-DOF linear displacement around a fixed point. The relative displacement between two platforms parallel 11 to each other (Figure 2(b)) can be used as well for circular motion generation. In this case a virtual pivot point or remote-center of rotation 12 is obtained, as the rotation is performed around a point, which is not part of the linkage 11.

In the present embodiment the remote center of rotation 12 is located at the center of the user's hand 13 to provide a natural control of the orientation of the hand 13. This mechanism provides three degrees of freedom of orientation, roll, pitch and yaw that coincide with the pronosupination (Figure 3), extension-flexion (Figure 4) and ulnar-radial deviation (Figure 5) degrees of freedom (DOF) of the human wrist respectively. Furthermore, the mechanism has been designed to provide the corresponding stroke to each degree of freedom. For instance, the stroke of the pitch DOF, which corresponds to the ulnar-radial deviation of the wrist (Figure 5) is limited to avoid postures that can lead to tenosynovitis, carpal tunnel syndrome or wrist physical discomfort. As it can be seen in Figure 5, to constrain the movement of the double parallelogram 11 the profiles of the adjacent links make contact at the limit of the stroke.

Alternatively, in the presented embodiment the order of the first and the third DOF can be interchanged.

This type of mechanism has been already used for applications in which a tool or a manipulator should rotate around a point in which due to space constrains mechanical components cannot be placed. For instance, in the patent US7594912 robotic devices and other systems including an offset remote center parallelogram manipulator linkage constraining a position of a surgical instrument during minimally invasive robotic surgery are disclosed. In reference [9] a haptic device for the surgical training of hysteroscopy, a gynecologic intervention based in a double parallelogram linkage is also presented. However, to the author's best knowledge this is the first device that uses double parallelogram kinematics to place the remote center of rotation in the center of the user's hand to develop and ergonomic haptic handle.

To reduce backlash and friction, each pivot joint features two preloaded bearings. To increase stiffness of the overall handle the double parallelogram is then doubled in two forming two parallel link chains. The axes are as well split in two parts and each of them features a bearing. This provides free space between the two double parallelograms 11 to allow hand movement especially for the yaw DOF (Figure 4).

Each DOF features a magnetic encoder 2, 4, 6 to measure the angles and thus determine the orientation of the user's hand by solving the handle kinematics. The device could alternatively use optical encoders 2, 4, 6 or potentiometers 2, 4, 6 to measure the angle of each DOF. The cylinders 2, 4, 6 represented in the Figures 1-5 represent the location of the actuators and/or position sensors 2 and 6 for the DOFs roll and yaw. The actuators and sensors 4 for the pitch DOF can be assembled to any of the pivot joints composing the double parallelogram 11, as indicated in figure 1.

The ergonomic handle is cinematically decoupled from the rest of the haptic device where it will be connected. This means that the user can use different hand orientations to approach the same point into the workspace. Furthermore, the user can change the hand orientation without changing the position.

The device can be mechanically grounded through the interface plate 3 (Figure 1). Additionally, this device could be attached to a haptic device that provides force feedback in the translations to add four extra DOF and increase its workspace. However, the DOF of the ergonomic handle are mechanically independent of the haptic device on which it is being installed and thus move relative to them.

Alternative means to attach the ergonomic handle to a haptic device are possible. For instance, instead of a plate interface 3 that has to be screwed it could be assembled through a clip mechanism or through a slider member or other equivalent means.

The proposed mechanism includes an actuator for each DOF to provide torque feedback in each orientation, see Figure 1. Although the present prototype uses brakes it could also integrate a motor in each DOF to provide active torque feedback. To provide active torque feedback DC motors, step motors or AC motors could be used. Nevertheless, these actuators should be backlash and friction free and preferably back drivable to preserve the transparency of the overall device.

Grasping feedback system 7

The grasping mechanism 7 is composed of two main parts (see Figure 6):

1) The moving part 21 that interacts with the user's thumb and that is actuated by a motor 22 and

2) the fixed part 23 that is grasped with the rest of the fingers 24.

The moving part 21 rotates around an axis attached to the fixed part of the handle. The fixed part 23 of the handle is directly attached to the yaw DOF of the spherical mechanism.

The grasping mechanism 7 has been designed to distribute the force among all the fingers 20, 24 and to combine both precision grip and a power grip finger postures see reference [5]. This design allows the operator to perform fine manipulation while maintaining the appropriate hand stiffness and force control.

The shape of the fixed part 23 of the handle is curved to prevent finger 24 tendons from being stretched and tense (Figure 6).

The moving part 21 is actuated through a cable 25 driven mechanism that provides force feedback when grasping a virtual or distal object. The cable 25 is wrapped around the motor 27 shaft 26 in two opposite directions and it passes through the shaft 26 in the middle of its length, see Figure 8. This way of assembling the cable 25 equilibrates the forces applied to the shaft 26 preventing motor failures. The rest of the cable 25 is wrapped around the motor 27 shaft 26 in both directions in order to have enough cable to turn the outer surface of the pulley 28. The two extremities of the cable 25 are then fixed to the pulley 28.

The axis 29 of the pulley 28 is located towards the axis of the human's thumb 20. Furthermore, the motor 27 is attached to the fixed part of the gripping mechanism 7 through a slanted plane replicating the axis orientation of the human's thumb 20. This ergonomic configuration allows the user to move its thumb 20 naturally.

The stroke of the gripping mechanism is 90 degrees. A pin located in the motor 27 fixation limits the stroke of the moving pulley 28 for safety reasons.

The radius of the pulley is R. The motor shaft 26 extension has a radius r. With the angle measured by the encoder integrated in the motor 27, the opening angle of the user's hand can be calculated. The cable 25 transmission amplifies the motor torque and the encoder resolution by a ratio of R/r.

All the fingers 20, 24 are attached to the gripping mechanism by adjustable straps 30, 31 or other equivalent means.

Additional tactile cues

The lack of tactile information prevents the user to perform common haptic explorations when manipulating virtual or distal objects. For instance, in the case of teleoperated robotic surgery, surgeons cannot palpate the internal tissues to localize hidden anatomical structures. During surgical procedures, palpation is often carried out in order to determine the position of arteries. This task is regularly performed to locate needle insertion sites for regional anesthesia, or to prevent accidental rupture of arteries.

Since user's fingers are constantly in contact with the presented ergonomic handle different tactile cues can be given through it to enhance user's telepresence. In the previous case, to provide surgeons with the sensation of palpating an artery, an array of small pins could provide a pulsating indentation in the finger, see Figure 9(a). This type of tactile display is often actuated pneumatically see reference [8], with dc motors see reference [6] or piezoelectric actuators see reference [1]. The first solution might be preferred because it is a lightweight solution and thus easier to be integrated.

Temperature information can also be displayed directly to the user's fingertip thought a display integrating several Peltier elements 32, see Figure 9(b). Vibration actuators, such as small dc motors with an eccentric mass attached or voice coils, can also convey additional information such as the slippage of an object between the fingertips.

These displays can be integrated on the fixed part of the grasping system under the chosen finger. The control electronics might be preferably apart to reduce the weight and size of the device.

In a teleoperation task the information displayed by this system might be measured by sensors integrated in the gripper of the slave robot. For instance, the array of pins 33 could render the information sensed by a matrix of pressure sensors. In the case of thermal information a sensor such as a Resistance Temperature Detector (RTD), a thermocouple or thermistor included in the slave robot sense directly the temperature of the contact point with the object.

If the device is applied in a virtual reality application the device can directly simulate the thermal or tactile characteristics of the virtual object commanded by the computer.

Of course, it is possible to combine different elements that render different tactile cues as described above.

Safety Features: brakes

As it was already mentioned, the ergonomic handle features safety brakes for the orientations. They may comprise a pneumatic brake system (see Figure 10). The main component of this braking system is a pneumatic hub 40 with a cylindrical air chamber 41 connected to an entrance of air. This cylindrical hub is attached to the fixed link 44 of the DOF by two antirotational pins. A moving shaft 42 passes though the hub 40 without making contact with it and is attached to an external tambour 43.

When the brake is switched off the tambour 43 moves freely around the pneumatic hub 40 concentrically. Therefore, the relative movement between the two links is allowed.

When the brake is activated the air inflates the pneumatic chamber 41 of the hub 40 and thus, it makes contact with the external tambour 43. Consequently, the fix part 44 and the moving shaft 42 are mechanically connected preventing relative movement between them.

Alternatively, magnetic particle brakes or other types of friction brakes can be used to generate a passive resistance or friction in each DOF.

In other embodiments, all or some of the actuator and sensor pairs can include only sensors to provide an apparatus without torque or grasping force feedback along designated DOF.

Safety Features: presence sensor

For safety reasons it is also desirable to sense or detect when the user is touching the handle. This measurement will allow the control system to block the user's orientation by enabling the safety brakes when the user's hand releases the handle.

The presence sensor should be able to detect if the handle is being touched, even if the user is wearing rubber gloves or if the hand presents high level of humidity. Additionally, the presence sensor should only detect the user's hand when it is actually in contact with the ergonomic handle and not when it is just near. In this embodiment, the most suitable sensor was found to be a capacitive sensor. Nevertheless, a pressure sensor could be also be used and achieve the same result. Of course, other equivalent means and sensors may be used.

Of course, all the embodiments described above a illustrative examples that should not be construed in a limiting manner. It is possible to use equivalent means and principles within the frame and scope of the present invention.

The device of the present application can be used in many different fields and adapted for said fields (materials, sizes etc): medical applications, simulation applications, game applications, etc.

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CLAIMS

1. An ergonomic handle comprising:
   - a plurality of degrees of freedom of orientation in which at least one of them is accomplished by a double parallelogram;
   - a remote center of rotation located inside the user's hand;
   - an input sensor per DOF, to measure the user's hand orientation.
2. The handle as claimed in claim 1, comprising a grasping mechanism with an input sensor to measure the user's hand aperture.
3. The handle as claimed in one of the preceding claims, involving all fingers to grasp the device and the thumb to control the action.
4. The handle as defined in one of the preceding claims, in which a moving part of the grasping mechanism has an axis ergonomically located to follow the natural thumb movement.
5. The handle as defined in one of the preceding claims, in which a fixed part of the grasping mechanism has a curved shape to avoid finger tension.
6. The handle as defined in one of the preceding claims, in which the moving part is actuated to provide grasping feedback.
7. The handle as claimed in one of the preceding claims, further comprising brakes to block user's hand orientation.
8. The handle as claimed in one of the preceding claims, further comprising actuators to provide torque feedback.
9. The handle as defined in one of the preceding claims, further comprising in the handle a contact sensor, to detect the presence of the user's hand.
10. The handle as defined in one of the preceding claims, with a safety feature that blocks user's hand movement when the user removes the hand from the handle.
11. The handle as defined in one of the preceding claims, with a safety feature that blocks user's hand movement when a safety issue arises.
12. The handle as claimed in one of the preceding claims, in which the double parallelogram is separated in two parallel link chains to increase the stiffness of the mechanism.
13. The handle as claimed in one of the preceding claims, with split axis to increase the workspace of the mechanism.

14. The handle as defined in one of the preceding claims, to be assembled on another input device providing extra DOF.
15. The handle as defined in one of the preceding claims, comprising Peltier elements to provide temperature tactile sensations.
16. The handle as defined in one of the preceding claims, comprising actuators providing vibrations to recreate tactile sensations on the user's hand skin.
17. The handle as defined in one of the preceding claims, comprising a tactile display composed by an array of pins to display a tactile pattern by indenting the skin of fingertip.
18. The handle as defined in one of the preceding claims, in which the array of pins is actuated in a pulsated manner to simulate heartbeats.
19. A device, such as a haptic device, comprising a handle as defined in one of the preceding claims.

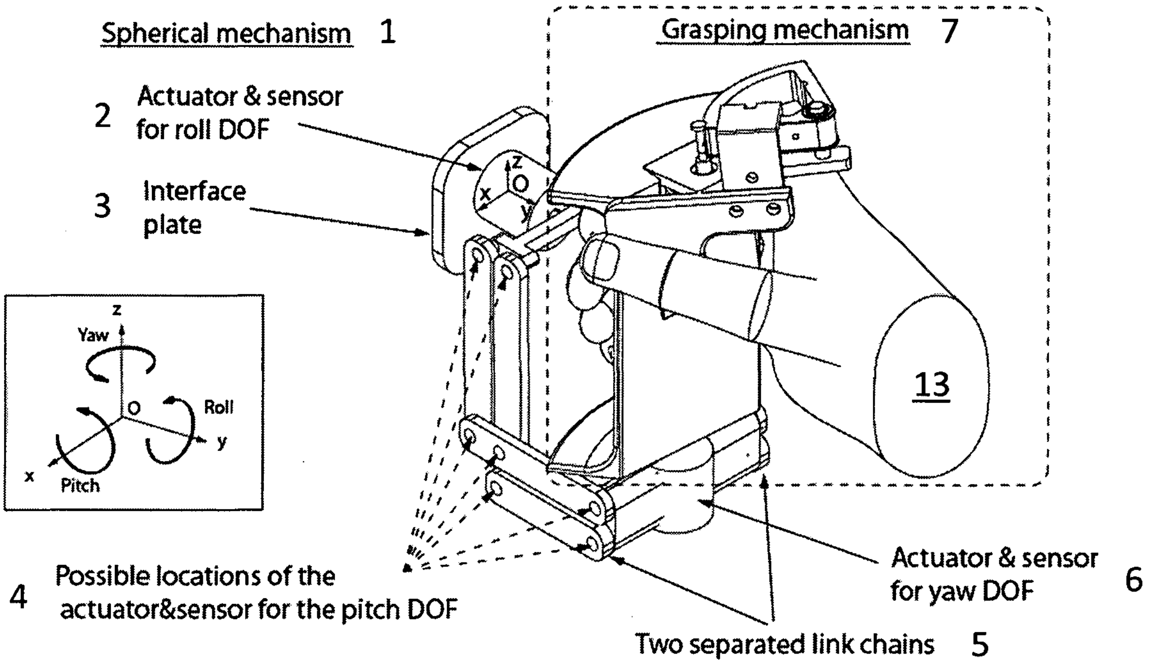

Figure 1 Represents the preferred embodiment with a hand model.

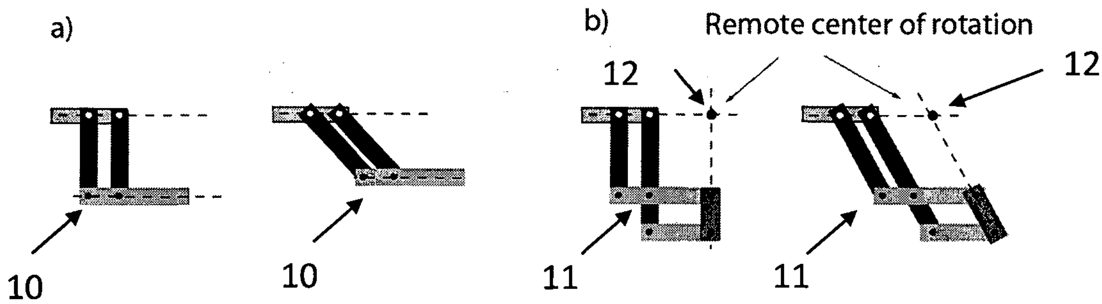

Figure 2 illustrates simple and double parallelogram mechanisms.

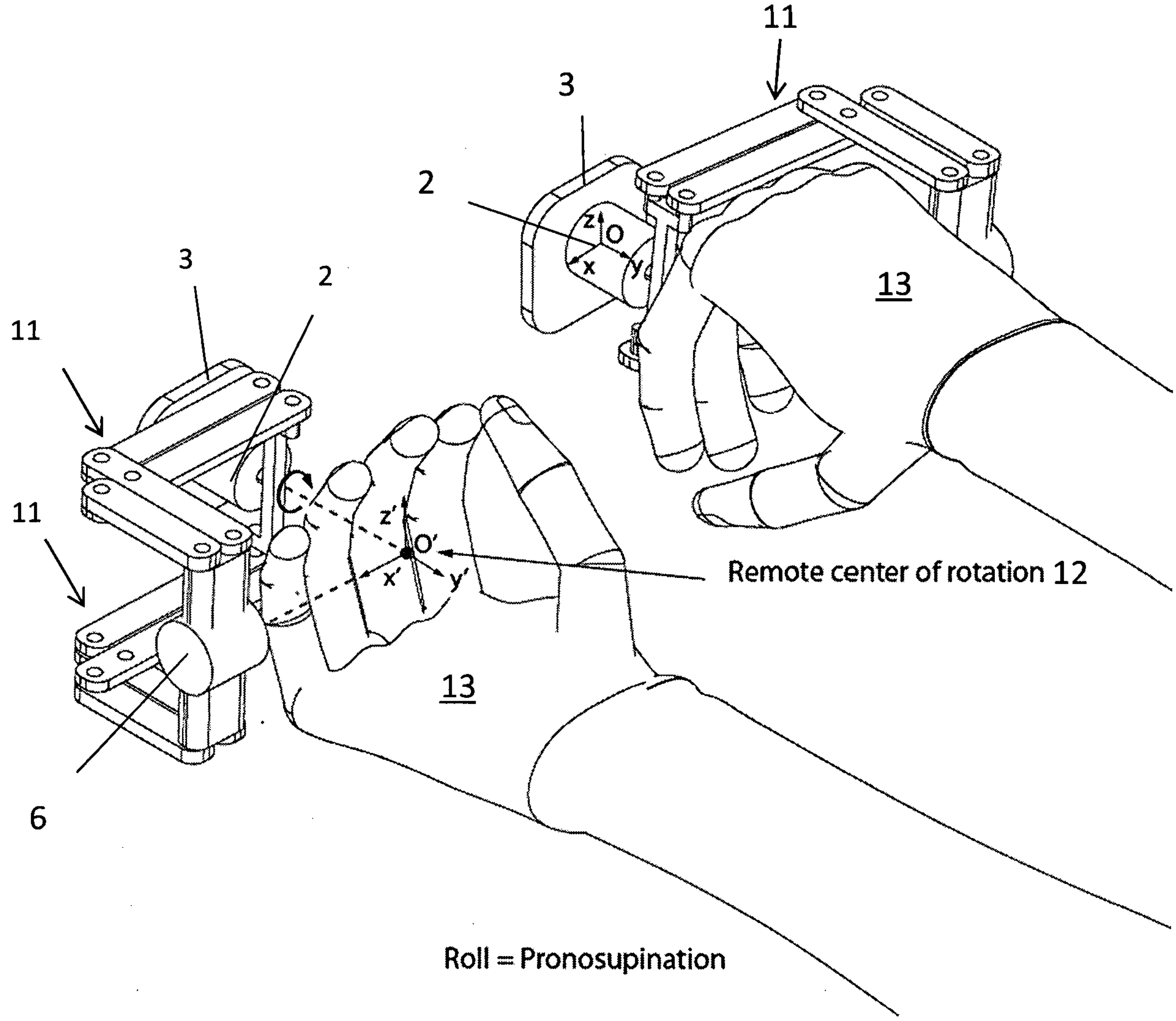

Figure 3 illustrates extreme positions of the spherical mechanism for the roll DOF.

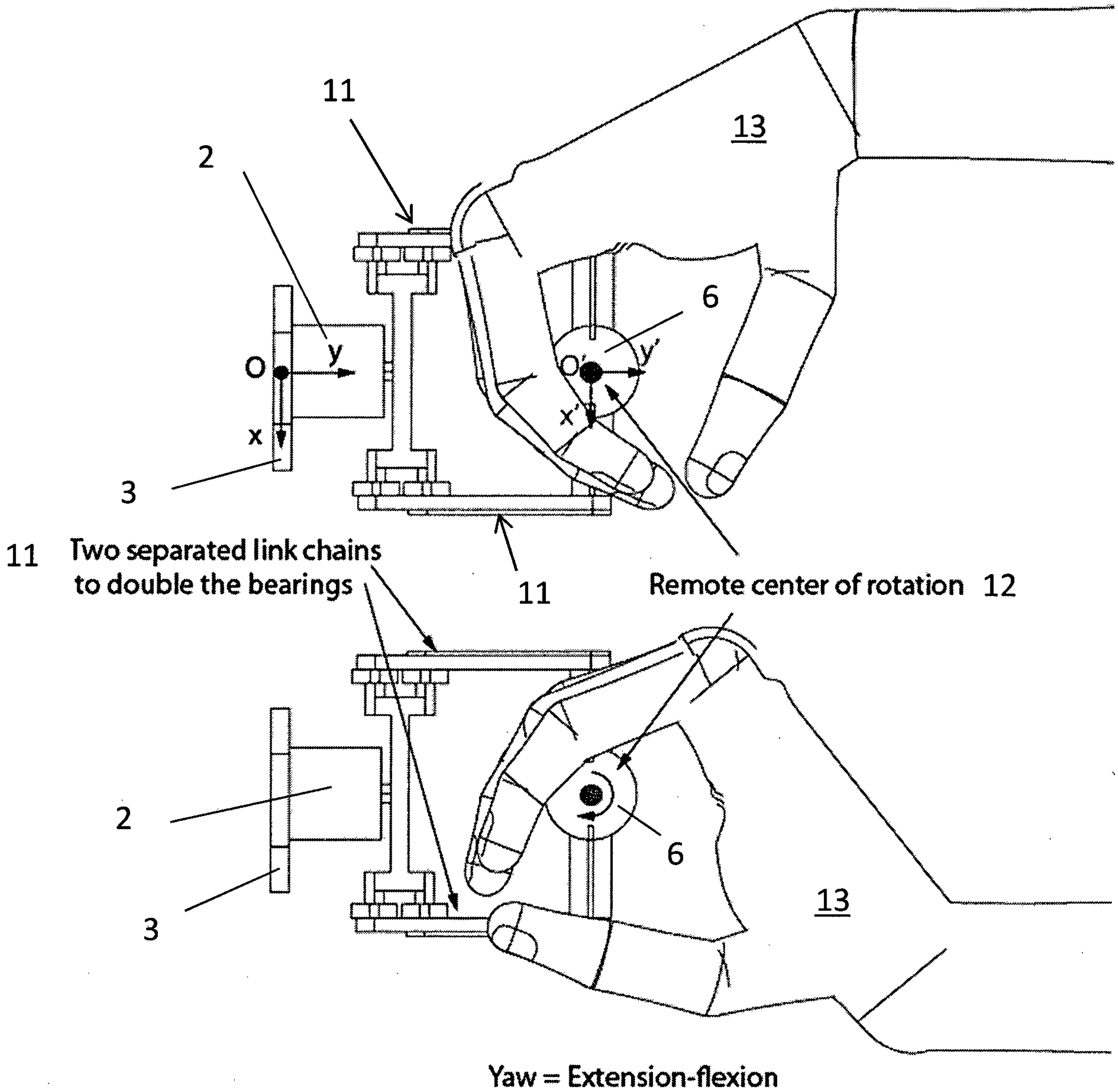

Figure 4 illustrates extreme positions of the spherical mechanism for the yaw DOF.

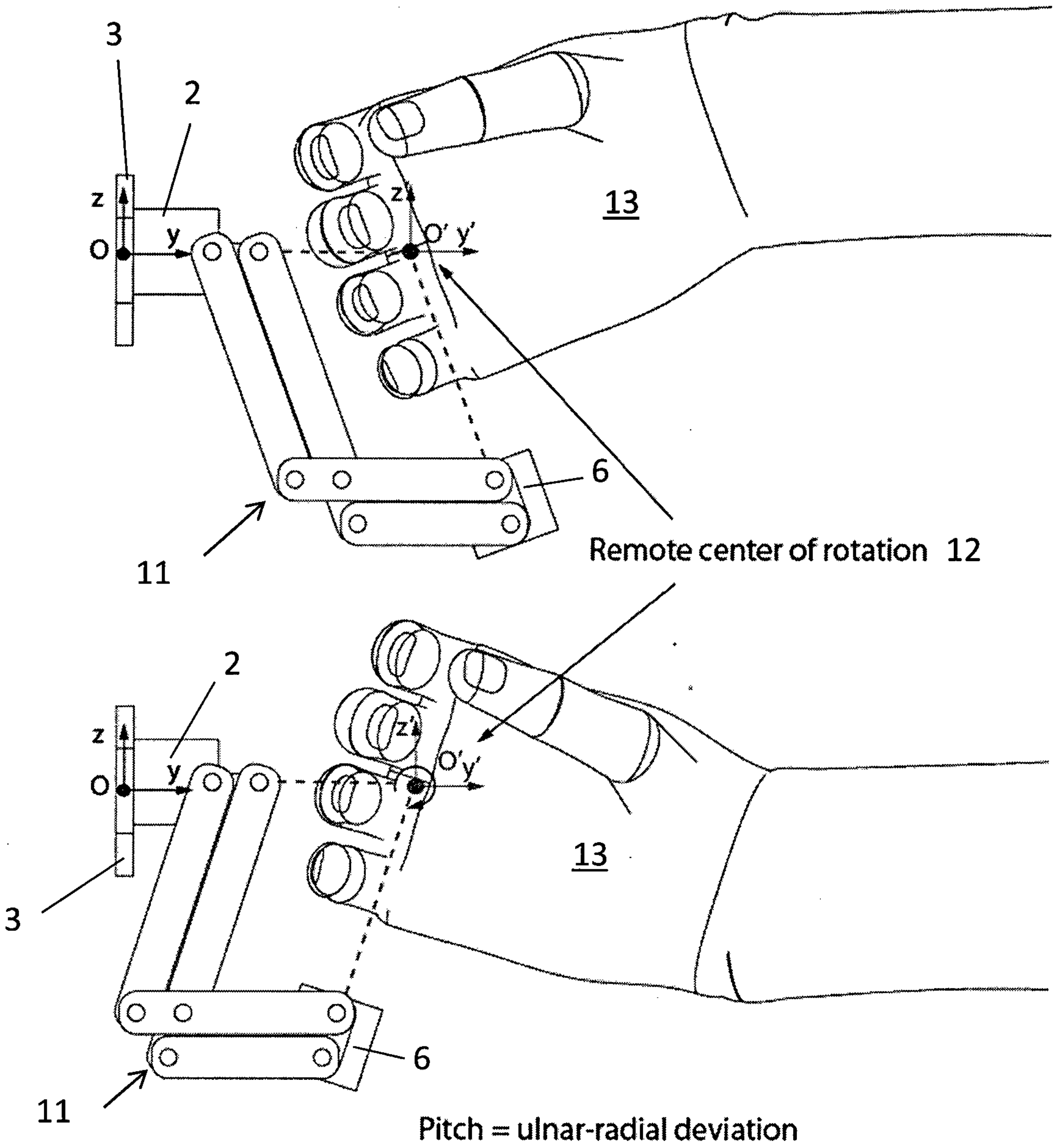

Figure 5 illustrates extreme positions of the spherical mechanism for the pitch DOF

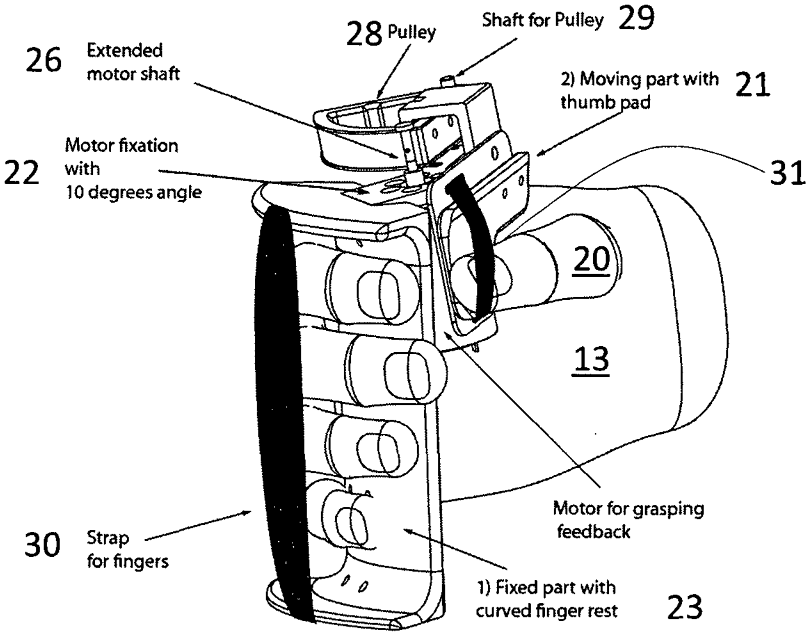

Figure 6 illustrates a detailed view of the grasping feedback system. 7

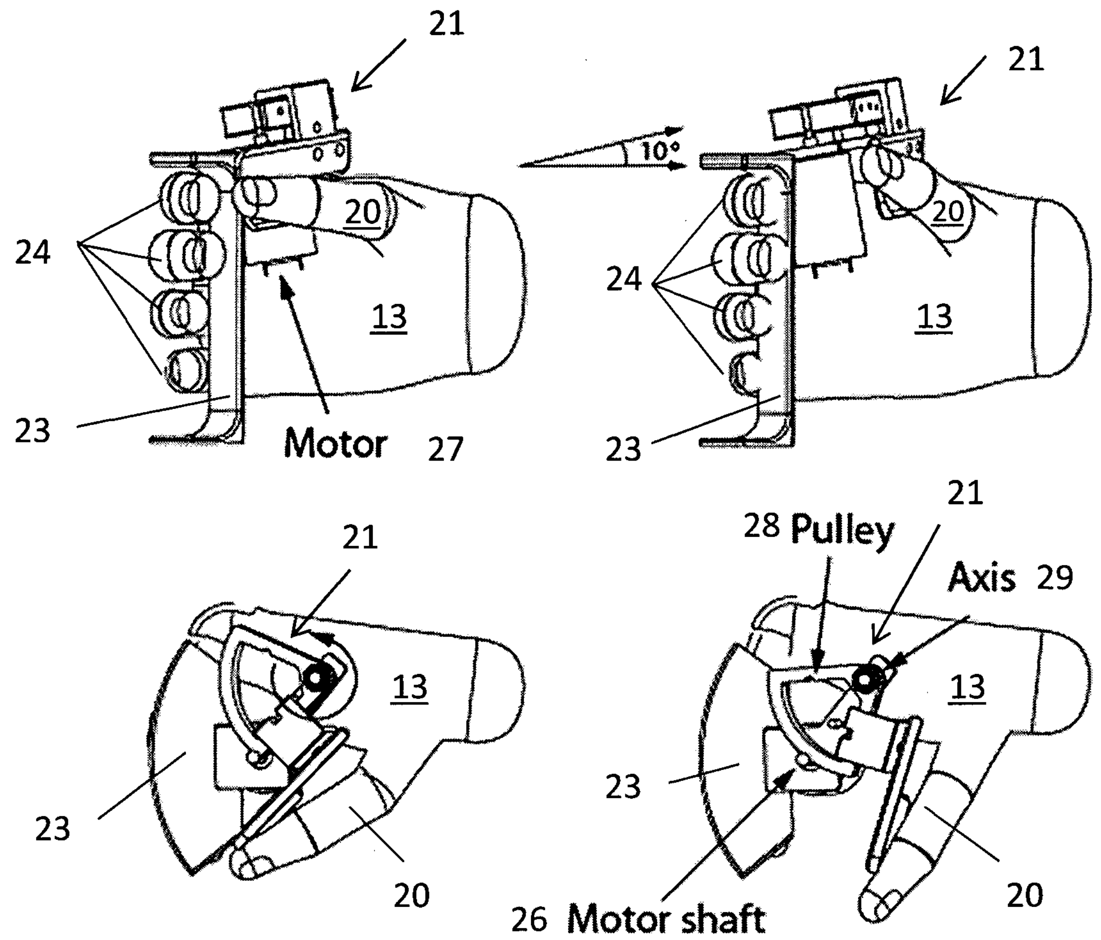

Figure 7 illustrates a grasping DOF.

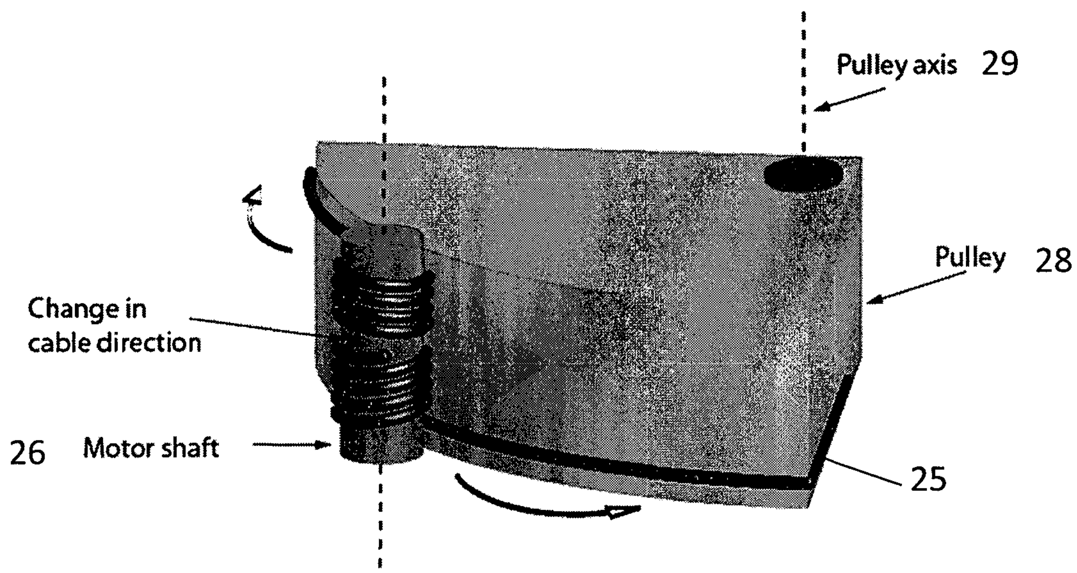

Figure 8 illustrates a detailed view of the cable transmission

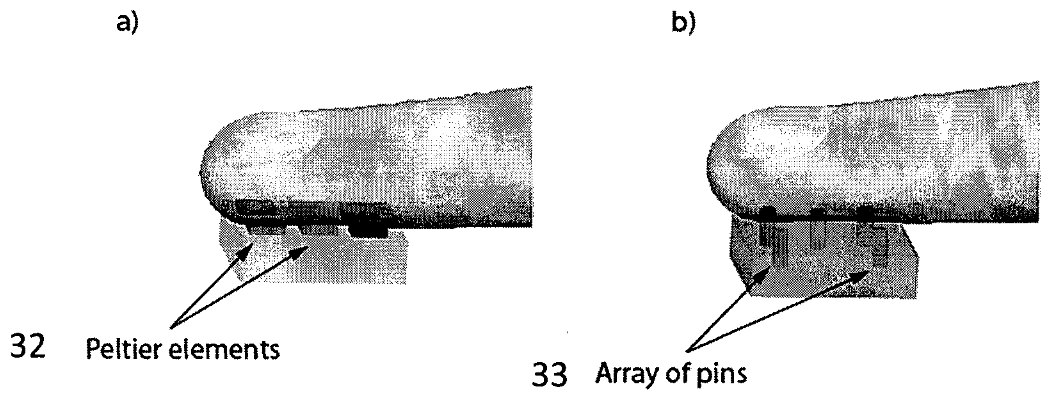

Figure 9 illustrates a detailed view of the pneumatic braking system.

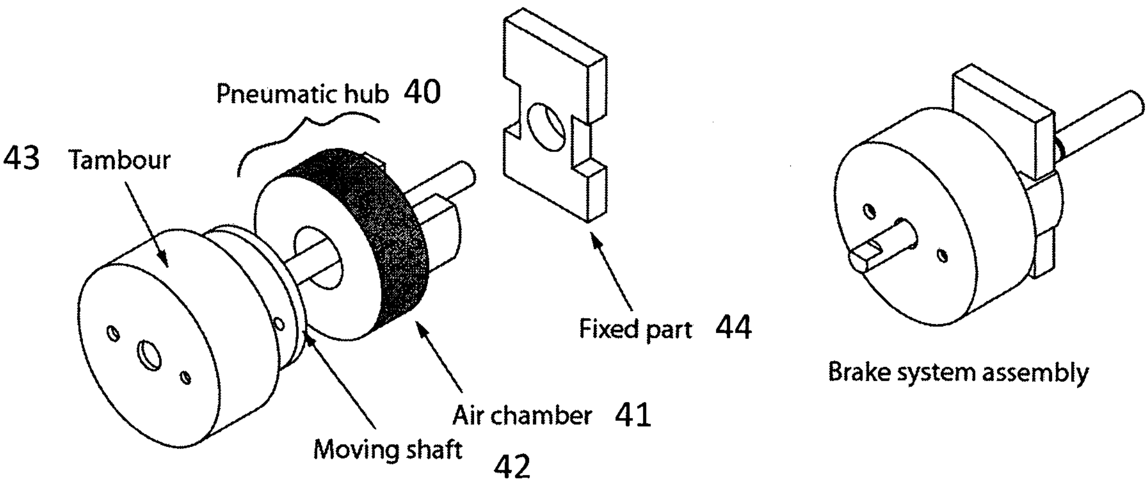

Figure 10 Detailed view of the pneumatic braking system.