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### SYSTEM AND METHOD FOR BREAKAWAY CLUTCHING IN AN ARTICULATED ARM

#### Abstract

A system and method of breakaway clutching in a device includes joints, links coupled to the joints, actuators coupled to drive motion of the articulated arm, and a control unit. The control unit is configured to switch a first joint of the joints from a first state of the first joint to a second state of the first joint in response to a determination that an external stimulus applied to the links or the joints meets at least a first criterion, wherein movement of the first joint is more restricted in the first state of the first joint than in the second state of the first joint; and switch the first joint from the second state of the first joint to the first state of the first joint in response to a determination that a speed associated with the first joint meets at least a second criterion.

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## Background/Summary

RELATED APPLICATIONS [0001] The present application is a continuation of U.S. patent application Ser. No. 18/765,417 filed Jul. 8, 2024, which is a continuation of U.S. patent application Ser. No. 18/306,046 filed Apr. 24, 2023, and now U.S. Pat. No. 12,089,904, which is a continuation of U.S. patent application Ser. No. 17/196,870 filed Mar. 9, 2021, and now U.S. Pat. No. 11,660,154, which is a continuation of U.S. patent application Ser. No. 16/563,342, filed Sep. 6, 2019 and now U.S. Pat. No. 10,973,596, which is a continuation of U.S. patent application Ser. No. 16/014,619 filed Jun. 21, 2018 and now U.S. Pat. No. 10,449,008, which is a continuation of U.S. patent application Ser. No. 15/126,996 filed Sep. 16, 2016 and now U.S. Pat. No. 10,034,717, which is the U.S. national phase of International Application No. PCT/US2015/021074 filed Mar. 17, 2015, which designated the U.S. and claims priority to U.S. Provisional Patent Application No. 61/954,120 entitled “System and Method for Breakaway Clutching in an Articulated Arm” filed Mar. 17, 2014, the entire contents of each of which are herein incorporated by reference.

## TECHNICAL FIELD

[0002] The present disclosure relates generally to operation of devices with articulated arms and more particularly to breakaway clutching of the articulated arms.

## BACKGROUND

[0003] More and more devices are being replaced with autonomous and semiautonomous electronic devices. This is especially true in the hospitals of today with large arrays of autonomous and semiautonomous 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 hand-held surgical instruments are being replaced by computer-assisted medical devices.

[0004] These electronic devices provide both advantages and challenges to the personnel operating them. Many of these electronic devices may be capable of autonomous or semi-autonomous motion of one or more articulated arms and/or end effectors. Before these articulated arms and their end effectors may be used, they are typically moved to or near a desired working position and orientation. This movement may be performed by teleoperation or remote operation using one or

more user input controls. As the complexity of these electronic devices increases and the articulated arms include large numbers of degrees of freedom, movement into the desired working position and orientation by teleoperation may become complex and/or time consuming. To streamline this operation, some articulated arms include a clutched or float state where one or more of the brakes and/or the actuators on the joints of articulated arms are released, allowing an operator to manually change the positions and/or the orientations of the articulated arms via direct manipulation. In this way the articulated arms may be quickly and easily positioned and/or oriented as desired. The clutch or float state is often engaged by manually activating one or more clutch controls on the articulated arm and/or selecting the clutch or float state at an operator console. This type of manual activation may be inconvenient and/or imprudent.

[0005] Accordingly, improved methods and systems for clutching articulated arms is desirable.

## SUMMARY

[0006] Consistent with some embodiments, a computer-assisted medical device includes an articulated arm having one or more first joints and a control unit coupled to the articulated arm and having one or more processors. The control unit operates each of the first joints in multiple states. The multiple states include a locked state, wherein movement of respective first joints is restricted, and a float state, wherein movement of the respective first joints is permitted. The control unit further switches one or more second joints selected from the first joints from the locked state to the float state when a stimulus on the second joints exceeds one or more unlock thresholds and switches the second joints from the float state to the locked state when a velocity of each of the second joints is below one or more lock thresholds.

[0007] Consistent with some embodiments, a method of controlling motion in a medical device includes operating each of one or more first joints of an articulated arm of the medical device in one of multiple states. The multiple states include a locked state, wherein movement of respective joints is restricted, and a float state, wherein movement of the respective joints is permitted. The method further includes determining a stimulus on one or more second joints selected from the joints, switching the second joints from the locked state to the float state when the stimulus exceeds one or more unlock thresholds, determining a velocity of each of the second joints, and switching the second joints from the float state to the locked state when the velocity of each of the second joints is below one or more lock thresholds.

[0008] Consistent with some embodiments, a non-transitory machine-readable medium comprising a plurality of machine-readable instructions which when executed by one or more processors associated with a medical device are adapted to cause the one or more processors to perform a method. The method includes operating each of one or more first joints of an articulated arm of the medical device in one of multiple states. The multiple states include a locked state, wherein movement of respective joints is restricted, and a float state, wherein movement of the respective joints is permitted. The method further includes determining a stimulus on one or more second joints selected from the first joints, switching the second joints from the locked state to the float state when the stimulus exceeds one or more unlock thresholds, determining a velocity of each of the second joints, and switching the second joints from the float state to the locked state when the velocity of each of the second joints is below one or more lock thresholds.

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## Description

### BRIEF DESCRIPTION OF THE DRAWINGS

[0009] FIG. 1 is a simplified diagram of a computer-assisted system according to some embodiments.

[0010] FIG. 2 is a simplified diagram showing an articulated arm according to some embodiments.

[0011] FIG. 3 is a simplified diagram of a method of breakaway clutching according to some

embodiments.

[0012] In the figures, elements having the same designations have the same or similar functions.

#### DETAILED DESCRIPTION

[0013] In the following description, specific details are set forth describing some embodiments consistent with the present disclosure. It will be apparent to one skilled in the art, however, that some embodiments may be practiced without some or all of these specific details. 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 and the spirit of this disclosure. In addition, to avoid unnecessary repetition, one or more features shown and described in association with one embodiment may be incorporated into other embodiments unless specifically described otherwise or if the one or more features would make an embodiment non-functional.

[0014] FIG. 1 is a simplified diagram of a computer-assisted system **100** according to some embodiments. As shown in FIG. 1, computer-assisted system **100** includes a device **110** with one or more movable or articulated arms **120**. Each of the one or more articulated arms **120** may support one or more end effectors. In some examples, device **110** may be consistent with a computer-assisted surgical device. The one or more articulated arms **120** each provide support for surgical instruments, imaging devices, and/or the like. Device **110** may further be coupled to an operator workstation (not shown), which may include one or more master controls for operating the device **110**, the one or more articulated arms **120**, and/or the end effectors. In some embodiments, device **110** and the operator workstation may correspond to a da Vinci® Surgical System commercialized by Intuitive Surgical, Inc. of Sunnyvale, California. In some embodiments, computer-assisted surgical devices with other configurations, fewer or more articulated arms, and/or the like may be used with computer-assisted system **100**.

[0015] Device **110** is coupled to a control unit **130** via an interface. The interface may include one or more cables, connectors, and/or buses and may further include one or more networks with one or more network switching and/or routing devices. Control unit **130** includes a processor **140** coupled to memory **150**. Operation of control unit **130** is controlled by processor **140**. And although control unit **130** is shown with only one processor **140**, it is understood that processor **140** 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 **130**. Control unit **130** 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.

[0016] Memory **150** may be used to store software executed by control unit **130** and/or one or more data structures used during operation of control unit **130**. Memory **150** 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.

[0017] As shown, memory **150** includes a motion control application **160** that may be used to support autonomous and/or semiautonomous control of device **110**. Motion control application **160** may include one or more application programming interfaces (APIs) for receiving position, motion, and/or other sensor information from device **110**, exchanging position, motion, and/or collision avoidance information with other control units regarding other devices, and/or planning and/or assisting in the planning of motion for device **110**, articulated arms **120**, and/or the end effectors of device **110**. And although motion control application **160** is depicted as a software application, motion control application **160** may be implemented using hardware, software, and/or a

combination of hardware and software.

[0018] In some embodiments, computer-assisted system **100** may be found in an operating room and/or an interventional suite. And although computer-assisted system **100** includes only one device **110** with two articulated arms **120**, one of ordinary skill would understand that computer-assisted system **100** may include any number of devices with articulated arms and/or end effectors of similar and/or different design from device **110**. In some examples, each of the devices may include fewer or more articulated arms and/or end effectors.

[0019] FIG. **2** is a simplified diagram showing an articulated arm **200** according to some embodiments. For example, the articulated arm **200** may be a portion of one of the articulated arms **120** in device **110**. As shown in FIG. **2**, the articulated arm **200** includes various links and joints. At the most proximal end of the articulated arm **200** is coupled to a platform **210**. In some examples, platform **210** may be at a distal end of additional joints and links (not shown) from a computer-assisted device. Coupled to platform **210** is a series of set-up joints and links **220**. The set-up joints and links **220** is rotationally coupled to platform **210** via a first set-up linkage joint **222**. In some examples, additional set-up links and joints for other articulated arms (not shown) may be rotationally coupled to platform **210** using additional first set-up linkage joints. Coupled to the first set-up linkage joint **222** is a set-up base linkage **224** that is coupled to a proximal end of a set-up linkage extension link **226** via a first set-up linkage prismatic joint **228**. A distal end of the set-up linkage extension link **226** is coupled to a proximal end of a set-up linkage vertical link **230** via a second set-up linkage prismatic joint **232**. A distal end of the set-up linkage vertical link **230** is rotationally coupled to a proximal end of a support link **234** via a second set-up linkage joint **236**. A first rotational joint **238** is coupled to a distal end of the support link **234**. The first rotational joint **238** provides rotational control over the additional links and joints located distal to the first rotational joint **238**. In some examples, a central axis **250** of the first rotational joint **238** may be aligned with a remote center **290** that may be fixed in location during teleoperation of the articulated arm **200**.

[0020] A coupling link **240** couples the first rotational joint **238** to a second rotational joint **242**. The second rotational joint **240** is coupled to a yaw joint **252** via a yaw link **254**. Coupled distal to the yaw joint **252** is a parallelogram pitch mechanism **260**. At a proximal end of the parallelogram pitch mechanism **260** is a first pitch link **262** coupling the yaw joint **252** to a first pitch joint **264**. A second pitch link **266** couples the first pitch joint **264** to a second pitch joint **268**. A third pitch link **270** couples the second pitch joint **268** to a third pitch joint **272**. An instrument carriage is coupled to the third pitch joint **272** and includes an instrument shaft **280**. One or more end effectors may be coupled to a distal end of the instrument shaft **280**. In some examples, the parallel pitch mechanism **260** may be controlled to maintain the instrument shaft **280** in alignment with the remote center **290**.

[0021] As shown in FIG. **2**, the articulated arm **200** includes numerous linkages **224**, **226**, **230**, **234**, **240**, **254**, **262**, **266**, **270**, and **280** whose relative positions and/or orientations may be adjusted using numerous prismatic joints **228** and **232** as well as numerous rotational joints **222**, **236**, **238**, **242**, **262**, **264**, **268**, and **272**. Each of the prismatic and rotational joints may include one or more sensors for sensing position, rotation, movement, force, torque, and/or the like on the respective joints.

[0022] Depending upon the desired ability to control the articulated arm **200** each of the various joints may be non-actuated or actuated joints. In some examples, a non-actuated joint may not include any actuators so that it is not capable of motion via teleoperation and/or motion control commands from a control unit for the articulated arm **200**. In some examples, the non-actuated joint may include a brake the permits the control unit to prevent and/or restrict motion in the non-actuated joint. In the examples, of FIG. **2**, joints **228**, **232**, and/or **236** may be non-actuated joints. In some examples, an actuated joint may include one or more actuators that may control motion of the actuated joint via teleoperation and/or motion commands. In some examples, an actuated joint

may further include a brake.

[0023] In some embodiments, to prevent unwanted movement the various joints and links in the articulated arm **200** may be placed in a locked state where each of the non-actuated joint brakes are activated and each of the actuated joint actuators are commanded to hold the actuated joints at a commanded position. In some examples, the locked state may additionally prevent unwanted motion due to gravity acting on the articulated arm **200**. Although not shown in FIG. 2, the articulated arm **200** may include one or more clutch buttons or controls. In some examples, the clutch buttons may be located at various locations along the instrument carriage. In some examples, additional clutch controls may be activated via operator controls at an operator console. By activating one or more of the clutch buttons or controls, one or more joints of the articulated arm may be switched from the locked state to a clutched or float state in which at least some of the non-actuated joint brakes may be at least partially released and at least some of the of the actuated joint actuators may permit motion of the joint away from the commanded positions. For example, activation of a clutch button located on the articulated arm **200** may place the articulated arm **200** in the float state while other portions of the computer-assisted device coupled to the platform **210** remain in the locked state. While the joints of the articulated arm **200** are in the float state, an operator may manually position and/or orient the articulated arm **200** into a desired working position and orientation.

[0024] In some embodiments, manual activation of the clutching mechanisms of the articulated arm **200** may not always be practical and/or prudent. In some examples, location of the clutch buttons or controls may not be convenient for easy activation by an operator. In some examples, the operator may not have a free finger and/or hand to operate the clutch controls. In some examples, coordination of the clutch controls with another operator located at an operator console may not be possible and/or practical. In some examples, the operator may not be able to operate the clutch controls without breaking a sterile field established around portions of the articulated arm **200**. Thus, it would be advantageous to have at least portions of the articulated arm **200** enter the float state without activation of a clutch control by an operator.

[0025] In some embodiments, movement of the articulated arm **200** may be desired without manual clutch activation. In some examples, inadvertent collisions may occur between the operator, a patient, and/or an object and one or more links and/or joints of the articulated arm **200**. In some examples, these inadvertent collisions may result in injury to the operator, injury to the patient, damage to the object, and/or damage to the articulated arm **200** due to the rigid position and/or orientation being maintained by the articulated arm **200**. In some examples, being able to detect an inadvertent collision and have the articulated arm **200** automatically enter the float state may reduce injury to the operator, injury to the patient, damage to the object, and/or damage to the articulated arm **200**.

[0026] FIG. 3 is a simplified diagram of a method **300** of breakaway clutching according to some embodiments. One or more of the processes **310-360** of method **300** 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 (e.g., the processor **140** in control unit **130**) may cause the one or more processors to perform one or more of the processes **310-360**. In some embodiments, the method **300** may be performed by an application, such as motion control application **160**.

[0027] At a process **310**, a locked state is entered. Joints of an articulated arm, such as articulated arms **120** and/or **200** may be placed in the locked state by default. In the locked state, motion of the articulated arm may be prevented and/or reduced by activating brakes in each of the non-actuated joints of the articulated arm and holding each of the actuated joints of the articulated arm at a respective commanded position using corresponding actuated joint actuators.

[0028] At a process **320**, external stimulus on one or more joints is determined. The one or more sensors associated with each of the joints of the articulated arm are periodically read and/or monitored to determine whether there is any external stimulus being applied to the one or more

joints of the articulated arm. In some examples, linear sensors associated with prismatic joints and/or rotation sensors associated with rotational joints are monitored to determine actual positions of respective joints. In some examples, position errors may be determined based on differences between the actual positions and commanded positions in actuated joints and/or braked positions in non-actuated joints. In some examples, the position errors may be converted to approximate forces and/or torques on the respective joints by using one or more kinematic models, inverse Jacobian transposes, and/or control models for the respective joints. In some examples, the forces and/or torques on the respective joints may be measured using force and/or torque sensors, respectively, monitoring the respective joints. In some examples, joint velocities of the actuated joints may also be determined using one or more velocity sensors associated with actuated joints or numerically based on changes in the actual positions of the actuated joints.

[0029] At a process **330**, it is determined whether the external stimulus on any of the joints exceeds an unlock threshold. The external stimulus values of each of the joints determined during process **320** is compared to one or more unlock thresholds to see whether any of the unlock thresholds are exceeded. In some examples, joints of the articulated arm may be switched to the float state using a process **340** when any one of the external joint stimulus values exceeds a respective unlock threshold. In some examples, joints of the articulated arm may be switched to the float state when a combination of two or more of the external joint stimulus values exceed respective unlock thresholds. In some examples, joints of the articulated arm may be switched to the float state when a weighted and/or un-weighted aggregation of external stimulus values from two or more joints exceeds a composite unlock threshold. In some examples, the aggregation may include an average, a median, a sum of squares, a minimum, a maximum, and/or like.

[0030] In some examples, each of the unlock thresholds for the respective joints may be different depending upon the location and/or purpose of the respective joints in the articulated arm. In some examples, the unlock thresholds may be adjusted based on a current pose, position, and/or orientation of the articulated arm. In some examples, the unlock threshold for a respective joint may be adjusted and/or disabled when the respective joint is beyond a soft stop near an end of possible motion for the respective joint. In some examples, the float state may be activated by default when the respective joint is beyond a soft stop. In some examples, determination of whether the external stimulus exceeds a threshold may be limited to a subset of the joints in the articulated arm. In some examples, external stimulus on non-actuated joints, which are braked, may not be monitored during process **320** and may not have corresponding unlock thresholds. In some examples, the unlock thresholds may be adjusted based on a size and/or a mass of the articulated arm. In some examples, the unlock thresholds may be large enough to avoid accidental switching to the float state due to gravitational forces and/or errors in the joint sensors.

[0031] In some examples, an unlock threshold may correspond to a threshold value associated with a position error between an actual position of a joint and a commanded and/or braked position of the joints. In some examples, the threshold value may be between 0.02 and 5 millimeters for a prismatic joint. In some examples, the threshold value may be between 0.03 and 0.5 degrees for a rotational joint. In some examples, one or more unlock thresholds may correspond to a force and/or torque being applied to the joint, either as measured and/or as determined during process **320**. In some examples, the threshold value may be between 1 and 30 N for a force on a prismatic joint. In some examples, the threshold value may be between 1 and 30 N-m for a torque on a rotational joint. In some examples, the threshold value may exceed a force and/or torque saturation value for the joint.

[0032] In some embodiments, the unlock thresholds should be exceeded for a predetermined period of time before switching the articulated arm to the float state. In some examples, joints of the articulated arm may be switched to the float state when a respective external stimulus value exceeds a corresponding unlock threshold continuously for the predetermined period of time. In some examples, joints of the articulated arm may be switched to the float state when an aggregate,

such as an average, of a respective external stimulus value over the predetermined period of time exceeds a respective stimulus value. In some examples, a sliding window and/or exponential smoothing may be used to determine the aggregate. In some examples, a filter may be used on the sensed external stimulus which puts an emphasis on mid-frequencies in order to better isolate disturbances due to human intention from disturbances due to gravity and other environmental factors which may be at low frequencies. In some examples, the mid-frequencies may extend from approximately 0.01 Hz to 10 Hz. In some examples, a discrete wavelet transform may be used in place of or combined with a filter to better isolate disturbances due to human intention. In some examples, the predetermined period of time may be set by an operator. In some examples, the predetermined period of time may be between 50 and 150 milliseconds. In some examples, the predetermined period of time may be different a first time breakaway clutching is activated, to avoid accidental switching to the float state due to residual momentum in the articulated arm due to other recently completed motion and/or static disturbances from the environment being confused with user input. In some examples, the locked state should be established with the external stimulus below the unlock threshold for a predetermined period of time before the first time breakaway clutching is activated, to avoid accidental switching to the float state due to likely transient situations, such as when an articulated arm is undocked from a patient, an end effector is attached or removed from the articulated arm, and/or the like. In some examples, the predetermined time may be extended between an additional 100 and 250 milliseconds after breakaway clutching is enabled.

[0033] When the external stimulus does not exceed the one or more unlock thresholds, the external stimulus is determined again using process **320**. When the external stimulus exceeds the one or more unlock thresholds, joints of the articulated arm are switched to the float state using process **340**.

[0034] At the process **340**, the float state is entered. One or more of the joints of the articulated arm are placed in a float state where free and/or mostly free movement of the joints is permitted. In some examples, the joints being placed in the float state may be a subset of the joints in the articulated arm. In some examples, this permits breakaway clutching to apply to those portions of the articulated arm subject to the external stimulus. In some examples, the brakes on each of the non-actuated joints being placed in the float state may be released allowing motion of each of the non-actuated joints. In some examples, each of the actuated joints being placed in the float state may be commanded to move to the actual positions determined during process **320** or while the actuated joints remain in the float state. In some examples, each of the actuated joints being placed in the float state may also be commanded to match the joint velocities determined during process **320** or while the actuated joints remain in the float state. In some examples, setting the command positions of a feedback controller of the actuated joints to the actual positions and/or the command velocities of the feedback controller to the actual joint velocities gives the impression that the actuated joints are moving freely, and when gravity compensation is also being applied, then also with the impression of apparent weightlessness.

[0035] In some embodiments, the movement of the joints in the float state may be subject to damping. To reduce and/or prevent unrestricted and/or wild movement of the articulated arm while in the float state, one or more of the joints placed in the float state may be subject to some form of damped motion. For example, it may not be desirable for an articulated arm subject to a strong external stimulus, such as a hard collision, to move away from the strong external stimulus without some limitation. Constraining the clutched movement may reduce the risks of injury and/or damage caused by a fast moving articulated arm. In some examples, the damped motion may be implemented on non-actuated joints by partially releasing the brakes so as to place a drag on movement of the non-actuated joints. In some examples, the brakes may be partially released by controlling one or more voltage, currents, duty cycles, and/or the like of signals used to control the brakes. In some examples, the damped motion may be implemented on actuated joints by



commanding the actuated joints to move a portion of the distance behind the actual position based on direction of motion, by increasing a derivative constant in the feedback controller without significantly affecting its stability margins, and/or by introducing a backward current and/or voltage on the actuators of the actuated joints to emulate a resisting force and/or torque. In some examples, the damped motion may be implemented on actuated joints by commanding the velocities of the actuated joints to a value below the joint velocities determined during process **320** or while the actuated joints remain in the float state. In some examples, the damped motion may be adjusted to account for a current pose, position, and/or orientation of the articulated arm, a size and/or a mass of the articulated arm, and/or the like.

[0036] In some embodiments, one or more of the joints in the articulated arm that are not placed in the float state may be subject to compliant motion restrictions. In some examples, the joints not placed in the float state may be commanded in response to detected movements of the joints placed in the float state. In some examples, the joints not placed in the float state may be commanded to one or more positions and/or orientations. In the examples, of FIG. 2, one or more of the joints in the parallelogram pitch mechanism **260** may be commanded to maintain intersection of the instrument shaft **280** with the central axis **250** at the remote center **290**.

[0037] At a process **350**, joint velocities are determined. The one or more sensors associated with each of the joints of the articulated arm are periodically read and/or monitored to determine the velocities of each of the joints that are in the float state. In some examples, changes in linear and/or rotational position between two consecutive monitoring intervals are used to estimate the joint velocities. In some examples, numerical and/or other differentiation techniques may be used to determine the joint velocities from the sensed positions. In some examples, velocity sensors on the joints may be monitored.

[0038] At a process **360**, it is determined whether the joint velocities drop below a lock threshold. During breakaway clutching, the joints of the articulated arm are kept in the float state as long as continued motion of the articulated arm is detected. The joint velocities determined during process **350** are compared to one or more lock thresholds to see whether any continuing motion is detected in the articulated arm. In some examples, each of the joint velocities may be compared to a corresponding lock threshold. When each of the joint velocities is below its corresponding lock threshold, lack of motion is detected and the joints of the articulated arm are switched to the locked state using process **310**. In some examples, joints of the articulated arm may be switched to the locked state using process **310** when a weighted and/or un-weighted aggregation of joint velocities from each of the joints is below a composite lock threshold. In some examples, the aggregation may include an average, a median, a sum of squares, a minimum, a maximum, and/or like.

[0039] In some examples, each of the lock thresholds for respective joints may be different depending upon the location and/or purpose of the respective joints in the articulated arm. In some examples, the lock thresholds may be adjusted based on a current, pose position, and/or orientation of the articulated arm. In some examples, the lock threshold for a respective joint may be adjusted and/or disabled when the respective joint is beyond a soft stop near an end of possible motion for the respective joint. In some examples, the locked state may be activated by default when the respective joint is beyond a soft stop. In some examples, determination of whether the joint velocities are below the lock thresholds may be limited to a subset of the joints in the articulated arm. In some examples, the lock thresholds may be adjusted based on a size and/or a mass of the articulated arm. In some examples, the lock thresholds may be large enough to avoid accidental switching to the lock due to errors in the joint sensors.

[0040] In some examples, the lock threshold may be between 0.1 and 10 millimeters per second for a prismatic joint. In some examples, the threshold value may be between 0.25 and 10 degrees per second for a rotational joint.

[0041] In some embodiments, the joint velocities should remain below the lock thresholds for a predetermined period of time before switching the joints of the articulated arm to the locked state.

In some examples, joints of the articulated arm may be switched to the locked state when the joint velocities are below a corresponding lock threshold continuously for the predetermined period of time. In some examples, joints of the articulated arm may be switch to the locked state when an aggregate, such as an average, of a respective joint velocity over the predetermined period of time is below a respective lock threshold. In some examples, a sliding window and/or exponential smoothing may be used to determine the aggregate. In some examples, the predetermined period of time may be set by an operator. In some examples, the predetermined period of time may be between 100 and 200 milliseconds.

[0042] When the joint velocities remain above the lock thresholds, the joint velocities are determined again using process **350**. When the joint velocities are below the lock thresholds, the joints of the articulated arm are switched to the locked state using process **310**.

[0043] As discussed above and further emphasized here, FIG. **3** 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 breakaway clutching of method **300** may be disabled during certain operating modes of the articulated arm. In some examples, breakaway clutching may be disabled when the articulated arm is in a hard locked state during storage and/or when a cart on which the articulated arm is mounted is being transported between locations. In some examples, breakaway clutching may be disabled when the articulated arm is in an actuated teleoperation mode and/or executing commanded motion, such as when docked to a patient. In some examples, disabling breakaway clutching during actuated operation may reduce the likelihood that manual interference and/or collision with the articulated arm will interfere with the teleoperation and/or commanded motion and thus reduce the further likelihood of damaging objects being manipulated and/or causing injury to a patient on which the articulated arm is being used. In some examples, breakaway clutching may be adjusted, forced, or disabled when any of the joints in the articulated arm is beyond a soft stop position.

[0044] Some examples of control units, such as control unit **130** may include non-transient, tangible, machine readable media that include executable code that when run by one or more processors (e.g., processor **140**) may cause the one or more processors to perform the processes of method **300**. Some common forms of machine readable media that may include the processes of method **300** 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.

[0045] 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 teleoperated device comprising: an articulated arm comprising a plurality of joints, a plurality of links coupled to the plurality of joints, and a plurality of actuators coupled to drive motion of the articulated arm; and a control unit comprising one or more hardware processors, the control unit coupled to the articulated arm; wherein the control unit is configured to: switch a first joint of the plurality of joints from a first state of the first joint to a second state of the first joint in response to a determination that an external stimulus applied to the plurality of links or the plurality of joints

meets at least a first criterion, wherein movement of the first joint is more restricted in the first state of the first joint than in the second state of the first joint; and switch the first joint from the second state of the first joint to the first state of the first joint in response to a determination that a speed associated with the first joint meets at least a second criterion.

**2.** The teleoperated device of claim 1, wherein the control unit is further configured to: detect the external stimulus by detecting an effect of the external stimulus on the first joint.

**3.** The teleoperated device of claim 1, wherein the control unit is further configured to: detect the external stimulus by detecting an effect of the external stimulus on a second joint of the plurality of joints.

**4.** The teleoperated device of claim 1, further comprising: a sensor; wherein the control unit is further configured to: determine whether the external stimulus meets the first criterion based on at least a value determined from information received from the sensor, the value being selected from the group consisting of: a position error in a joint of the plurality of joints; a force applied to a joint of the plurality of joints; and a torque applied to a joint of the plurality of joints.

**5.** The teleoperated device of claim 1, wherein the first criterion comprises: the external stimulus exceeding a stimulus threshold; or the external stimulus exceeding the stimulus threshold continuously for a predetermined period of time.

**6.** The teleoperated device of claim 1, wherein the second criterion comprises: the speed associated with the first joint falling below a speed threshold; or an aggregate of the speed associated with the first joint over a predetermined period of time is below the speed threshold; or the speed associated with the first joint remaining below the speed threshold continuously for the predetermined period of time.

**7.** The teleoperated device of claim 1, wherein the control unit is further configured to: command, on condition that the first joint is in the second state of the first joint, an actuator of the plurality of actuators associated with the first joint to move the first joint to: a commanded position based on a current actual position of the first joint, or to a commanded velocity based on a current actual velocity of the first joint.

**8.** The teleoperated device of claim 1, wherein the control unit is further configured to: prevent switching of the first joint to the second state of the first joint when an operating mode of the teleoperated device corresponds to a transport mode, a teleoperation mode, or a commanded motion mode.

**9.** The teleoperated device of claim 1, wherein the control unit is further configured to: prevent switching of the first joint to the second state of the first joint when the articulated arm is determined to be docked to a patient.

**10.** The teleoperated device of claim 1, wherein the control unit is further configured to: determine the first criterion is based on at least a property selected from the group consisting of: a location of the first joint in the articulated arm; a location of a second joint of the plurality of joints in the articulated arm; an amount of error in a joint sensor associated with the first joint; an amount of error in a joint sensor associated with the second joint; whether the first joint is beyond a soft stop position near an end of possible motion for the first joint; whether the second joint is beyond a soft stop position near an end of possible motion for the second joint; whether the first joint is actuated or non-actuated; whether the first joint is prismatic or rotational; whether the second joint is actuated or non-actuated; and whether the second joint is prismatic or rotational.

**11.** The teleoperated device of claim 1, wherein: the second criterion is based on at least a property selected from the group consisting of: a location of the first joint in the articulated arm; an amount of error in a joint sensor associated with the first joint; whether the first joint is beyond a soft stop position near an end of possible motion for the first joint; and whether the first joint is prismatic or rotational.

**12.** A method of controlling a teleoperated device, the method comprising: switching, by a control unit having one or more hardware processors, a first joint from a first state of the first joint to a

second state of the first joint in response to a determination that an external stimulus applied to an articulated arm of the teleoperated device meets at least a first criterion, the articulated arm comprising: a plurality of joints, a plurality of links coupled to the plurality of joints, and a plurality of actuators coupled to drive motion of the articulated arm, the plurality of joints comprising the first joint; and switching, by the control unit, the first joint from the second state of the first joint to the first state of the first joint in response to a determination that a speed associated with the first joint meets at least a second criterion.

**13.** The method of claim 12, further comprising detecting the external stimulus by detecting an effect of the external stimulus on the first joint.

**14.** The method of claim 12, further comprising detecting the external stimulus by detecting an effect of the external stimulus on a second joint of the plurality of joints.

**15.** The method of claim 12, further comprising: receiving, by the control unit, information about the plurality of joints or the plurality of links; wherein determining whether the external stimulus meets the first criterion comprises determining a value based on the received information, the value being selected from the group consisting of: a position error in a joint of the plurality of joints; a force applied to a joint of the plurality of joints; and a torque applied to a joint of the plurality of joints.

**16.** The method of claim 12, further comprising: preventing, by the control unit, the switching of the first joint to the second state of the first joint when an operating mode of the teleoperated device corresponds to a transport mode, a teleoperation mode, a commanded motion mode, or a docked to a patient mode.

**17.** A non-transitory machine-readable medium comprising a plurality of machine-readable instructions which, when executed by one or more hardware processors associated with a teleoperated device, are adapted to cause the one or more hardware processors to perform a method comprising: switching a first joint from a first state of the first joint to a second state of the first joint in response to a determination that an external stimulus applied to an articulated arm of the teleoperated device meets at least a first criterion, the articulated arm comprising a plurality of joints, a plurality of links coupled to the plurality of joints, and a plurality of actuators coupled to drive motion of the articulated arm, the plurality of joints comprising the first joint; and switching the first joint from the second state of the first joint to the first state of the first joint in response to a determination that a speed associated with the first joint meets at least a second criterion.

**18.** The non-transitory machine-readable medium of claim 17, wherein the external stimulus is a stimulus detected on the first joint.

**19.** The non-transitory machine-readable medium of claim 17, wherein the external stimulus is a stimulus detected on a second joint of the plurality of joints.

**20.** The non-transitory machine-readable medium of claim 17, wherein the method further comprises: preventing the switching of the first joint to the second state of the first joint when an operating mode of the teleoperated device corresponds to a transport mode, a teleoperation mode, a commanded motion mode, or a docked to a patient mode.

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