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(54) SYSTEM AND METHOD FOR VIRTUAL FEEDBACK WITH HAPTIC DEVICES

SYSTEME UND VERFAHREN FÜR VIRTUELLES FEEDBACK MIT HAPTISCHEN
VORRICHTUNGEN

SYSTÈME ET PROCÉDÉ DE RETOUR VIRTUEL À L'AIDE DE DISPOSITIFS HAPTIQUES

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(73) Proprietor: **Intuitive Surgical Operations, Inc.
Sunnyvale, CA 94086 (US)**

(72) Inventor: **AZIZIAN, Mahdi
Sunnyvale, California 94089 (US)**

(74) Representative: **MacDougall, Alan John Shaw
Mathys & Squire LLP
The Shard
32 London Bridge Street
London SE1 9SG (GB)**

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Description

TECHNICAL FIELD

[0001] The present disclosure relates generally to haptic devices for computing systems and more particularly to the use of virtual feedback with haptic devices.

BACKGROUND

[0002] More and more devices are being replaced with electronic and electro-mechanical devices of ever increasing complexity. This is especially true in the hospitals of today with large arrays of autonomous and semi-autonomous electronic devices being found in operating rooms, interventional suites, intensive care wards, emergency rooms, and the like. For example, glass and mercury thermometers are being replaced with electronic thermometers, intravenous drip lines now include electronic monitors and flow regulators, and traditional handheld surgical instruments are being replaced by computer-assisted medical devices.

[0003] A common improvement in many of these devices is the replacement of largely mechanical device controls with hybrid electro-mechanical controls that provide drive-by-wire functionality. Rather than rely on an arrangement of mechanical parts including linkages, pivots, springs, and/or the like, these hybrid electro-mechanical controls monitor an input mechanism, such as a dial, joy stick, switch, articulated arm, and/or the like, to receive commands from an operator. Changes in the input device are converted to input electrical signals that are passed to a control system for processing. The processed input electrical signals are used to determine output electrical signals that become control signals for one or more corresponding actuators. In this way, the operator controls the behavior of the electro-mechanical device indirectly through the processing performed by the control system.

[0004] This approach allows for added flexibility in how the electro-mechanical device can be operated. Not only can the parameters and/or algorithms of the control system be adjusted to change the behavior of the electro-mechanical device, but the lesser reliance on potentially complex linkages, pivots, and springs may result in simpler mechanical designs, smaller devices, and/or the like. In addition, the use of electro-mechanical controls may reduce the amount of force that an operator may exert to obtain a corresponding operation of the electro-mechanical device. Further, the use of haptic input devices allows the control system to additionally provide force feedback to the operator along with the control signals for the actuators.

[0005] US 2004/0106916 A1 discloses methods and systems for surgical procedures with improved feedback. It is often desirable to define objects with respect to images of an anatomy displayed using an image guided surgery system. For non-trivial objects, or those with

complicated two or three dimensional forms, it may be difficult to present information in a manner that is simple for a user to understand. The local distance to a surface of interest, such as the surface of the defined object, or to a desired position, the local penetration distance of the surface of interest, or haptic repulsion force, often provides the most useful information for augmenting the interaction of the user with the image guided surgery system. The scalar value of the local distance may be conveyed to the user by visual, audio, tactile, haptic, or other means.

[0006] US 2009/0326556 A1 discloses a medical robotic system which includes an entry guide with surgical tools and a camera extending out of its distal end. To supplement the view provided by an image captured by the camera, an auxiliary view including articulatable arms of the surgical tools and/or camera is generated from sensed or otherwise determined information about their positions and orientations and displayed on a display screen from the perspective of a specified viewing point. Intuitive control is provided to an operator with respect to the auxiliary view while the operator controls the positioning and orienting of the camera.

[0007] US 2011/0032090 A1 discloses an active handrest system with haptic guidance which comprises a haptic interface device operable to be manipulated by a user's fingers. The haptic interface device is operatively connected to a movement sensing mechanism capable of sensing motion of the haptic interface device in three dimensions. An active handrest is operatively associated with the haptic interface device, the active handrest including an actuated support platform actuated in at least one degree of freedom. The active handrest is configured to support a hand, wrist, and/or arm of a user and is moveably responsive to motions of the haptic interface device detected by the movement sensing mechanism.

[0008] WO 99/14842 A1 discloses actuators and mechanisms which use opposing repulsive magnetic forces. The repulsive forces are typically generated between a stationary magnet and a moving magnet, where the moving magnet is coupled to the mechanism output member. The mechanisms are generally configured such that the repulsive force from one electromagnet is opposed by a repulsive force from another electromagnet, where the opposing forces are simultaneously applied to the mechanism's output member. The opposing configuration allows for open loop control of position and stiffness. The actuator mechanism may have both rotary and linear motion output, and may have either a single degree of freedom or multiple degrees of freedom. Permanent magnets can be used to create a baseline repulsive force without electrical power, and electromagnets can modulate the repulsive force magnitude. Applications include force feedback joysticks, adjustable stiffness devices and high bandwidth mechanisms.

[0009] Accordingly, it is desirable to provide improved methods and systems for providing feedback to operators through haptic input devices.

SUMMARY

[0010] The invention is defined by the appended independent claims. Preferred embodiments of the invention are illustrated in the dependent claims. The present invention provides a control unit for a computer-assisted medical device comprising: one or more processors; and an interface configured to couple the control unit to a first input device; wherein the control unit is configured to: determine a reference point for the first input device; select a first virtual feedback model (VFM) for the first input device from among a plurality of VFMs for the first input device; configure one or more parameters of the first VFM; determine a first position of the first input device based on information from one or more first sensors associated with the first input device; determine a displacement between the first position and the reference point; determine a first feedback level for the first input device based on the displacement and the first VFM, wherein the first feedback level is zero until the displacement exceeds a threshold and the first feedback level is proportional to the displacement above the threshold; and send, based on the first feedback level, one or more first feedback commands to one or more first actuators associated with the first input device.

[0011] The present invention also provides a method of providing feedback on an input device of a computer-assisted medical device, the method comprising: determining a reference point for the input device; selecting a first virtual feedback model (VFM) for the input device from among a plurality of VFMs for the input device; configuring one or more parameters of the first VFM; determining a position of the input device based on information from one or more sensors associated with the input device; determining a displacement between the position and the reference point; determining a feedback level for the input device based on the displacement and the first VFM, wherein the feedback level is zero until the displacement exceeds a threshold and the feedback level is proportional to the displacement above the threshold; and sending, based on the feedback level, one or more feedback commands to one or more actuators associated with the input device.

[0012] Consistent with some examples, a haptic input device for use with a computer-assisted medical device includes an input control, one or more sensors for detecting information related to a position of the input control, one or more actuators for inducing feedback on the input control, a virtual feedback device virtually coupled to the input control, and a control unit. The control unit includes one or more processors and an interface coupling the control unit to the input control. The control unit is configured to determine a reference point for the input control, select a first VFM for the virtual feedback device, configure the first VFM, determine the position of the input control based on information received from the one or more sensors, determine a feedback level for the input control based on the reference point, the position, and

the first VFM, and send one or more feedback commands to the one or more actuators based on the feedback level.

[0013] Consistent with some examples, a compliant motion system for use with a computer-assisted medical device includes a first device, one or more first sensors for detecting information related to a position of the first device, one or more first actuators for inducing feedback on the first device, one or more second sensors for detecting information related to a position of the second device, one or more second actuators for inducing feedback on the second device, a virtual feedback device virtually coupled between the first device and the second device, and a control unit. The control unit includes one or more processors and an interface coupling the control unit to the first device and the second device. The control unit is configured to select a first VFM for the virtual feedback device from among a plurality of VFMs for the virtual feedback device, configure the first VFM, determine a relative position between the first device and the second device based on information received from the one or more first sensors and the one or more second sensors, determine a feedback level based on the relative position and the first VFM, send one or more first feedback commands to the one or more first actuators based on the feedback level, and send one or more second feedback commands to the one or more second actuators based on the feedback level.

[0014] Consistent with some examples, a method of operating a computer-assisted medical device. The method includes sending feedback determined according to a first virtual feedback model (VFM) for a haptic control input, receiving a command to configure the haptic input control according to a second VFM for the haptic input control, and sending, to the haptic control input, feedback determined according to a second VFM. The feedback determined according the first and second VFMs is sent to the haptic control input.

BRIEF DESCRIPTION OF THE DRAWINGS

[0015]

Figures 1A and 1B are simplified diagrams of a mechanical input device having force feedback.

Figure 2 is a simplified diagram of an articulated input control according to some embodiments.

Figure 3 is a simplified diagram of an input device with a virtual feedback mechanism according to some embodiments.

Figure 4 is a simplified diagram of several example virtual feedback models according to some embodiments.

Figure 5 is a simplified diagram of several example virtual feedback mechanism configurations accord-

ing to some embodiments.

Figure 6 is a simplified diagram of a method of generating feedback on an input control according to some embodiments.

Figure 7 is a simplified diagram of control system according to some embodiments.

[0016] In the figures, elements having the same designations have the same or similar functions.

DETAILED DESCRIPTION

[0017] In the following description, specific details are set forth describing some embodiments consistent with the present disclosure. The specific embodiments disclosed herein are meant to be illustrative but not limiting. One skilled in the art may realize other elements that, although not specifically described here, are within the scope of this disclosure.

[0018] Figures 1A and 1B are simplified diagrams of a side-view and a top-view, respectively, of a mechanical input device 100. For example, the mechanical input device 100 may be consistent with a joy stick. Mechanical input device 100 includes an arrangement of mechanical parts that may be used to control another device or system. Mechanical input device 100 includes a shaft 110 and a pivoting mechanism 120. As shown in Figure 1A, an operator of mechanical input device 100 may manipulate an upper end of shaft 110. As the operator manipulates the upper end of shaft 110, the motion rotates shaft 110 about pivoting mechanism 120. At a lower end of shaft 110, one or more springs 130 are coupled between shaft 110 and respective anchor points 140. As lateral force is applied to the upper end of shaft 110 in the directions of arrows 150 (i.e., the x-direction), the upper end of the shaft 110 is displaced laterally causing shaft 110 to rotate about pivoting mechanism 120. This rotation then results in a corresponding lateral displacement of the lower end of shaft 110, which results in the stretching and/or compressing of the springs 130 in the directions of arrows 160. For example, when the lateral displacement of the upper end of shaft 110 is toward the left as shown in Figure 1A, the lateral displacement of the lower end of shaft 110 is to the right causing the left spring 130 to stretch and the right spring 130 to compress. As the left spring 130 stretches, it may generate a force that pulls the lower end of shaft 110 to the left, and as the right spring 130 compresses, it may generate a force that pushes the lower end of shaft 110 to the left. When the lateral displacement of the upper end of shaft 110 is to the right, the opposite may occur. Thus, both the left and right spring 130 may operate to push shaft 110 back to an equilibrium position or a reference point. In some examples, this tendency to return to equilibrium may be used to resist lateral displacement of the upper end of shaft 110, provide force and/or haptic feedback to the

operator, and/or to provide a dead-man's mechanism that returns mechanical input device 100 to the equilibrium position/reference point in the absence of lateral force from the operator.

[0019] The top view of Figure 1B shows that additional springs 130 and anchor points 140 may be used to provide return to equilibrium forces in more than one direction. The four springs 130 of Figure 1B may be used to provide resistive and/or feedback force to the operator of mechanical input device 100 to displacements of shaft 110 in any lateral direction. The left and right springs 130 in Figure 1B may provide feedback force to x-direction displacements and the top and bottom spring 130 in Figure 1B may provide feedback force to y-direction displacements. In combination, the x-direction and y-direction feedback forces provide feedback force to displacements in any combination of the x- and y-directions and help create an equilibrium position/reference point for shaft 110 in the x- and y-directions.

[0020] Although not shown in Figure 1, mechanical input device 100 may provide commands to a mechanical and/or an electro-mechanical control system. In some examples, shaft 110 may be used to activate one or more switches in response to the lateral displacements of the operator. In some examples, pivoting mechanism 120 may include one or more position sensors for determining angular displacement of shaft 120 from its equilibrium or reference orientation. In some examples, the rotational sensor may be implemented using a potentiometer, an optical encoder, Hall Effect sensor, and/or the like. In some examples, one or more of springs 130 may be coupled to displacement and/or force sensors to determine the magnitude by which each of springs 130 is being stretched and/or compressed. In some examples, the force sensors may include strain gauges, and/or the like.

[0021] Mechanical input device 100 demonstrates some of the limitations of mechanical input systems. In some embodiments it may not be possible to change either the force feedback characteristics or the reference point without physically making changes to mechanical input device 100. In some examples, changing the force feedback characteristics may involve replacing one or more of the springs 130 with springs having a different stiffness or spring constant and/or adjusting the location of pivoting mechanism 120 between the upper and lower ends of shaft 110. In some examples, changing the reference point may involve using longer or shorter springs 130, changing the positions of anchor points 140 relative to shaft 110, and/or the like.

[0022] In some embodiments, it may not be possible to easily provide different kinds of force feedback to the operator. As designed, mechanical input device 100 provides a force resisting the operator as the operator introduces lateral displacement to the upper end of shaft 110. In some examples, it may not be possible to easily adapt mechanical input device 100 to oppose or resist movement in the z-direction and/or rotations of shaft 110 about its longitudinal axis. In some examples, as more complex

springs and/or other mechanical dampers are added to mechanical input device 100, the complexity and the amount of space occupied by mechanical input device 100 may become impractical and/or unacceptable.

[0023] Figure 2 is a simplified diagram of an articulated input control 200 according to some embodiments. The articulated input control 200 of Figure 2 further demonstrates the limitations of mechanical feedback elements in the context of an input device having more than the two degrees of freedom of mechanical input device 100. As shown in Figure 2, articulated input control 200 includes a series of links 210 and joints 220 that form an articulated arm that has a handle 230 located at its distal end. In some examples, handle 230 is designed to be manipulated by an operator who may change both the position and the orientation of handle 230 during use of articulated input control 200. In some examples, the links 210 and joints 220 of articulated input control 200 may allow manipulation of handle 230 through six degrees of freedom (e.g., x, y, and z positions as well as roll, pitch, and yaw orientations) within limits imposed by ranges of motion limits on joints 220 and the sizes and shapes of links 210. In some embodiments, articulated input control 200 may correspond to a master input control found in a da Vinci® Surgical System commercialized by Intuitive Surgical, Inc. of Sunnyvale, California.

[0024] To illustrate some of the problems in providing force feedback and/or return to reference point behavior to handle 230, a feedback mechanism 240 is shown coupled between handle 230 and an anchor point 250. Because of the large flexibility in motion of handle 230 due to the links 210 and joints 220, it is likely that implementation of feedback mechanism 240 and anchor point 250 as physical components will result in feedback mechanism 240 and/or anchor point 250 to interfere with the ranges of motion for links 210 and joints 220. This is especially true when the reference point for handle 230 is defined in a world coordinate system and not in a coordinate system that is relative to handle 230. As feedback forces are desired for additional degrees of freedom, any increase in the number of physical feedback mechanisms and/or anchor points is likely to further compound the interference problem. Additionally, as additional physical feedback mechanisms and/or anchor points are added for the additional degrees of freedom, the mechanical complexity of the resulting system may become quite high. As a further problem, designing the physical feedback mechanisms and/or anchor points to allow changes in the location of the reference point and/or the amount of feedback force for different displacements may not be easy and/or practical.

[0025] Consequently, for systems that have input devices that would like to take advantage of movable reference points and/or adjustable feedback forces, physical feedback mechanisms are generally not recommended. This is especially true for input devices with large numbers of degrees of freedom, such as articulated input control 200. To provide flexibility in reference point loca-

tions and feedback force levels, one solution is to use virtual feedback mechanisms with haptic input devices. For example, for articulated input control 200 in Figure 2, feedback mechanism 240 may be implemented as a virtual feedback mechanism and anchor point 250 may be implemented as a virtual anchor point.

[0026] Figure 3 is a simplified diagram of an input device 300 with a virtual feedback mechanism according to some embodiments. As shown in Figure 3, input device 300 includes an input control 310. Input control 310 is capable of being moved by an operator in at least a horizontal direction consistent with a slider or similar input control so that input control 310 may be moved at least to the left or right as shown in Figure 3.

[0027] Although not completely shown in Figure 3, input device 300 and/or input control 310 may be coupled to one or more sensors that may detect the position and/or the changes in position of input control 310. In some examples, each of the one or more sensors may include potentiometers, optical encoders, Hall Effect sensors, and/or the like. In some examples, the one or more sensors may generate an electrical signal encoding the position of input control 310 and/or indications of movement of input control 310 and then output those values as one or more electrical signals on one or more outputs 340. In some embodiments, input control 310 may be a haptic control including one or more actuators or other mechanisms that may apply feedback to input control 310. As the amount of feedback to apply to input control 310 is determined, it may be communicated to input control 310 using one or more electrical signals on one or more inputs 350. The electrical signals on the one or more outputs 340 and/or the one or more inputs 350 may use any suitable signaling pattern or technique including analog voltages or currents, one or more pulses or pulse patterns, pulse width modulation, one or more command bits or bytes, network packets, and/or the like.

[0028] Rather than constrain input control 310 with a mechanical feedback mechanism, such as one of the springs 130, input control 310 is virtually coupled to a virtual feedback mechanism 320 which may be anchored to a virtual anchor point 330. In some examples, input control 310 may be consistent with handle 230, virtual feedback mechanism 320 may be consistent with feedback mechanism 240, and virtual anchor point 330 may be consistent with anchor point 250. As input control 310 is moved, the position and/or the changes in position of input control 310 are applied to a virtual feedback model associated with virtual feedback mechanism 320. The virtual feedback model may then be used to determine the amount, if any, of feedback to be applied to input control 310 via the one or more haptic actuators.

[0029] In some embodiments, the virtual feedback model of virtual feedback mechanism 320 may be consistent with that of a virtual spring. As input control 310 moves left and right, the movement may be interpreted as a displacement from a reference point 360 associated with input control 310. As the displacement increases

and/or decreases, this may be interpreted as stretching and/or compressing of the virtual spring. By assigning a virtual spring constant to the virtual spring, the displacements may be converted to one or more force or other values that may be communicated back to the one or more haptic actuators.

[0030] Because virtual feedback mechanism 320 is virtual, its use in generating feedback for input control 310 is very flexible, depending upon the virtual feedback model used with virtual feedback mechanism 320 and the functional limits of the one or more haptic actuators. As long as the position, displacement, changes in position, and/or changes in displacement of input control 310 are made available to the virtual feedback model, any mapping may be used to convert the position, displacement, changes in position, and/or changes in displacement into corresponding feedback. The advantages of such an approach include the ability to easily change the magnitude and/or profile of the mapping used in the virtual feedback model and/or to change the position of input control 310 that corresponds to reference point 360.

[0031] In some embodiments, the virtual feedback model of virtual feedback mechanism 320 may be configured so as to model any desired feedback behavior. In some examples, virtual feedback mechanism 320 may emulate a mechanical feedback device even though the space around input control 310 may not be capable of supporting such a mechanical feedback device. In some examples, the emulated mechanical feedback device may include a mechanical spring, a damper, a dashpot, a shock absorber, a gas spring, and/or the like. In some examples, virtual feedback mechanism 320 and the virtual feedback model may emulate feedback that may not be practical and/or even possible to implement using mechanical feedback devices. For example, this may include a virtual spring of zero size that opposes any displacement about a reference point. In some examples, because physical size is irrelevant to virtual feedback mechanism 320, the location of virtual anchor point 330 may correspond to reference point 360. In some examples, the relative positions between virtual anchor point 330 and reference point 360 may depend on the virtual feedback model.

[0032] Figure 4 is a simplified diagram of several example virtual feedback models according to some embodiments. Each of the virtual feedback models in Figure 4 is representative of a potential feedback model that may be used with an input control that may be displaced and/or moved along a single axis in a manner consistent with the horizontal movement described with respect to input control 310 in Figure 3. Each of the virtual feedback models are also based on an input control that may be displaced about the single axis of motion from a reference point. The virtual feedback models of Figure 4 are shown in the form of a transfer function that describes the relationship between an amount of displacement as represented by the horizontal axis, with the crossing point at the vertical axis representing the reference point, and an

amount of feedback as represented by the vertical axis. In some examples, the amount of feedback may correspond to or be proportional to an amount of force that may be applied to the input control by one or more haptic feedback actuators. As can be appreciated, any of the various parameters of the virtual feedback models may be changed at any time allowing an operator and/or another control system to change the pattern and/or amount of feedback applied to the input control. In some examples, this may include dynamically changing the reference point about which the displacement is determined (e.g., separating the reference point from the virtual anchor point and/or moving the virtual anchor point) and/or dynamically changing any of the slopes, setpoints, or even the virtual feedback model being used with a corresponding input control.

[0033] As one example, Figure 4 depicts a unidirectional linear feedback model 410. As shown, unidirectional feedback model 410 generates feedback proportional to a positive displacement of an input control from a reference point and no feedback for a negative displacement. The amount of feedback is controlled by the slope k , with larger values of k providing higher force feedback for a given displacement and smaller values of k providing lower force feedback for the given displacement. In some examples, the role of positive and negative displacements may be reversed with feedback being generated for negative displacements and not for positive displacements. In some examples, unidirectional feedback model 410 may provide a suitable approximation of the force feedback that may be applied by a virtual spring that provides force feedback only when under tension.

[0034] Figure 4 also depicts a bidirectional linear feedback model 420. As with unidirectional feedback model 410, bidirectional linear feedback model 420 provides an amount of feedback that is proportional to the amount of displacement with the scaling controlled by the slope k . Bidirectional linear feedback model 420, however, applies to both positive and negative displacements. Thus, bidirectional feedback model 420 may be used to provide feedback in a direction toward the reference point. In some examples, bidirectional feedback model 420 may provide a suitable approximation of the force feedback that may be applied by a virtual spring that provides force feedback during both tension and compression.

[0035] The virtual feedback models may be non-linear as well, such as is shown in a non-linear feedback model 430. Non-linear feedback model 430 includes three zones of general feedback operation. According to the invention, in a start-up zone 432, little or no feedback is applied until the displacement exceeds a start-up threshold. According to the invention, start-up zone 432 may reduce undesirable vibrations in the input control due to no feedback. According to the invention, in a primary operational zone 434, the amount of feedback is proportional to the amount of displacement. And, in a saturation zone 436, the amount of feedback provided may reach

a pre-assigned maximum value. In some examples, the pre-assigned maximum value may be based on a maximum amount of feedback that may be supplied by the one or more haptic actuators, a physical strength of a user, and/or the like.

[0036] The virtual feedback models may also include hysteresis and/or hysteresis-like effects, as is shown in a hysteresis feedback model 440. Like non-linear feedback model 430, hysteresis feedback model 440 includes a start-up zone 442, a ramp-up operational zone 444, and a saturation zone 446. Hysteresis feedback model 440 further includes a ramp-down operational zone 448 that is different from ramp-up operational zone 444. In some examples, hysteresis feedback model 440 provides the advantages of non-linear feedback model 430, but may also provide a better return to reference point characteristic as feedback may be applied up to the point where the input control is returned to the reference point.

[0037] Although not shown in Figure 4, other variations in the virtual feedback models are possible. According to some embodiments, the virtual feedback models may represent other physical components. In some examples, the horizontal axis may represent position and/or velocity rather than displacement. In some examples, the vertical axis may represent force, friction, and/or the like. According to some embodiments, more complex virtual feedback models may be used. In some examples, the virtual feedback model may approximate a piece-wise linear behavior. In some examples, other non-linear models may be used.

[0038] In some examples, the virtual feedback models may include two, three, or even more input dimensions with corresponding multiple displacement axes and/or a virtual feedback surface for each of the corresponding two, three, or more dimensional feedback axes. In some examples, each of the input dimensions and/or axes may correspond with a positional degree of freedom, a rotational degree of freedom, a physical direction, time, and/or the like. In some embodiments, the multi-dimensional feedback model may be isotropic and/or non-isotropic. In some examples, the virtual feedback model may emulate a non-isotropic virtual spring having different coefficients in different directions. In some examples, the virtual feedback model may emulate higher stiffness in one direction and lower stiffness in another direction. In some examples, the virtual feedback model may show linear behavior in one direction, and nonlinear direction in another direction. In general, it is not usually possible to implement this flexibility in feedback using physical feedback mechanisms, such as a series of spring, dampers, and/or the like.

[0039] According to some embodiments, the virtual feedback models may be asymmetric. In some examples, different slopes, non-linear patterns, hysteresis, and/or the like may be applied to the positive and negative displacements. For example, bidirectional linear feedback model 420 for negative displacements may be combined with hysteresis feedback model 440 for positive

displacements. According to some embodiments, the virtual feedback models may provide feedback values that correspond to other behaviors associated with the corresponding input control. In some examples, virtual feedback model 430 may roughly approximate the same shape as a control model used to interpret the displacement of the input control for a control algorithm or model, so that small displacements of the input control result in zero input into the control algorithm and large displacements on the input control provide a saturated maximum input into the control algorithm.

[0040] In some embodiments, virtual feedback mechanism 320 may be easily adapted to handle displacements and/or movement along any degree of freedom in movement including positional and/or rotational displacements. In some examples, any measured displacement of input control 310 may be converted into components along any degree of freedom. In some examples, when input control 310 is displaced in both the horizontal and vertical directions, the components in the horizontal and vertical directions may be determined and then one or more virtual feedback models may be applied to the horizontal and vertical components. In some examples, this may include separate vertical and horizontal virtual feedback models so that it is possible to determine and apply different models of feedback to input control 310 in the horizontal and vertical directions.

[0041] Figure 5 is a simplified diagram of several example virtual feedback mechanism configurations according to some embodiments. Each of the configurations in Figure 5 is representative of a potential configuration of one or more virtual feedback mechanisms with one or more input controls and demonstrates how the one or more virtual feedback mechanisms may provide feedback to the one or more input controls. As with the configuration of Figure 3, any virtual feedback model, such as the virtual feedback models of Figure 4 may be used for the virtual feedback mechanisms shown in Figure 5.

[0042] A configuration 510 demonstrates how two or more virtual feedback mechanisms may be used with an input control 520. As shown, input control 520 is virtually coupled to a virtual feedback mechanism 532 anchored to a virtual anchor point 534 and a virtual feedback mechanism 536 anchored to a virtual anchor point 538. In some examples, virtual anchor points 534 and 538 may correspond to different locations and/or reference points. In some examples, virtual anchor points 534 and/or 538 may correspond to a reference point 525 located near a central position on input control 520. According to some embodiments, configuration 510 may be consistent with a joy-stick type input control similar to the one shown in Figures 1A and 1B, and/or may be consistent with articulated input control 200.

[0043] Use of both virtual feedback mechanisms 532 and 536 may simplify the feedback modeling for input control 520. In some examples, by using separate virtual feedback mechanisms 532 and 536, each of the virtual

feedback mechanisms 532 and 536 may include simpler one-dimensional virtual feedback models. The virtual feedback model for virtual feedback mechanism 532 may provide feedback based on horizontal displacements of input control 520 and the virtual feedback model for virtual feedback mechanism 536 may provide feedback based on vertical displacements of input control 520. In some examples, the feedback from virtual feedback mechanism 532 may be used to generate feedback levels for the one or more haptic actuators of input control 520 that apply to horizontal movement and feedback from virtual feedback mechanism 536 may be used to generate feedback levels for the one or more haptic actuators of input control 520 that apply to vertical movement. In some examples, superposition or some other combining strategy may be used to generate a composite feedback amount from the virtual feedback models of both virtual feedback mechanisms 532 and 536. In some examples, when multiple virtual feedback mechanisms are virtually coupled to handle 230, the feedback levels and/or composite feedback may be used to apply feedback forces on handle 230 through the actuators associated with the joints 220.

[0044] A configuration 540 demonstrates the use of a virtual feedback mechanism 560 to induce compliant behavior between an input control 550 and an input control 555. By using a relative displacement between input controls 550 and 555, an amount of feedback may be generated to, for example, encourage operation so that input controls 550 and 555 may track each other. In some examples, this may support coordination between two separate operators, respectively operating input controls 550 and 555.

[0045] A configuration 570 demonstrates an example torsion-type virtual feedback mechanism for use with a rotatable input control 580. A virtual torsional feedback mechanism 592 may be virtually coupled to rotatable input control 580 and a virtual anchor point 594. The virtual feedback model of virtual torsional feedback mechanism 592 may emulate the behavior of a torsional spring. Thus, as rotatable input control 580 is rotated and generates an angular displacement, the angular displacement may be used to induce a torsional feedback in rotatable input control 580. In some examples, virtual torsional feedback mechanism 592 may be used to provide rotational feedback to an input control, such as to provide torsional feedback to roll, pitch, and/or yaw orientations in an articulated input control like articulated input control 200.

[0046] Although not shown in Figure 5, other configurations of virtual feedback mechanisms are possible. According to some embodiments, more than two virtual feedback mechanisms may be used. In some examples, a third virtual feedback mechanism may be used to handle displacements in an up and down direction orthogonal to both the horizontal and the vertical. In some examples, a series of virtual feedback mechanisms may be virtually coupled radially about input control 520 so as to more uniformly direct input control 520 to a centrally located

reference point. According to some embodiments, the combinations may be mixed and matched. In some examples, additional virtual feedback mechanisms may virtually couple additional input controls and/or virtual anchor points to either input control 550 and/or input control 555. Thus, a mesh of virtually coupled input controls may be created. According to some embodiments, different types of virtual feedback mechanisms may be combined. In some examples, a joy-stick type input control may be virtually coupled to horizontal and vertical virtual feedback mechanisms, such as those shown in configuration 510 and a torsional virtual feedback mechanism, such as virtual torsional feedback mechanism 592 in configuration 570. In this way feedback could be applied to the joy-stick type input control to support both horizontal and vertical displacements, but also for rotational displacements. In some examples, an articulated input control, such as articulated input control 200 may be virtually coupled to one or more virtual feedback mechanisms that provide feedback that push handle 230 toward a reference point and one or more virtual torsional feedback mechanisms to push handle 230 toward a reference orientation with roll, pitch, and/or yaw components.

[0047] Figure 6 is a simplified diagram of a method 600 of generating feedback on an input control according to some embodiments. One or more of the processes 610-670 of method 600 may be implemented, at least in part, in the form of executable code stored on non-transient, tangible, machine readable media that when run by one or more processors, may cause the one or more processors to perform one or more of the processes 610-670. In some embodiments, the input control may be any of the input controls 200, 310, 520, 550, 555, and/or 580. In some embodiments, method 600 may be used to implement the equivalent of a dead-man's switch.

[0048] At a process 610, a reference point for an input control is determined. Before feedback may be applied to an input control, a reference point is generally determined for the input control. In most instances the reference point becomes a reference point about which displacements and/or motions are determined and may often be at a point where zero feedback is typically applied to the input control. In some embodiments, the reference point may be determined based on the physical geometry of the input control. In some examples, the reference point may be at one end or another of the range of motion of the input control and/or may be at any point along the range of motion, such as at a center point. In some examples, when the input control is an articulated input control, the reference point may correspond to a point within a console workspace. In some examples, where the input control has unrestricted motion, such as a rotational input control without stops, the reference point may be at any rotational angle of the rotational input control. In some examples, the reference point may be selectable based on a command received from another input device and/or from an operator. In some examples, the reference point may be determined based on the position of the input

control when the command is received. In some examples, the position of the input control may be determined using one or more input/output (I/O) lines, buses, and/or network links coupled to the input control. In some examples, the input control may be any of the input controls 200, 310, 520, 550, 555, and/or 580.

[0049] At a process 620, a virtual feedback model for the input control is selected and configured. Depending on the feedback behavior desired for the input control, a virtual feedback model is selected and then configured. In some examples, this may include selecting any of the virtual feedback models described in Figure 4 or some other suitable virtual feedback model. This may include selecting between unidirectional and bidirectional models, linear and non-linear models, isotropic and/or non-isotropic models, and/or models with or without hysteresis. The virtual feedback model may then be configured with appropriate slopes, break points, start-up thresholds, saturation values, and/or the like. In some examples, the virtual feedback model may be selected and/or configured by an operator using a catalog of one or more parameterized virtual feedback models.

[0050] At a process 630, a position and/or motion of the input control is detected. Positional and/or movement information for the input control is received from the input control. In some examples, the position and/or movement of the input control may be determined using the one or more I/O lines, buses, and/or network links coupled to the input control. In some examples, the position and/or motion may be received as one or more analog or digital values, one or more pulse counts or pulse widths, in one or more messages, in one or more network packets, and/or the like. In some examples, the position and/or input control may be determined from one or more joint angles, one or more joint positions, and/or one or more kinematic models of an articulated arm associated with the input control. In some examples, the kinematic models may be used to determine a position and/or an orientation of a handle or user grasp point in a console workspace based on the joint angles and/or positions. In some examples, the position and/or motion may be converted to a displacement from the reference point determined during process 610. In some examples, when the input control is being used to control an end effector, either remotely and/or via teleoperation, the displacement may correspond to a position and/or an orientation of the end effector relative to a reference point for the end effector.

[0051] At a process 640, the position and/or motion is reported. Because the input control is also likely providing a command and/or other input to a motion control and/or motion planning algorithm, the received position and/or motion are provided to the motion control and/or motion planning algorithm. In some examples, the position and/or motion may be subject to signal conditioning, scaling, shifting, and/or the like before it is reported to the motion control and/or motion planning algorithm. In some examples, the motion control and/or motion planning algorithm may be responsible for manipulating an end ef-

fector in response to changes in position and/or orientation of the input control.

[0052] At a process 650, a feedback level for the input control is determined. Using the position and/or motion detected during process 630 and the virtual feedback model selected and configured during process 620, a feedback level or amount for the input control is determined. In some examples, the displacement determined based on the position and/or movement is converted to a feedback force using the virtual feedback models like those discussed with respect to Figure 4.

[0053] At a process 660, haptic feedback is applied based on the feedback level. Using the feedback level determined during process 650, one or more output signals and/or commands are generated and sent to the one or more haptic actuators of the input control using the I/O lines, buses, and/or network links coupled to the input control. In some examples, the one or more output signals or commands may include one or more analog or digital values, one or more pulse counts or pulse widths, one or more messages, one or more network packets, and/or the like. In some examples, when the input control is an articulated input control, the feedback level may be converted to joint forces and/or torques using one or more inverse kinematic models and/or Jacobians for the articulated arm associated with the articulated input control.

[0054] At an optional process 670, the input control is forced towards the reference point. When a suitable virtual feedback model is being applied to the input control, the haptic feedback applied during process 660 may apply a force that directs the input control back towards the reference point. In some examples, the virtual feedback model may push the input control back to the reference point when no operator or other input is applied.

[0055] Processes 630-670 are then repeated as more positions and/or motions of the input control are detected, reported, and then used to determine and generate appropriate feedback using the one or more haptic actuators.

[0056] As discussed above and further emphasized here, Figure 6 is merely an example which should not unduly limit the scope of the claims. One of ordinary skill in the art would recognize many variations, alternatives, and modifications. According to some embodiments, the input control may be subject to feedback from more than one virtual feedback mechanism. In some examples, the position and/or motion detected during process 630 may be used to generate feedback levels from multiple virtual feedback models that are then used to determine the amount of haptic feedback to apply. In some examples, superposition or other combining algorithm may be used to generate the composite feedback for the input control. According to some embodiments, processes 610 and/or 620 may be executed periodically during the performance of method 600. In some examples, input may be received from an operator and/or another system that may change the selection and/or configuration of the vir-

tual feedback model being used. In some examples, process 610 may be used to change the reference point for the input control. In some examples, process 620 may be used to change the feedback model being applied to the detected positions and/or motions.

[0057] Figure 7 is a simplified diagram of control system 700 according to some embodiments. As shown in Figure 7, control system 700 is based around a control unit 710. Control unit 710 may be part of a larger computer and/or electronic system (not shown) that may receive inputs from user controls, process those inputs, and implement one or more control algorithms based on those inputs. According to some embodiments, control system 700 may be used as part of and/or in conjunction with an operator workstation for a computer-assisted surgical device that corresponds to a da Vinci® Surgical System commercialized by Intuitive Surgical, Inc. of Sunnyvale, California and/or a computer-assisted imaging device. The one or more control algorithms may use the inputs received from various input controls on the operator workstation to help control the position and movement of the computer-assisted surgical device and/or the computer-assisted imaging device. In some examples, these one or more control algorithms may account for kinematic models, support collision avoidance and/or coordinated motion, and/or the like.

[0058] Control unit 710 includes a processor 720 coupled to memory 730. Operation of control unit 710 is controlled by processor 720. And although control unit 710 is shown with only one processor 720, it is understood that processor 720 may be representative of one or more central processing units, multi-core processors, microprocessors, microcontrollers, digital signal processors, field programmable gate arrays (FPGAs), application specific integrated circuits (ASICs), and/or the like in control unit 710. Control unit 710 may be implemented as a stand-alone subsystem and/or board added to a computing device or as a virtual machine. In some embodiments, control unit may be included as part of the operator workstation and/or operated separately from, but in coordination with the operator workstation.

[0059] Memory 730 may be used to store software executed by control unit 710 and/or one or more data structures used during operation of control unit 710. Memory 730 may include one or more types of machine readable media. Some common forms of machine readable media may include floppy disk, flexible disk, hard disk, magnetic tape, any other magnetic medium, CD-ROM, any other optical medium, punch cards, paper tape, any other physical medium with patterns of holes, RAM, PROM, EPROM, FLASH-EPROM, any other memory chip or cartridge, and/or any other medium from which a processor or computer is adapted to read.

[0060] As shown, memory 730 includes an input control feedback application 740 that may be used to support the generation of feedback in various input controls coupled to control unit 710. Input control feedback application 740 may include one or more application program-

ming interfaces (APIs) for implementing method 600, which includes one or more processes for receiving input control positions, displacements, and/or movement from one or more input devices, determining corresponding feedback values, and generating output signals for one or more haptic feedback actuators. And although input control feedback application 740 is depicted as a software application, input control feedback application 740 may be implemented using hardware, software, and/or a combination of hardware and software.

[0061] To support input control feedback application 740, control unit 710 additionally includes an interface 750 with one or more I/O ports. Interface 750 may be of any suitable type such as dedicated I/O lines, network links, inter-integrated circuit (I²C) buses, serial peripheral interface (SPI) buses, parallel ports, analog I/O lines, and/or the like. Interface 750 may include one or more output lines, buses, and/or network links 760 for coupling control unit 710 to the one or more haptic actuators of an input control so that input control feedback application 740 may control feedback in the input control. Interface 750 may also include one or more input lines and/or buses 770 for coupling control unit 710 to one or more sensors of the input control so that input control feedback application 740 may receive position, displacement, and/or movement information of the input control. In some examples, the one or more output lines 760 may be coupled to inputs 350 of input control 310 and the one or more input lines, buses, and/or network links 770 may be coupled to outputs 340 of input control 310. In some examples, the one or more output lines 760 and the one or more input lines 770 may be combined in the same bi-directional lines, the same buses, and/or the same network links. In some examples, interface circuitry associated with the one or more interface 750 may include one or more bus controllers, I/O controllers, network interfaces, analog to digital convertors, digital to analog convertors, data acquisition systems, and/or the like.

[0062] Some examples of control units, such as the control unit 700 may include non-transient, tangible, machine readable media that include executable code that when run by one or more processors (e.g., processor 710) may cause the one or more processors to perform the processes of method 600. Some common forms of machine readable media that may include the processes of method 600 are, for example, floppy disk, flexible disk, hard disk, magnetic tape, any other magnetic medium, CD-ROM, any other optical medium, punch cards, paper tape, any other physical medium with patterns of holes, RAM, PROM, EPROM, FLASH-EPROM, any other memory chip or cartridge, and/or any other medium from which a processor or computer is adapted to read.

[0063] Although the illustrative embodiments described in Figures 3-7 are directed to input controls, such as haptic input controls, one of ordinary skill would understand that the virtual feedback mechanisms have broader applicability. Thus, for example, the example configuration 540 may be adapted to provide compliant

motion between the end effectors of two devices with articulated arms where the virtual feedback model of virtual feedback mechanism 560 may be used to encourage a desired physical relationship between the two end effectors by basing the amount of feedback on the relative distances between the two end effectors.

[0064] Although illustrative embodiments have been shown and described, a wide range of modification, change and substitution is contemplated in the foregoing disclosure and in some instances, some features of the embodiments may be employed without a corresponding use of other features. One of ordinary skill in the art would recognize many variations, alternatives, and modifications. Thus, the scope of the invention should be limited only by the following claims, and it is appropriate that the claims be construed broadly and in a manner consistent with the scope of the embodiments disclosed herein.

Claims

1. A control unit (710) for a computer-assisted medical device comprising:

one or more processors (720); and
an interface (750) configured to couple the control unit (710) to a first input device (100, 230, 360, 520, 550, 555, 580);
wherein the control unit (710) is configured to:

determine a reference point for the first input device (100, 230, 360, 520, 550, 555, 580);
select a first virtual feedback model (VFM) (410, 420, 430, 440) for the first input device (100, 230, 360, 520, 550, 555, 580) from among a plurality of VFMs (410, 420, 430, 440) for the first input device (100, 230, 360, 520, 550, 555, 580);
configure one or more parameters of the first VFM (410, 420, 430, 440);
determine a first position of the first input device (100, 230, 360, 520, 550, 555, 580) based on information from one or more first sensors associated with the first input device (100, 230, 360, 520, 550, 555, 580);
determine a displacement between the first position and the reference point;
determine a first feedback level for the first input device (100, 230, 360, 520, 550, 555, 580) based on the displacement and the first VFM (410, 420, 430, 440), wherein the first feedback level is zero until the displacement exceeds a threshold and the first feedback level is proportional to the displacement above the threshold; and
send, based on the first feedback level, one or more first feedback commands to one or more first actuators associated with the first

input device (100, 230, 360, 520, 550, 555, 580).

2. The control unit (710) of claim 1, wherein the reference point is determined based on an initial position of the first input device (100, 230, 360, 520, 550, 555, 580) or a physical geometry of the first input device (100, 230, 360, 520, 550, 555, 580).
3. The control unit (710) of claim 1, wherein the reference point is determined in response to a command received from an operator.
4. The control unit (710) of claim 1, 2, or 3, wherein the first feedback level is limited to a pre-assigned maximum value.
5. The control unit (710) of any of claims 1 to 4, wherein the first VFM (410, 420, 430, 440) emulates one or more feedback devices selected from a group consisting of a mechanical spring, a damper, a dashpot, a shock absorber, a torsion spring, and a gas spring.
6. The control unit (710) of any of claims 1 to 5, wherein the first position is at a linear or an angular displacement from the reference point, and wherein the first feedback level is based on the linear or angular displacement.
7. The control unit (710) of any of claims 1 to 6, wherein the one or more first feedback commands direct the first input device (100, 230, 360, 520, 550, 555, 580) toward the reference point.
8. The control unit (710) of any of claims 1 to 7, wherein in an absence of external force being applied to the first input device (100, 230, 360, 520, 550, 555, 580), the one or more first feedback commands implement a dead-man's switch using the first input device (100, 230, 360, 520, 550, 555, 580).
9. The control unit (710) of any of claims 1 to 8, wherein the control unit (710) is further configured to:
change a parameter of the one or more parameters of the first VFM (410, 420, 430, 440), or
replace the first VFM (410, 420, 430, 440) with a second VFM (410, 420, 430, 440) different from the first VFM (410, 420, 430, 440), or
change the reference point.
10. The control unit (710) of any of claims 1 to 8, wherein the control unit is further configured to:
select a second VFM for the first input device from among the plurality of VFMs (410, 420, 430, 440) for the first input device (100, 230, 360, 520, 550, 555, 580);

configure the second VFM (410, 420, 430, 440);
and
determine the first feedback level further based
on the second VFM (410, 420, 430, 440).

11. The control unit (710) of any of claims 1 to 10, wherein:

the interface (750) further couples the control
unit (710) to a second input device; and
the control unit (710) is further configured to:

determine a second position of the second
input device (100, 230, 360, 520, 550, 555,
580) using one or more second sensors as-
sociated with the second input device (100,
230, 360, 520, 550, 555, 580);
determine the first feedback level further
based on the second position; and
send one or more second feedback com-
mands to one or more second actuators as-
sociated with the second input device (100,
230, 360, 520, 550, 555, 580), wherein the
one or more first feedback commands and
the one or more second feedback com-
mands induce compliant motion between
the first input device (100, 230, 360, 520,
550, 555, 580) and the second input device
(100, 230, 360, 520, 550, 555, 580).

12. The control unit (710) of any of claims 1 to 10, wherein:

the interface (750) further couples the control
unit (710) to a second input device (100, 230,
360, 520, 550, 555, 580); and
the control unit (710) is further configured to:

determine a second position of the second
input device (100, 230, 360, 520, 550, 555,
580) using one or more second sensors as-
sociated with the second input device (100,
230, 360, 520, 550, 555, 580);
determine a displacement between the first
position and the second position; and
determine the first feedback level further
based on the displacement between the first
position and the second position.

13. The control unit (710) of any of claim 1 to 10, wherein
the control unit (710) is further configured to:

determine, based on the reference point, a ref-
erence location for an end effector being con-
trolled by the first input device (100, 230, 360,
520, 550, 555, 580);
determine a second position of the end effector;
and

determine the first feedback level for the first in-
put device (100, 230, 360, 520, 550, 555, 580)
further based on the reference location and the
second position.

14. A method of providing feedback on an input device
of a computer-assisted medical device, the method
comprising:

determining a reference point for the input de-
vice (100, 230, 360, 520, 550, 555, 580);
selecting a first virtual feedback model (VFM)
(410, 420, 430, 440) for the input device (100,
230, 360, 520, 550, 555, 580) from among a
plurality of VFMs (410, 420, 430, 440) for the
input device (100, 230, 360, 520, 550, 555, 580);
configuring one or more parameters of the first
VFM (410, 420, 430, 440);
determining a position of the input device based
on information from one or more sensors asso-
ciated with the input device (100, 230, 360, 520,
550, 555, 580); determining a displacement be-
tween the position and the reference point;
determining a feedback level for the input device
(100, 230, 360, 520, 550, 555, 580) based on
the displacement and the first VFM (410, 420,
430, 440), wherein the feedback level is zero
until the displacement exceeds a threshold and
the feedback level is proportional to the dis-
placement above the threshold; and
sending, based on the feedback level, one or
more feedback commands to one or more actu-
ators associated with the input device (100, 230,
360, 520, 550, 555, 580).

15. The method claim 14, wherein the feedback level is
limited to a pre-assigned maximum value.

Patentansprüche

1. Steuereinheit (710) für eine computergestützte me-
dizinische Vorrichtung, die Folgendes umfasst:

einen oder mehrere Prozessoren (720); und
eine Schnittstelle (750), die dafür konfiguriert ist,
die Steuereinheit (710) mit einer ersten Eingabevorrichtung (100, 230, 360, 520, 550, 555, 580) zu koppeln;
wobei die Steuereinheit (710) für Folgendes konfiguriert ist:

Bestimmen eines Referenzpunkts für die
erste Eingabevorrichtung (100, 230, 360,
520, 550, 555, 580);
Auswählen eines ersten virtuellen Rück-
meldungsmodells (Virtual Feedback Model,
VFM) (410, 420, 430, 440) für die erste Ein-

- gabevorrichtung (100, 230, 360, 520, 550, 555, 580) aus einer Vielzahl von VFMs (410, 420, 430, 440) für die erste Eingabevorrichtung (100, 230, 360, 520, 550, 555, 580); Konfigurieren eines oder mehrerer Parameter des ersten VFM (410, 420, 430, 440); Bestimmen einer ersten Position der ersten Eingabevorrichtung (100, 230, 360, 520, 550, 555, 580) basierend auf Informationen von einem oder mehreren ersten Sensoren, die der ersten Eingabevorrichtung (100, 230, 360, 520, 550, 555, 580) zugeordnet sind; Bestimmen einer Verschiebung zwischen der ersten Position und dem Referenzpunkt; Bestimmen eines ersten Rückmeldungspegels für die erste Eingabevorrichtung (100, 230, 360, 520, 550, 555, 580) basierend auf der Verschiebung und dem ersten VFM (410, 420, 430, 440), wobei der erste Rückmeldungspegel Null ist, bis die Verschiebung einen Schwellenwert überschreitet und der erste Rückmeldungspegel proportional zur Verschiebung über dem Schwellenwert liegt; und Senden, basierend auf dem ersten Rückmeldungspegel, eines oder mehrerer erster Rückmeldungsbefehle an einen oder mehrere erste Aktuatoren, die der ersten Eingabevorrichtung (100, 230, 360, 520, 550, 555, 580) zugeordnet sind.
2. Steuereinheit (710) nach Anspruch 1, wobei der Referenzpunkt basierend auf einer Anfangsposition der ersten Eingabevorrichtung (100, 230, 360, 520, 550, 555, 580) oder einer physikalischen Geometrie der ersten Eingabevorrichtung (100, 230, 360, 520, 550, 555, 580) bestimmt wird.
 3. Steuereinheit (710) nach Anspruch 1, wobei der Referenzpunkt als Reaktion auf einen Befehl bestimmt wird, der von einem Bediener empfangen wird.
 4. Steuereinheit (710) nach Anspruch 1, 2 oder 3, wobei der erste Rückmeldungspegel auf einen vorab zugewiesenen Maximalwert begrenzt ist.
 5. Steuereinheit (710) nach einem der Ansprüche 1 bis 4, wobei das erste VFM (410, 420, 430, 440) eine oder mehrere Rückmeldungsrichtungen emuliert, die aus einer Gruppe ausgewählt sind, die aus einer mechanischen Feder, einem Dämpfer, einem Öldämpfer, einem Stoßdämpfer, einer Torsionsfeder und einer Gasfeder besteht.
 6. Steuereinheit (710) nach einem der Ansprüche 1 bis 5, wobei sich die erste Position in einer linearen Verschiebung oder einer Winkelverschiebung von dem Referenzpunkt befindet, und wobei der erste Rückmeldungspegel auf der linearen Verschiebung oder der Winkelverschiebung basiert.
 7. Steuereinheit (710) nach einem der Ansprüche 1 bis 6, wobei der eine oder die mehreren ersten Rückmeldungsbefehle die erste Eingabevorrichtung (100, 30, 360, 520, 550, 555, 580) in Richtung des Referenzpunkts lenken.
 8. Steuereinheit (710) nach einem der Ansprüche 1 bis 7, wobei in Abwesenheit einer externen Kraft, die auf die erste Eingabevorrichtung (100, 230, 360, 520, 550, 555, 580) ausgeübt wird, der eine oder die mehreren ersten Rückmeldungsbefehle einen Totmannschalter unter Verwendung des ersten Eingabevorrichtung (100, 230, 360, 520, 550, 555, 580) implementieren.
 9. Steuereinheit (710) nach einem der Ansprüche 1 bis 8, wobei die Steuereinheit (710) ferner für Folgendes konfiguriert ist:
 - Ändern eines Parameters des einen oder der mehreren Parameter des ersten VFM (410, 420, 430, 440) oder
 - Ersetzen des ersten VFM (410, 420, 430, 440) durch ein zweites VFM (410, 420, 430, 440), das sich vom ersten VFM (410, 420, 430, 440) unterscheidet, oder
 - Ändern des Referenzpunkts.
 10. Steuereinheit (710) nach einem der Ansprüche 1 bis 8, wobei die Steuereinheit ferner für Folgendes konfiguriert ist:
 - Auswählen eines zweiten VFM für die erste Eingabevorrichtung aus der Vielzahl von VFMs (410, 420, 430, 440) für die erste Eingabevorrichtung (100, 230, 360, 520, 550, 555, 580); Konfigurieren des zweiten VFM (410, 420, 430, 440); und
 - Bestimmen des ersten Rückmeldungspegels ferner basierend auf dem zweiten VFM (410, 420, 430, 440).
 11. Steuereinheit (710) nach einem der Ansprüche 1 bis 10, wobei:
 - die Schnittstelle (750) ferner die Steuereinheit (710) mit einer zweiten Eingabevorrichtung koppelt; und
 - die Steuereinheit (710) ferner für Folgendes konfiguriert ist:
 - Bestimmen einer zweiten Position der zweiten Eingabevorrichtung (100, 230, 360, 520, 550, 555, 580) unter Verwendung eines oder mehrerer zweiter Sensoren, die der zweiten Eingabe-

- vorrichtung (100, 230, 360, 520, 550, 555, 580) zugeordnet sind;
Bestimmen des ersten Rückmeldungspegels basierend auf der zweiten Position; und
Senden eines oder mehrerer zweiter Rückmeldungsbe-
fehle an einen oder mehrere zweite Ak-
tuatoren, die der zweiten Eingabevorrichtung
(100, 230, 360, 520, 550, 555, 580) zugeordnet
sind, wobei der eine oder die mehreren ersten
Rückmeldungsbe-
fehle und der eine oder die
mehreren zweiten Rückmeldungsbe-
fehle eine
konforme Bewegung zwischen der ersten Ein-
gabevorrichtung (100, 230, 360, 520, 550, 555,
580) und der zweiten Eingabevorrichtung (100,
230, 360, 520, 550, 555, 580) induzieren.
12. Steuereinheit (710) nach einem der Ansprüche 1 bis
10, wobei:
- die Schnittstelle (750) ferner die Steuereinheit
(710) mit einer zweiten Eingabevorrichtung
(100, 230, 360, 520, 550, 555, 580) koppelt; und
die Steuereinheit (710) ferner für Folgendes
konfiguriert ist:
- Bestimmen einer zweiten Position der zwei-
ten Eingabevorrichtung (100, 230, 360,
520, 550, 555, 580) unter Verwendung ei-
nes oder mehrerer zweiter Sensoren, die
der zweiten Eingabevorrichtung (100, 230,
360, 520, 550, 555, 580) zugeordnet sind;
Bestimmen einer Verschiebung zwischen
der ersten Position und der zweiten Positi-
on; und
Bestimmen des ersten Rückmeldungspe-
gels ferner basierend auf der Verschiebung
zwischen der ersten Position und der zwei-
ten Position.
13. Steuereinheit (710) nach einem der Ansprüche 1 bis
10, wobei die Steuereinheit (710) ferner für Folgen-
des konfiguriert ist:
- Bestimmen eines Referenzorts für einen Endef-
faktor, der von der ersten Eingabevorrichtung
(100, 230, 360, 520, 550, 555, 580) gesteuert
wird, basierend auf dem Referenzpunkt;
Bestimmen einer zweiten Position des Endef-
fektors; und
Bestimmen des ersten Rückmeldungspegels
für die erste Eingabevorrichtung (100, 230, 360,
520, 550, 555, 580) ferner basierend auf dem
Referenzort und der zweiten Position.
14. Verfahren zum Bereitstellen einer Rückmeldung
über eine Eingabevorrichtung einer computerge-
stützten medizinischen Vorrichtung, wobei das Ver-
fahren Folgendes umfasst:

- Bestimmen eines Referenzpunkts für die Eingabevorrichtung (100, 230, 360, 520, 550, 555, 580);
Auswählen eines ersten virtuellen Rückmel-
dungsmodells (VFM) (410, 420, 430, 440) für
die Eingabevorrichtung (100, 230, 360, 520,
550, 555, 580) aus einer Vielzahl von VFMs
(410, 420, 430, 440) für die Eingabevorrichtung
(100, 230, 360, 520, 550, 555, 580);
Konfigurieren eines oder mehrerer Parameter
des ersten VFM (410, 420, 430, 440);
Bestimmen einer Position der Eingabevorrich-
tung basierend auf Informationen von einem
oder mehreren Sensoren, die der Eingabevor-
richtung (100, 230, 360, 520, 550, 555, 580) zu-
geordnet sind;
Bestimmen einer Verschiebung zwischen der
Position und dem Referenzpunkt;
Bestimmen eines ersten Rückmeldungspegels
für die erste Eingabevorrichtung (100, 230, 360,
520, 550, 555, 580) basierend auf der Verschie-
bung und dem ersten VFM (410, 420, 430, 440),
wobei der Rückmeldungspegel Null ist, bis die
Verschiebung einen Schwellenwert überschrei-
tet und der Rückmeldungspegel proportional zur
Verschiebung über dem Schwellenwert liegt;
und
Senden, basierend auf dem Rückmeldungspe-
gel, eines oder mehrerer Rückmeldungsbe-
fehle an einen oder mehrere Aktuatoren, die der Ein-
gabevorrichtung (100, 230, 360, 520, 550, 555,
580) zugeordnet sind.
15. Verfahren nach Anspruch 14, wobei der Rückmel-
dungspegel auf einen vorab zugewiesenen Maxi-
malwert begrenzt ist.

Revendications

1. Unité de commande (710) pour un dispositif médical assisté par ordinateur comprenant :
- un ou plusieurs processeurs (720) ; et
une interface (750) configurée pour coupler l'unité de commande (710) à un premier dispositif d'entrée (100, 230, 360, 520, 550, 555, 580) ;
dans laquelle l'unité de commande (710) est configurée pour :
- déterminer un point de référence pour le premier dispositif d'entrée (100, 230, 360, 520, 550, 555, 580) ;
sélectionner un premier modèle de retour virtuel (VFM) (410, 420, 430, 440) pour le premier dispositif d'entrée (100, 230, 360, 520, 550, 555, 580) parmi une pluralité de

- VFM (410, 420, 430, 440) pour le premier dispositif d'entrée (100, 230, 360, 520, 550, 555, 580) ;
configurer un ou plusieurs paramètres du premier VFM (410, 420, 430, 440) ;
déterminer une première position du premier dispositif d'entrée (100, 230, 360, 520, 550, 555, 580) sur la base d'informations provenant d'un ou de plusieurs détecteurs associés au premier dispositif d'entrée (100, 230, 360, 520, 550, 555, 580) ;
déterminer un déplacement entre la première position et le point de référence ;
déterminer un premier niveau de retour pour le premier dispositif d'entrée (100, 230, 360, 520, 550, 555, 580) sur la base du déplacement et du premier VFM (410, 420, 430, 440), dans laquelle le premier niveau de retour est zéro jusqu'à ce que le déplacement dépasse un seuil et le premier niveau de retour est proportionnel au déplacement au-dessus du niveau seuil ; et
envoyer, sur la base du premier niveau de retour, une ou plusieurs premières commandes de retour à un ou plusieurs actionneurs associés au premier dispositif d'entrée (100, 230, 360, 520, 550, 555, 580).
2. Unité de commande (710) selon la revendication 1, dans laquelle le point de référence est déterminé sur la base d'une position initiale du premier dispositif d'entrée (100, 230, 360, 520, 550, 555, 580) ou d'une géométrie physique du premier dispositif d'entrée (100, 230, 360, 520, 550, 555, 580).
3. Unité de commande (710) selon la revendication 1, dans laquelle le point de référence est déterminé en réponse à une commande reçue d'un opérateur.
4. Unité de commande (710) selon la revendication 1, 2, ou 3, dans laquelle le premier niveau de retour est limité à une valeur maximale pré-attribuée.
5. Unité de commande (710) selon l'une quelconque des revendications 1 à 4, dans laquelle le premier VFM (410, 420, 430, 440) émule un ou plusieurs dispositifs de retour sélectionnés parmi un groupe constitué par un ressort mécanique, un atténuateur, un amortisseur, un absorbeur de chocs, un ressort de torsion, et un ressort à gaz.
6. Unité de commande (710) selon l'une quelconque des revendications 1 à 5, dans laquelle la première position est à un déplacement linéaire ou angulaire du point de référence, et dans laquelle le premier niveau de retour est basé sur le déplacement linéaire ou angulaire.
7. Unité de commande (710) selon l'une quelconque des revendications 1 à 6, dans laquelle les une ou plusieurs premières commandes de retour dirigent le premier dispositif d'entrée (100, 230, 360, 520, 550, 555, 580) vers le point de référence.
8. Unité de commande (710) selon l'une quelconque des revendications 1 à 7, dans laquelle en l'absence d'une force externe appliquée au premier dispositif d'entrée (100, 230, 360, 520, 550, 555, 580), les une ou plusieurs premières commandes de retour mettent en œuvre un bloqueur de sécurité utilisant le premier dispositif d'entrée (100, 230, 360, 520, 550, 555, 580).
9. Unité de commande (710) selon l'une quelconque des revendications 1 à 8, dans laquelle l'unité de commande (710) est configurée en outre pour :
modifier un paramètre des un ou plusieurs paramètres du premier VFM (410, 420, 430, 440), ou remplacer le premier VFM (410, 420, 430, 440) par un deuxième VFM (410, 420, 430, 440) différent du premier VFM (410, 420, 430, 440), ou modifier le point de référence.
10. Unité de commande (710) selon l'une quelconque des revendications 1 à 8, dans laquelle l'unité de commande est configurée en outre pour :
sélectionner un deuxième VFM pour le premier dispositif d'entrée parmi la pluralité de VFM (410, 420, 430, 440) pour le premier dispositif d'entrée (100, 230, 360, 520, 550, 555, 580) ;
configurer le deuxième VFM (410, 420, 430, 440) ; et
déterminer le premier niveau de retour sur la base en outre du deuxième VFM (410, 420, 430, 440).
11. Unité de commande (710) selon l'une quelconque des revendications 1 à 10, dans laquelle :
l'interface (750) couple en outre l'unité de commande (710) à un deuxième dispositif d'entrée ; et l'unité de commande (710) est configurée en outre pour :
déterminer une deuxième position du deuxième dispositif d'entrée (100, 230, 360, 520, 550, 555, 580) utilisant un ou premier détecteurs associés au deuxième dispositif d'entrée (100, 230, 360, 520, 550, 555, 580) ;
déterminer le premier niveau de retour sur la base en outre de la deuxième position ; et
envoyer une ou plusieurs deuxièmes commandes de retour à un ou plusieurs deuxièmes actionneurs associés au deuxième dispositif d'entrée (100, 230, 360, 520, 550, 555, 580), dans laquelle les une ou plusieurs commandes de retour et les une ou plusieurs deuxièmes commandes

- des de retour induisent un mouvement élastique entre le premier dispositif d'entrée (100, 230, 360, 520, 550, 555, 580) et le deuxième dispositif d'entrée (100, 230, 360, 520, 550, 555, 580) . 5
- 12.** Unité de commande (710) selon l'une quelconque des revendications 1 à 10, dans laquelle :
l'interface (750) couple en outre l'unité de commande (710) au deuxième dispositif d'entrée (100, 230, 360, 520, 550, 555, 580) ; et l'unité de commande (710) est configurée en outre pour : 10
- déterminer une deuxième position du deuxième dispositif d'entrée (100, 230, 360, 520, 550, 555, 580) en utilisant un ou plusieurs deuxième détecteurs associés au deuxième dispositif d'entrée (100, 230, 360, 520, 550, 555, 580) ; 15
- déterminer un déplacement entre la première position et la deuxième position ; et 20
- déterminer le premier niveau de retour sur la base en outre du déplacement entre la première position et la deuxième position.
- 13.** Unité de commande (710) selon l'une quelconque des revendications 1 à 10, dans laquelle l'unité de commande (710) est configurée en outre pour : 25
- déterminer, sur la base du point de référence, un emplacement de référence pour un effecteur terminal étant commandé par le premier dispositif d'entrée (100, 230, 360, 520, 550, 555, 580) ; 30
- déterminer une deuxième position de l'effecteur terminal ; et 35
- déterminer le premier niveau de retour pour le premier dispositif d'entrée (100, 230, 360, 520, 550, 555, 580) sur la base en outre de l'emplacement de référence et de la deuxième position. 40
- 14.** Procédé de fourniture d'un retour sur un dispositif d'entrée d'un dispositif médical assisté par ordinateur, le procédé comprenant : 45
- la détermination d'un point de référence pour le dispositif d'entrée (100, 230, 360, 520, 550, 555, 580) ;
- la sélection d'un premier modèle de retour virtuel (VFM) (410, 420, 430, 440) pour le dispositif d'entrée (100, 230, 360, 520, 550, 555, 580) parmi une pluralité de VFM (410, 420, 430, 440) pour le dispositif d'entrée (100, 230, 360, 520, 550, 555, 580) ; 50
- la configuration d'un ou de plusieurs paramètres du premier VFM (410, 420, 430, 440) ; 55
- la détermination d'une position du dispositif d'entrée sur la base d'informations provenant d'un ou de plusieurs détecteurs associés au dis-
- positif d'entrée (100, 230, 360, 520, 550, 555, 580) ;
la détermination d'un déplacement entre la position et le point de référence ;
la détermination d'un niveau de retour pour le dispositif d'entrée (100, 230, 360, 520, 550, 555, 580) sur la base du déplacement et du premier VFM (410, 420, 430, 440), dans lequel le niveau de retour est zéro jusqu'à ce que le déplacement dépasse un seuil et le niveau de retour est proportionnel au déplacement au-dessus du seuil ;
et
l'envoi, sur la base du niveau de retour, d'une ou de plusieurs commandes à un ou plusieurs actionneurs associés au dispositif d'entrée (100, 230, 360, 520, 550, 555, 580).
- 15.** Procédé selon la revendication 14, dans lequel le niveau de retour est limité à une valeur maximale pré-attribuée.

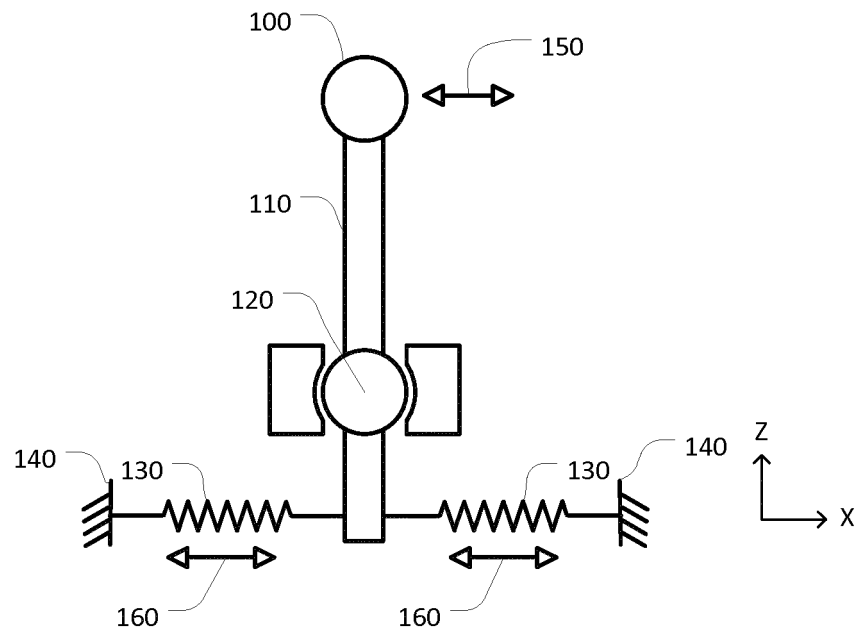


FIG. 1A

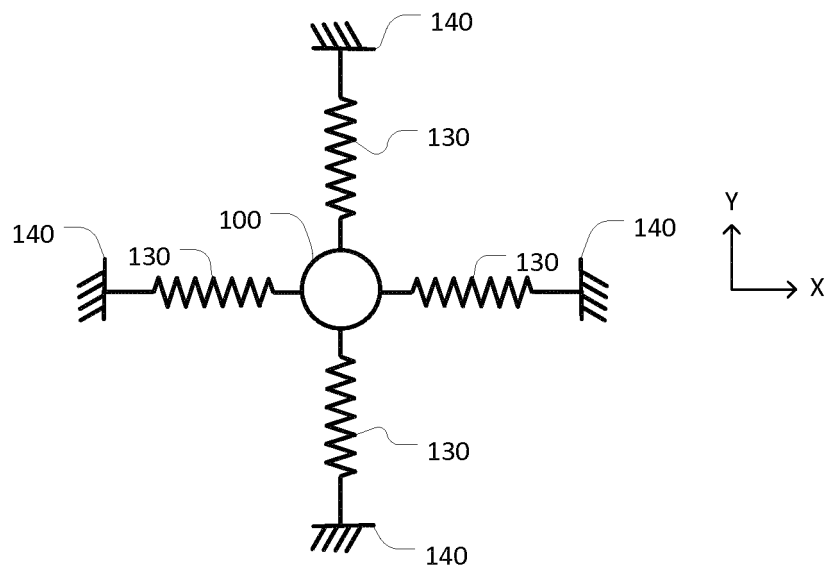


FIG. 1B

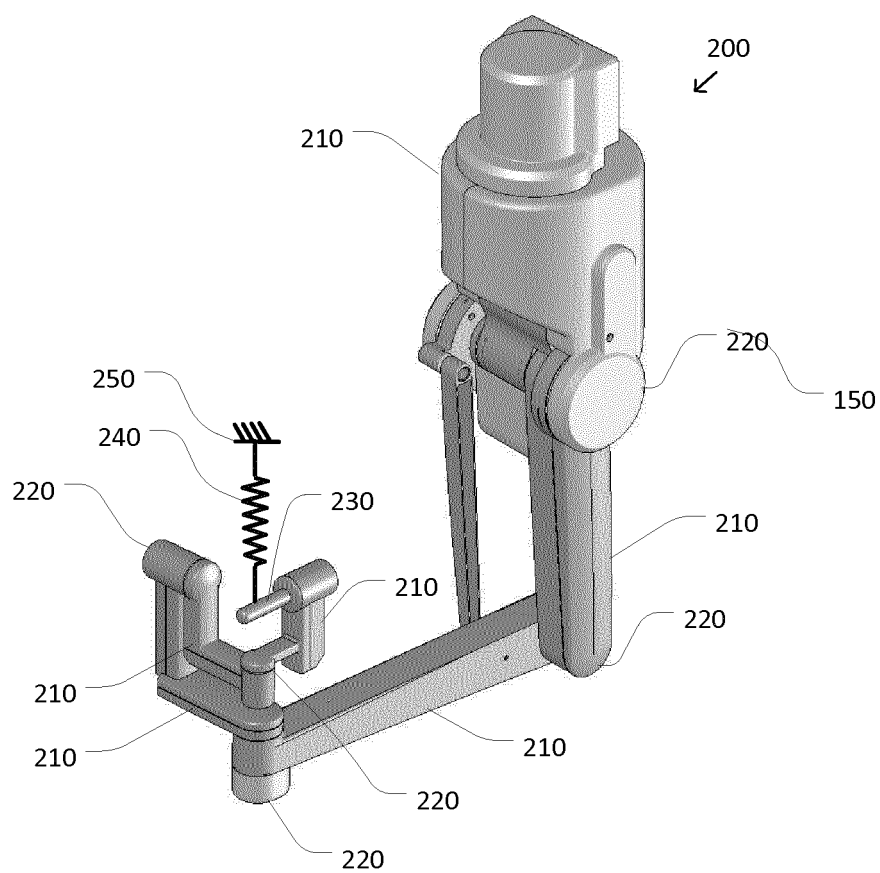


FIG. 2

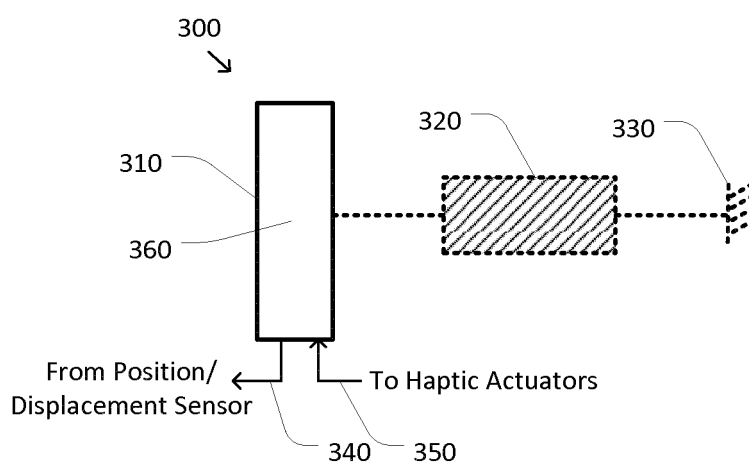


FIG. 3

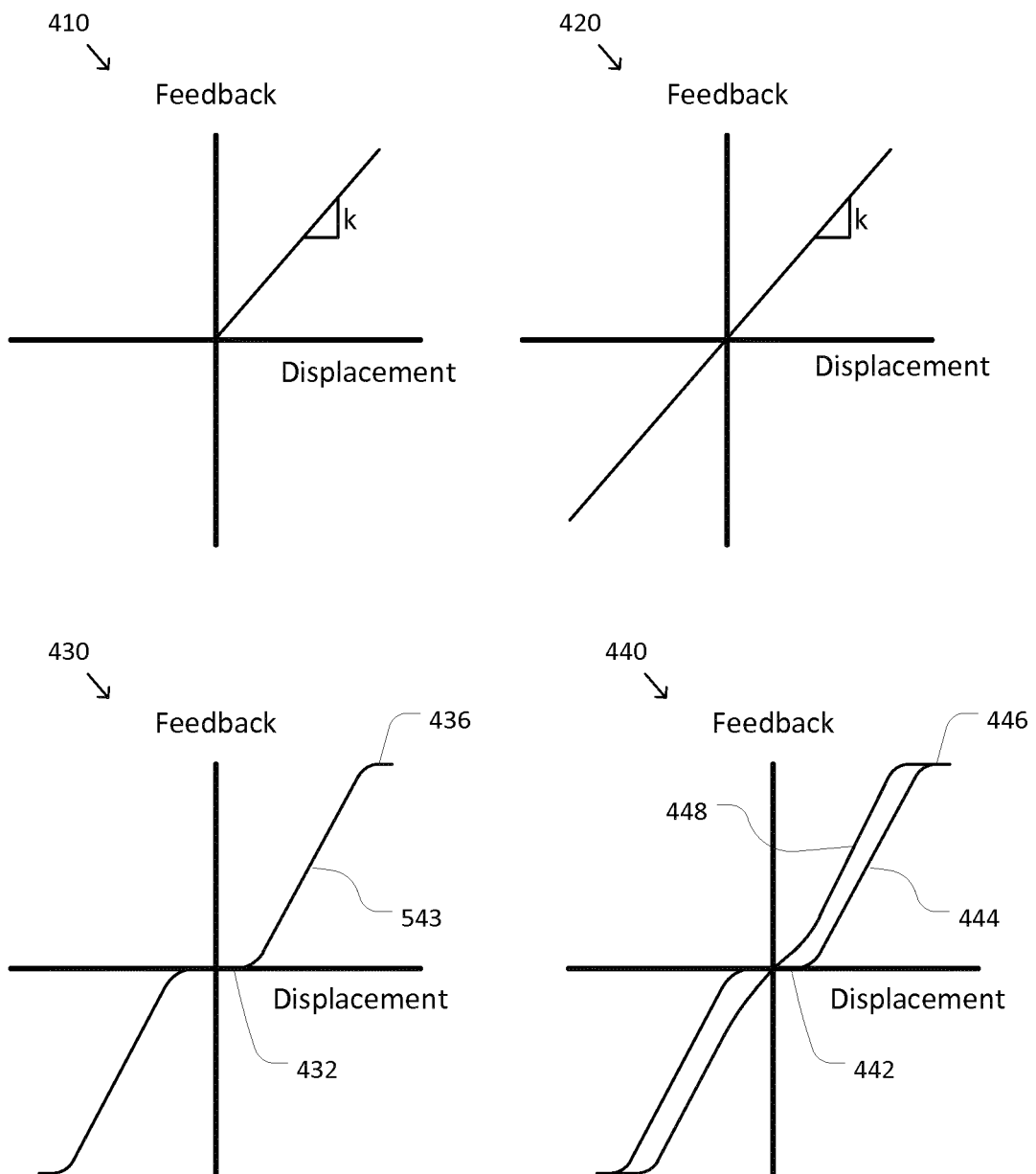


FIG. 4

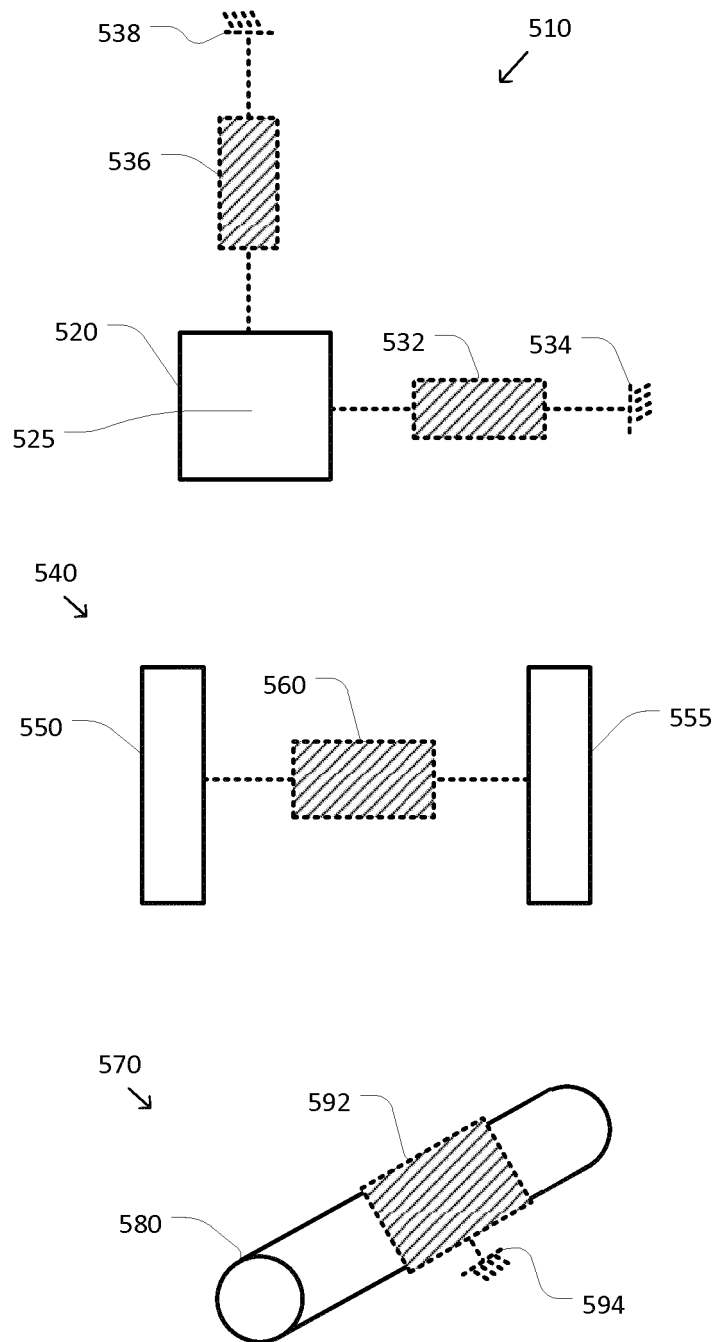


FIG. 5

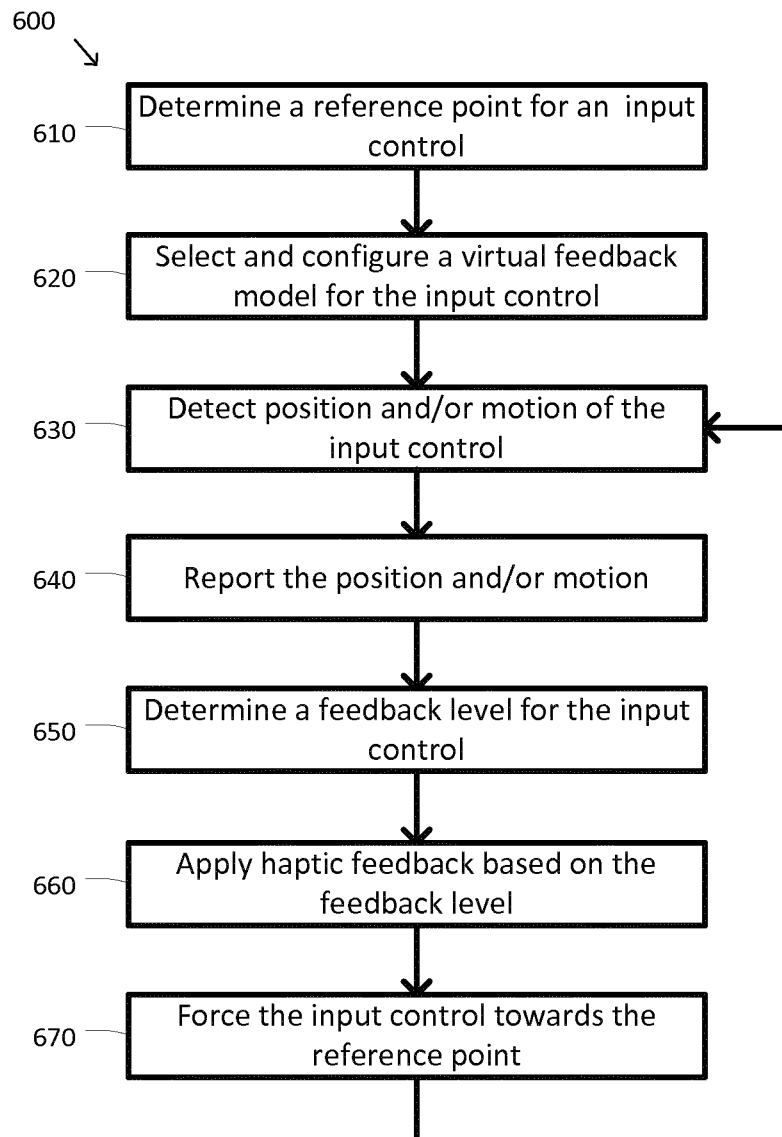


FIG. 6

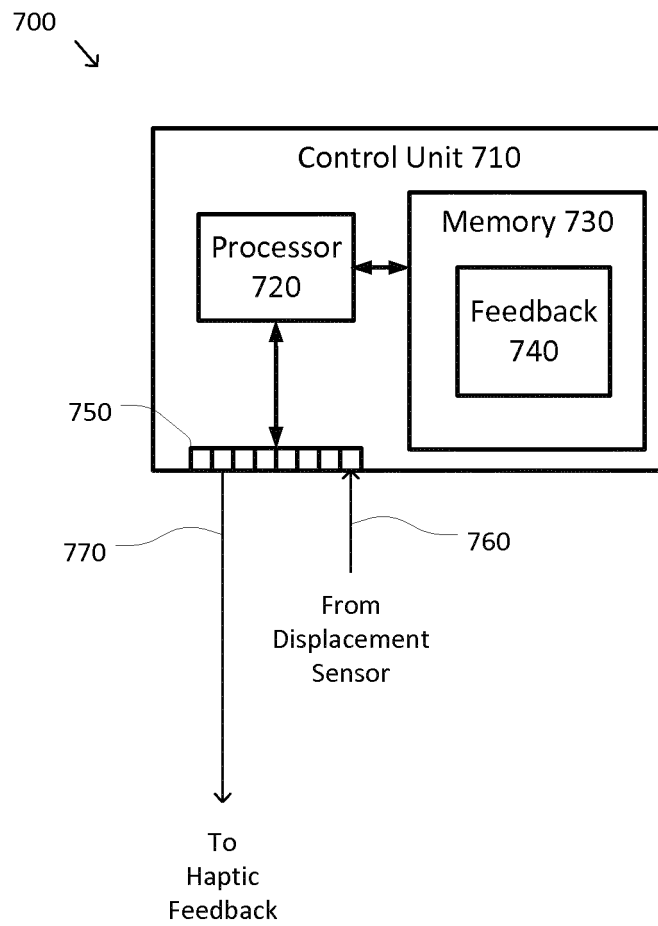


FIG. 7

REFERENCES CITED IN THE DESCRIPTION

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专利名称(译)	具有虚拟设备的虚拟反馈系统和方法		
公开(公告)号	EP3123284B1	公开(公告)日	2020-05-06
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[标]申请(专利权)人(译)	直观外科手术操作公司		
申请(专利权)人(译)	Intuitive Surgical公司运营，INC.		
当前申请(专利权)人(译)	Intuitive Surgical公司运营，INC.		
[标]发明人	AZIZIAN MAHDI		
发明人	AZIZIAN, MAHDI		
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其他公开文献	EP3123284A1 EP3123284A4		
外部链接	Espacenet		

摘要(译)

用于计算机辅助医疗设备的带有触觉设备的虚拟反馈的系统和方法，包括一个或多个处理器以及与控制单元耦合的输入设备，该控制单元配置为确定输入设备的参考点，选择虚拟反馈模型（VFM）从多个VFM中为输入设备配置VFM的参数，基于来自与该输入设备关联的一个或多个传感器的信息确定输入设备的位置，基于参考点确定输入设备的反馈水平，位置和VFM，并根据反馈级别向与输入设备关联的一个或多个执行器发送一个或多个反馈命令。在一些实施例中，VFM包括传递函数，该传递函数具有选自单向，双向，线性，非线性，不对称，对称，各向同性，非各向同性和滞后的一个或多个特性。

