

A LIFTING MODULE FOR A PATIENT LIFTING SYSTEM WITH HIGH FORCE AND HIGH-SPEED CAPABILITIES

TECHNICAL FIELD

5 The present invention relates, generally, to a patient lift system and their components and assemblies, and, more particularly to a lift operator for patient handling system with double speed and a controllable braking force configured to move a patient handled by the patient handling system in a comfortable and safe way.

10 BACKGROUND

Patient transfer devices, such as patient lifts, are commonly used in hospitals and other care centers, as well as in the homes of those with mobility impairments, to assist in moving patients at a controlled pace by supporting their full weight to different areas of a building, for example, from a bed to a bathroom or from a bed to a chair. Patient lifts permit the movement of the individual with far decreased effort on the part of the caregiver, all while helping to preserve the comfort and dignity of the immobile individual. Patient lifts can be used in acute care facilities, hospitals, long term care facilities, nursing facilities, hospices, and homes or any type of environment where healthcare services are provided and/or patient handling is needed.

Patient lifts, also referred to as patient hoists, are commonly used to raise, lower and transfer patients who are disabled or who otherwise have mobility problems. Two common types of patient lifts are stanchion-mounted lifts, also known as floor lifts and ceiling lifts. Floor lifts often have a hoist assembly. The hoist assembly may be disposed at the upper end of a stanchion. The stanchion has a wheeled base, which allows for the patient lift to be moved along the ground to different locations.

For example, the lift might be wheeled to position the hoist assembly and lifting member over or adjacent to a patient. A lifting member may then be lowered to receive the patient and subsequently raise the lifting member and patient so that they may be wheeled elsewhere to be lowered and placed.

- 5 A ceiling lift may be utilized in a similar manner; however, the hoist assembly is movably engaged to ceiling-mounted tracks such that the hoist assembly can be moved about the track from location to location. A ceiling lift may be described as a motor unit movable along a track, a flexible member is attached to a lifting member in the form of a spreader bar. The motor unit commonly
- 10 comprises a transmission, batteries and a control module. Ceiling lifts use ceiling hoist technology, which hoists the person from above using various forms of hoists. One form of such a ceiling lift is a lift that is able to travel on one or more tracks that are suspended from the ceiling or elevated structure. Such lift systems include fixed ceiling lifts, where the track is affixed to the
- 15 ceiling and the lifting assembly is directly attached to the track, and portable ceiling lifts, where the lift assembly is removably attached to the ceiling track or a member attached to the ceiling track.

- Generally, the lifting member which may be in the form of a spreader bar, such as a two-point attachment spreader bar, a three-point attachment spreader
- 20 bar, a four-point attachment spreader bar, a five-point attachment spreader bar or a powered spreader bar for adjusting the angle of the patient in the spreader bar, for supporting a patient harness or sling descends from the hoist assembly on a strap or a cable. The strap or cable is wound around a motorized drum for raising and lowering the patient harness or sling.

- 25 For example, the lift might be wheeled, such as a floor lift, to position the hoist assembly and lifting member over or adjacent to a patient. The lifting member may then be lowered to receive the patient and subsequently raise the lifting member and patient so that they may be wheeled elsewhere to be lowered and placed. A ceiling lift may be utilized in a similar manner, however the hoist

assembly is movably engaged to ceiling-mounted tracks such that the hoist assembly can be moved about the track from location to location.

A ceiling lift may be described as a motor unit movable along a rail or track with a flexible member attached to a spreader bar. The motor unit commonly
5 comprises a transmission, batteries and a control module.

The transmission is subjected to a number of challenges. For example, the transmission needs to be able to lift a patient, maintain the patient at a prescribed height for a certain period of time and lower the patient. Further, the transmission needs to be able to lift and support a weight of around 450
10 kg.

In order to support such large weights, large motors capable of providing a high amount of torque are often used. Such motors may handle even heavy loads. However, large motors are usually expensive and consumes a lot of power.

15 To save cost and power, some manufacturers uses smaller motors able to deliver a high RPM. In order for the smaller motors to be able to support and lift higher loads, the RPM is often reduced and torque increased by means of different types of transmissions.

Conventional patient lifts have the function of transferring patient at 4 cm/s, which is too slow for assisting patients in rehabilitation. Some patient lifts
20 includes a solution at 10 cm/s, which is still too slow. Some patient lifts include a series elastic actuators device, which are very costly. There also exist patient lifts with a modified lifting module with double motors and a modified transmission, which can reach ~20 cm/s, but this is still not fast enough for
25 assisting patients in rehabilitation.

Studies have shown that it would be beneficial to have the patient move by themselves and having the device assist them instead of lifting their full weight. Equipment that can bring assistance to a patient have been used in

rehabilitation facilities for years, but it would be too expensive to implement them in every hospital's rooms. Existing patient transfer equipment already available in hospital rooms could have additional rehabilitation functions that would improve patient mobility. Commercial lifting devices include versatility

5 for both patient transfer and patient assistance, but the maximum speed of the device is 10 cm/s, which is too slow for some daily activities. For instance, during a sit-to-stand, the center of mass of a person can reach a vertical velocity of 51 cm/s, making this system unable to follow the patient for all their movements. Therefore, the mechanical requirements for patient assistance

10 differ significantly from those for patient transfer. For patient assistance, the device unloads a certain percentage of the weight of the patient while following their movements. This means working at high speed and low force, where force quality (or force tracking) is important so that the system feels transparent to the user. For patient transfer, the device needs to lift the full weight (high

15 force) of the patient but at lower speed and with velocity control to position the patient.

A single-motor actuator technology would have to be very big and expensive to be able to reach all these requirements for both operating mode. Lightly-g geared electric motors are well suited for low force, high speed and high force

20 quality, but the motor would be inefficient in transfer mode and its weight, size and cost would be detrimental for reaching the high force requirement of transfers. Using a smaller motor and augmenting the gear ratio like in available transfer devices limits the maximum velocity and increases the reflected inertia and friction, penalizing the force quality.

25 Using a variable gear ratio would allow to reach the desired performances for both applications without oversizing the motor. The system could downshift to a large reduction ratio to achieve high force capabilities during patient transfers and upshift to a small reduction ratio for high speed capabilities while assisting a patient. Assistance implies applying a weight relief force on a patient and

30 follow seamlessly at any speed during his motion or just following his motion

without applying a weight relief force but be able to stop his motion in case of a fall. T. Takayama and al. have used a force-magnification drive for a robotic hand that can move at high speed and apply high force when gripping an object. But the range of motion at high force becomes limited and the high speed mode is not back drivable, which would penalize force quality if used with a force controller. To overcome those problems, P. Vanich and al. designed a prosthetic hand using a dual-motor actuator to maximize grasp speed and grip strength. Dual-motor actuators are an efficient solution for systems with two discrete points of operation, since each motor can be used at their optimal power. For instance, T. Verstraten and al. present a hopping robot, which uses a series elastic dual-motor actuator that exploit the redundant degree of freedom to optimize the power distribution between the two inputs. One important aspect of variable gear ratio systems for lifting devices with assistive capabilities is that it needs to be able to stop safely when handling a patient that falls during a training session. However, the impact from the transition would be uncomfortable for the patient.

SUMMARY OF THE INVENTION

The present disclosure relates to a patient lift system and their components and assemblies, and, more particularly to a patient lift system for patient handling such as patient assistance and patient transfer.

With the above description in mind, then, an aspect of some embodiments of the present invention is to provide a lifting module for patient handling system with high force and high speed capabilities. More particular a lifting module configured to provide double speed and variable and controllable braking force, which seeks to mitigate, alleviate or eliminate one or more of the above-identified deficiencies in the art and disadvantages singly or in any combination.

- An aspect of the present invention relates to a lifting module for a patient lifting system. The lifting module being coupled to a drum of the patient lifting system. The lifting module comprising a first electric motor configured to drive the drum, a second electric motor configured to drive the drum, a planetary gearbox
- 5 connecting the first and second motor to the drum, the planetary gearbox being configured to transfer torque from the first and/or second motor to the drum and variable locking mechanism. The locking mechanism is configured to being coupled to the second motor, wherein the variable locking mechanism is configured to provide controlled deceleration of an output shaft of the
- 10 planetary gearbox. Wherein, by utilizing the first motor, the second motor and the variable locking mechanism, the lifting module is configured to adjust the gear ratio of the planetary gearbox in real time for ensuring seamless transitions between the different operational modes of the patient lifting system regardless of movement of the patient.
- 15 In one embodiment, the operational modes includes a high-speed operational mode, which includes patient assistance mode, a high force operational mode, which includes patient transfer mode and transition mode, which includes fall prevention and fall recovery.
- In one embodiment, the lifting module comprises a control system configured
- 20 to synchronizes the operation of the first and second electric motors during the transition between the different operational modes for optimizing the performance of the lifting module.
- In one embodiment, the first electric motor is connected to a first input shaft of the planetary gearbox and the second electric motor is connected to a second
- 25 input shaft of the planetary gearbox, and wherein the output shaft of the planetary gearbox is associated with the load bearing member for movement of the patient.

In one embodiment, the first electric motor is configured as a highly geared electric motor and the second motor is configured as a lightly geared electric motor.

5 In one embodiment, the planetary gearbox is configured to switch between a high-geared ratio for a high force operational mode and a light-geared ratio for high-speed operational mode.

10 In one embodiment, the lifting module is configured for allowing precise control of the output force and speed for controlling deceleration movement and enhancing patient comfort and safety during transition between the different operational modes.

In one embodiment, the variable locking mechanism is a disc brake.

In one embodiment, the drum being configured to control a vertical movement of a patient support mounting device of the patient lifting system via a load bearing member.

15 In one embodiment, the load bearing member is any one of lifting strap or cable, the strap being extendable or retractable as the drum rotates.

In one embodiment, the patient lifting system is anyone of a ceiling based patient lifting system and a floor-based patient lifting system.

20 The features of the above-mentioned embodiments can be combined in any combinations.

25 It is an advantage with some embodiments of the invention that they may allow for assisting patients in rehabilitation while also able to perform patient transfers. This is achieved by a dual-motor actuator, lifting module, with a planetary differential gearbox and variable locking mechanism configure to control which motor is giving energy to the output of the gearbox and thus provides seamless transition between the different operational modes.

BRIEF DESCRIPTION OF THE DRAWINGS

Further objects, features and advantages of the present invention will appear from the following detailed description of the invention, wherein embodiments of the invention will be described in more detail with reference to the

5 accompanying drawings, in which:

FIG. 1a is a ceiling base patient lifting system according to one aspect of the present disclosure.

FIG. 1b is a floor based patient lifting system according to one aspect of the present disclosure.

10 FIG. 2a-b is a lifting module overview with illustration of three operation modes according to one aspect of the present disclosure.

FIG. 3 illustrates an operation point mapping according to one aspect of the present disclosure.

15 FIG. 4 illustrates a system model according to one aspect of the present disclosure.

FIG. 5 illustrates a scheme of gearing topology according to the present disclosure.

FIG. 6 illustrates a mode state machine according to one aspect of the present disclosure.

20 FIG. 7 a-e shows a control architecture and force controllers according to an aspect of the present disclosure.

FIG. 8 shows a contribution algorithm according to one aspect of the present disclosure.

FIG. 9 shows a fall sequence with the output speed, the speed contribution of the motors, the output force, the servo angle and the output position according to one aspect of the present disclosure.

5 DETAILED DESCRIPTION

Embodiments of the present invention will be described more fully hereinafter with reference to the accompanying drawings, in which embodiments of the invention are shown. This invention may, however, be embodied in many different forms and should not be construed as limited to the embodiments set forth herein. Rather, these embodiments are provided so that this disclosure will be thorough and complete, and will fully convey the scope of the invention to those skilled in the art. Like reference signs refer to like elements throughout.

For purposes of the description hereinafter, the terms "upper", "lower", "right", "left", "vertical", "horizontal", "top", "bottom", "lateral", "longitudinal", and derivatives thereof, shall relate to the invention as it is oriented in the figures. However, it is to be understood that the invention may assume alternative variations and step sequences, except where expressly specified to the contrary. It is also to be understood that the specific systems and processes illustrated in the attached drawings, and described in the following specification, are simply exemplary examples of the invention. Hence, specific dimensions and other physical characteristics related to the examples disclosed herein are not to be considered as limiting.

The present application is directed to a lifting module 100 for a patient lifting system 300a, 300b, as shown in FIG. 1a, and 1b, such as a ceiling based patient lifting system 300a or a floor based patient lifting system 300b. The present application is further directed to a system for assisting and transferring a person. In an exemplary embodiment, the application is directed to patient lifting systems including a patient hoist assembly 310 and a patient lift support

320, i.e. patient sling, which is removable secured to a patient support mounting device 330.

In one embodiment, the patient hoist assembly 310 include wheels that engage track(s) 350 mounted at the ceiling. The patient hoist assembly 310 including the lifting module 100 configured to operate the patient hoist assembly 310 to raise and lower the individual 200 i.e. patient. There are various types of hoist assemblies that are used based on the conditions and weight of the individual to be lifted.

With reference to FIG. 1a and 1b, a patient hoist assembly 310, is provided, which raises and lowers the patient lift support 320- The patient hoist assembly 310 includes the lifting module 100 for winding and unwinding a flexible load-supporting member 51. The lifting module 100 is connected to a drum 50 upon which the flexible load-supporting member 51 is wound.

A patient support mounting device 330, which is connected to and positioned below the patient hoist assembly 310, includes or is configured to connect to the patient lift support 320 or conveyance. For example, the patient lift support 320 or conveyance is a sling, harness, basket or the like. The patient support mounting device 330 includes a lifting or spreader bar, or a mounting block for supporting the patient lift support 320 or conveyance. The patient lifting system 300a, 300b and/or its components is powered and also may generate, use, and/or communicate data, by way of, for example, visual displays, sensors, sound emitting components, controls, and the like.

The flexible load-supporting member 51 is a strap, a cable, or the like, and is formed of webbing, mesh, braided cable, layered cable, and the like, with the power and/or data lines defining strands or layers therein. The flexible load-supporting member 51 is load-bearing and includes integrated load-bearing power and/or data communication lines, for example, light transmitters, electrical power conductors, data or signal conductors, and the like, that transmit power and/or data along the length of the load-supporting member

51. In one example, the load bearing components, communications and power transmitting components are integral with the flexible load-supporting member 51. The flexible load-supporting member 51 is located between the patient hoist assembly 310 and the patient support mounting device 330 and transmits
5 power and/or communications between the patient hoist assembly 310 and the patient support mounting device 330 if configured in that manner.

As set forth above, in exemplary embodiments, a ceiling based patient lifting systems 300a is configured as fixed ceiling lifts and portable ceiling lifts, shown in FIG. 1a. A ceiling patient lifting system 300a includes track 350, a receiving
10 module, not shown, a patient hoist assembly 310, a flexible load-supporting member 51, and a patient support mounting device 330. In one aspect, the patient support mounting device 330 include a spreader bar having attachment elements 360 or other means of attaching a patient lift support 320 and/or a conveyance. The spreader bar 330 moves in a vertical direction by retracting
15 the cord 51 to, for example, raise a patient 200 from a bed, chair, gurney, or the like. The hoist assembly 310 with the cord 51 and the spreader bar 330 (and hence the patient sling 320) is moved horizontally to move a patient 200 from one location to another. The patient lifting system 300a is used to carry a patient to a desired location using a sling 320 connected to the spreader bar
20 330 as a conveyance for the patient 200.

As set forth above, in exemplary embodiments, a floor based patient lifting systems 300b is configured as floor lift as shown in FIG. 1b. The floor lift 300b comprises a lift mast 370, a base frame 380 and a patient hoist assembly 310, i.e. a lift arm 390. The lift mast 370 is arranged, connected, to the base frame
25 380. The base frame 380 may be arranged with castors, wheels, for moving or transporting the floor lift. The lift arm 310 may be movable arranged with the lift mast 370 and adopted for raising and lowering the lift arm 310 to a desired position for lifting and/or carrying or supporting a patient via the lift arm 310. The patient may be arranged in patient lift support 320, i.e. a sling, arranged
30 from the lift arm 310 (not shown in figure). Further, the floor lift 300b includes

a flexible load-supporting member 51, and a patient support mounting device 330, not shown, coupled to the connecting unit 340. In one aspect, the patient support mounting device 330 include a spreader bar having attachment elements 360 or other means of attaching the patient lift support 320. The

5 spreader bar 330 moves in a vertical direction by retracting the cord 51 to, for example, raise a patient 200 from a bed, chair, gurney, or the like. The hoist assembly 310 with the cord 51 and the spreader bar 330 (and hence the patient sling 320) is moved horizontally to move a patient 200 from one location to another. The patient lifting system 300b is used to carry a patient to a

10 desired location using a sling 320 connected to the spreader bar 330 as a conveyance for the patient 200.

The present invention is directed to a multifunctional patient lifting system 300a, 300b including a lifting module 100, i.e. a dual-motor actuator that extends the capabilities of current healthcare lifting devices up to the

15 capabilities of current assistive devices, with little compromise on system mass, efficiency and cost.

A dual-motor actuator is a type of actuator that uses two motors to provide precise control and increased power for moving or controlling a mechanism. The dual-motor actuator is equipped with two motors, which can work in either

20 tandem or independently, depending on the design and application. The motors are synchronized to ensure smooth and coordinated movement. This synchronization can be achieved through electronic control systems that manage the speed and position of each motor. By using two motors, the actuator can distribute the load more evenly, reducing the strain on each motor

25 and increasing the overall efficiency and lifespan of the system. In some designs, the dual motor setup provides redundancy. If one motor fails, the other can continue to operate, ensuring the actuator remains functional. The use of two motors allows for finer control over the movement, which is particularly useful in applications requiring high precision.

With reference to FIG 2a-c, aspects of a dual-motor actuator 100, in the systems three operating conditions is shown, FIG 2a shows patient transfer, FIG 2b shows patient assistance, and FIG. 2c shows fall prevention. The patient lifting system 300a, 300b provides for an enhanced control scheme for the dual-motor actuator 100 with a variable locking mechanism 30, i.e. a brake, for a seamless transition between the operating conditions at high speed and high force. The dual-motor actuator 100 is configured for a medical equipment used for patient transfer and patient assistance. A force control friction compensation algorithm is provided that utilizes both motors 10, 20 to improve the performances over a single motor solution.

The dual-motor actuator 100 enhances the patient lifting system 300a, 300b in several ways, such as by utilizing two motors, the dual-motor actuator 100 can switch between different gear ratios and thus provides for variable gear ratio solution. This allows it to operate in a highly-gearred mode for high force HF applications, such as lifting or transfer a patient, and a lightly-gearred mode for high speed HS applications, to provide assistance to the patient.

The dual-motor actuator 100 also provides precise control over the actuator's output force and speed. This precision helps in controlling the deceleration of the patient during transitions between HS and HF, reducing the risk of sudden movements that could cause discomfort or injury. Thus, the dual-motor actuator of the present disclosure provides improved comfort and safety.

Further, the dual-motor actuator 100 of the present disclosure provides enhanced control during transitions. The actuator's ability to adjust gear ratios in real-time ensures seamless transitions between different operational modes, such as from patient assistance to patient transfer. This is particularly important for fall prevention and recovery, where controlled movements are crucial.

A synchronization process between the two motors 10, 20 in the dual-motor actuator 100 involves several key steps to ensure smooth and efficient

operation. The dual-motor actuator 100 is equipped with a control system 60, shown in FIG 4, that manages the operation of both motors 10, 20. This control system 60 is responsible for coordinating the motors' actions to achieve the desired output.

- 5 Sensors and feedback mechanisms continuously monitor the performance of each motor 10, 20. This includes tracking parameters such as speed, torque, current and position. The planetary output shaft 43 include a torque sensing sensor, not shown, and the load bearing member 51 include a force sensing sensor, not shown. The control system 60 processes the data from the sensors
- 10 to determine the current state of the dual-motor actuator 100 and the required adjustments. This involves complex algorithms that calculate the optimal gear ratio and motor output needed for the specific task. Based on the processed data, the control system 60 sends precise commands to each motor 10, 20. These commands ensure that the motors work in harmony, adjusting their
- 15 speeds and torques to maintain the desired gear ratio and output. As the patient lifting system 300a, 300b operates, the control system 60 continuously adapts to changes in load, movement, and other variables. This real-time adjustment helps in maintaining a smooth and controlled operation, especially during transitions between modes. The dual-motor actuator 100 operates in a
- 20 closed-loop configuration, where the output torque of the planetary output shaft 43 or force applied on load bearing member 51 is constantly fed back into the control system 60. This feedback loop allows for immediate corrections and fine-tuning, ensuring that the motors 10, 20 remain synchronized and the dual-motor actuator 100 performs optimally. In one aspect, the lifting module 100
- 25 can also operate in open-loop force control, where a motor current value is commanded to the first and second motor 10, 20 to obtain desired torques at the planetary output shaft 43 or force on load bearing member 51.

By synchronizing the two motors 10, 20 in this manner, the dual-motor actuator 100 can provide precise control over the movements of the patient lifting

system 300a, 300b, enhancing both the safety and comfort of the patient 200 during handling of the patient.

Further, the dual-motor actuator 100 includes a feedback mechanism that monitors the patient's movement and adjusts the gear ratio accordingly. This
5 real-time adjustment helps in maintaining a consistent and comfortable experience for the patient.

Overall, the dual-motor actuator 100 significantly improves the functionality and reliability of patient handling devices, making them safer and more comfortable for patients.

10 FIG 3 shows an operation point mapping with these operating conditions on a force-velocity plot. The target requirements are described below.

Patient transfer mode, shown in FIG 2a, is for hoisting patients up to 272 kg (600 lb) at 4 cm/s (107 W). This fits within the range of typical patient lifting systems 300a, 300b which can lift patients weighting between 200 and 450 kg
15 with a speed between 3 and 5 cm/s. Safe and precise manipulation of the patient limits the desired speed in this mode.

Patient assistance mode, shown in FIG 2b, is for assisting the muscles of patients during their daily activities. It is set to 50 kgf (100 kgf peak) at 50 cm/s (245 W nominal, 490 W peak). This corresponds to dynamically unload 27 %
20 of the weight of the heaviest user the patient lifting system 300a, 300b can transfer. The speed is sufficient to follow sit-to-stands. Current patient assistance devices can unload a weight up to 100 kg with enough speed to follow the patient in their daily activities. Force quality is also important in this mode. A 5% tracking error is targeted for the patient not to feel any force
25 variation.

Fall prevention mode, shown in FIG 2c. is for ensuring safe and comfortable immobilize when patient falls during a training session. Since the system is fast, back drivable and unable to lift heavy patients in assistance mode, injuries

may occur if the patient falls. The system must then detect a falling condition and transition to the patient transfer mode in high-speed motion. The maximum acceptable transition height is set to 0.4 m based on the height between knee and ground. Furthermore, a 1m/s^2 maximum acceleration is set for a comfortable falling transitions as it is dependent on the patient's acceleration. Studies show that discomfort starts at an acceleration of 1 m/s^2 and up to 2 m/s^2 can be tolerated.

The mechanical principle of the dual-motor actuator 100 is described with a simplified comparison showing how this design is superior to more typical design strategies for reaching the same functions. Then, the equation of motions are detailed. Finally, the dual-motor patient lifting system is detailed with the actual specifications.

With reference to FIG. 4, the mechanical principle behind the dual-motor actuator 100 architecture consists of a first and a second motor 10, 20, a variable locking mechanism 30 and a planetary gearbox 40.

The planetary gearbox 40, also known as an epicyclical gear train, is a complex gear system that consists of four main components: a sun gear 40a, the central gear around which the other gears revolve, planet gears 40b, multiple gears that rotate around the sun gear. These are mounted on a movable arm called the planet carrier 40c and a ring gear 40d, an outer gear with internal teeth that mesh with the planet gears. The sun gear 40a is located at the center and drives the surrounding planet gears 40b. The planet gear 40b are mounted on a rotating carrier 40c, which also allows them to revolve around the sun gear 40a. The ring gear 40d encircles the planet gears 40b and meshes with them. By holding one of these components stationary, different gear ratios and directions of rotation are achieved. For example, if the sun gear 40a is held stationary, the planet gears 40b will rotate around it and drive the ring gear 40d, resulting in a reduction in speed but an increase in torque. Planetary gearboxes or trains 40 are widely used in various applications due to their compact size, high efficiency, and ability to handle high torque loads. They are

commonly found in automatic transmissions, electric vehicles, and industrial machinery.

Planetary gearboxes offer several advantages, making them a popular choice in various applications. Planetary gearboxes are more compact than traditional
5 gear systems, allowing for a smaller overall size and weight. They provide high efficiency due to the load distribution among multiple gears, reducing the stress on individual gears. These gearboxes can handle high torque loads, making them suitable for heavy-duty applications. They offer a wide range of gear ratios and can easily switch between different modes of operation (e.g.,
10 forward, reverse, and neutral). The design of planetary gearboxes results in smooth and quiet operation, with reduced vibration and noise. The load-sharing capability among the planet gears enhances the durability and lifespan of the gear train.

With reference to FIG 4, the first motor 10 is a highly geared electric motor,
15 while the second motor 20 is a lightly geared electric motor. The output of first and second motors 41, 42 are connected to planetary gearbox 40. The output shaft 43 of the planetary gearbox 40 is connecting a drum 50 to the planet carrier 40c. At the output of the drum, the load bearing member 51 is attached to the patient 200. The planetary gearbox 40 is thus used as a differential
20 device. This results in a redundant system, the displacement of each motor adds up to drive the output.

With reference to FIG 6, this architecture has two operating modes, a high-force mode HF and a high-speed mode HS. In HF mode 410, the variable locking mechanism 30 is closed and the first motor 10 drives the planetary
25 output shaft 43, resulting in slow displacement but providing high force capabilities. In HS mode 420, the variable locking mechanism 30 is opened and the second motor 20 drives the planetary output shaft 43, resulting in high-speed capabilities and low reflected inertia, which is beneficial for patient assistance during daily activities that require fast movements. Controlling the
30 variable locking mechanism slippage ensures seamless transitions between

both control modes of the system by means of high power dissipation capabilities, i.e. high forces at high speed. This provides even more flexibility in meeting the requirements for patient transfer and assistance. For instance, when a patient is falling at high speed, the system needs to apply a large force
5 to stop the patient.

In one embodiment, a lifting module 100 for a patient lifting system 300a, 300b is provided. The lifting module 100 being coupled to a drum 50 of the patient lifting system. The lifting module comprises a first electric motor 10 configured to drive the drum 50, a second electric motor 20 configured to drive the drum
10 50, a planetary gearbox 40 connecting the first 10 and second motor 20 to the drum 50, the planetary gearbox 40 being configured to transfer torque from the first 10 and/or second 20 motor to the drum 50 and a variable locking mechanism 30. The locking mechanism 30 is configured to being coupled to the second motor 20, wherein the variable locking mechanism 30 is configured
15 to provide controlled deceleration of an output shaft 43 of the planetary gearbox 40 dependent on the movement of the patient 200. Wherein, by utilizing the first motor 10, the second motor 20 and the variable locking mechanism 30. The lifting module 100 is configured to adjust the gear ratio of the planetary gearbox 40 in real time for ensuring seamless transitions
20 between the different operational modes of the patient lifting system regardless of movement of the patient 200.

In one aspect, the variable locking mechanism 30 is configured to provide controlled deceleration of the second motor 20 to prevent falls and provide aid during movement of the patient.

25 In one embodiment, in HS mode, assistance 420, the first and second motors works 10, 20 together at high speed. This results in that the overall speed adds up.

In one embodiment, in HF, transfer mode 410, the first motor 10 works and the variable locking mechanism 30 is applied to the second motor 20.

In one embodiment, in rehabilitation mode 430, the lifting speed is 50 cm/s and the assisting capability is up to 100 kg.

In one embodiment, in transfer mode 440, the lifting speed is 4 cm/s and the lifting capacity is up to 357 kg.

- 5 Since both motors 10, 20 work to drive the output 43 of the planetary gearbox 40, the kinematic equation of the system, equation of motion, can be simplified using a lumped parameter approach, which leads to:

$$v_0/r = \omega_1/R_1 + \omega_2/R_2 \quad (1)$$

- 10 where v_0 is the linear velocity of the output strap 43, and ω_1 and ω_2 are the angular velocity of the highly geared electric motor 10 and the lightly geared electric motor 20. The radius r of the drum 50 is assumed to be constant, and R_1 and R_2 are the gear ratios between each motors and the output of the drum 50, including any gear ratio the drum, the planetary gearbox 40 and the motor gearbox. The static force relationship is:

$$F_m r = R_1 \tau_1 = R_2 (\tau_2 - \tau_B \text{sign}(\omega_2)) \quad (2)$$

15

where F_m represents the output force on the drum, τ_1 and τ_2 the motor torques of the first motor 10 and the second motor 20. τ_B is the friction torque of the brake. When considering the inertial properties of the system, a 2 degrees of freedom state space model can be constructed with the states being v_0 and

20 ω_1 :

$$\begin{bmatrix} \dot{v}_0 \\ \dot{\omega}_1 \end{bmatrix} = [-H^{-1}D] \begin{bmatrix} v_0 \\ \omega_1 \end{bmatrix} + [H^{-1}B] \begin{bmatrix} \tau_1 \\ \tau_2 - \tau_B \text{sign}(\omega_2) \\ F_m \end{bmatrix} \quad (3) \text{ with:}$$

$$H = \begin{bmatrix} m + \frac{R_2^2 I_2}{r^2} & -\frac{R_2^2 I_2}{R_1 r} \\ -\frac{R_2^2 I_2}{R_1 r} & I_1 + \frac{R_2^2 I_2}{R_1^2} \end{bmatrix} \quad (4)$$

$$D = \begin{bmatrix} b_0 + \frac{R_2^2 b_2}{r^2} & -\frac{R_2^2 b_2}{R_1 r} \\ -\frac{R_2^2 b_2}{R_1 r} & b_1 + \frac{R_2^2 b_2}{R_1^2} \end{bmatrix} \quad B = \begin{bmatrix} 0 & \frac{R_2}{r} & -1 \\ 1 & -\frac{R_2}{R_1} & 0 \end{bmatrix} \quad (5)$$

with m being the load on the load bearing member 51 and including the inertia of the drum 50, and I_1 and I_2 the inertia of the first and second motor 10, 20. b_0 , b_1 and b_2 represent the viscous friction of the output of first motor 41 and the output of second motor 42.

In HF mode, the variable locking mechanism 30 is fully closed and only the first motor 10 can drive the output of the planetary gearbox 43. Hence, the equation can be simplified to a single motor, single output system:

$$(m + I_1 \frac{R_1^2}{r^2}) \dot{v}_0 = \frac{R_1}{r} (\tau_1 - b_1 \omega_1) - b_0 v_0 - F_m \quad (6)$$

- 10 For HS mode, both motors 10, 20 can contribute to the motion of the planetary output 43. However, since the first motor 10 has a greater mechanical advantage over the second motor 20, the equation can be simplified when $R_1 \gg R_2$, which is the case for the prototype by design:

$$(m + I_2 \frac{R_2^2}{r^2}) \dot{v}_0 = \frac{R_2}{r} (\tau_2 - \tau_B \text{sign}(\omega_2) - b_2 \omega_2) - b_0 v_0 - F_m \quad (7)$$

The influence of the first motor 10 in HS mode therefore mostly comes from the kinematic equation 1 and can be used to offset the output speed. All in all, the equations for both mode have the same structure and the differences come from the relation between the mechanical advantage of l_1 over l_2 .

- 5 FIG 5 shows an embodiment of a dual-motor actuator 100 of a patient lifting system 300a, 300b, including a drum 50 that winds a load bearing member 51. The first motor 10, i.e. Maxon RE40 150 W, with a 66:1 integrated gearbox, is coupled to the ring gear 40d of the planetary gearbox 40. The second motor 20, i.e. Tecnotion QTR-A-78-25, is coupled directly to the sun gear 40a of the planetary gearbox 40. The planetary gearbox 40 also includes a planetary gear stage 40b. In one aspect, the total reduction ratios are respectively $R_1 = 600:1$ and $R_2 = 18:1$ for the first motor 10 and the second motor 20. The planetary output shaft 43 is connected to the drum 50 (average 4 cm radius r). Encoders are implemented on both motors 10, 20 and a load cell measures the load applied on the load bearing member 51. The variable locking mechanism 30 is coupled to the second motor 20 to variable controlling the locking mechanism from being back driven by the first motor 10 during HF mode and fall prevention mode. In one aspect, the variable locking mechanism 30 is a disc brake and made of carbon fiber to minimize the reflected inertia in HS mode.

In one embodiment, in HF mode, the load is limited by the 66:1 gearbox rated torque. In HS mode, the peak force is reached when sending twice the nominal current of the motor.

- 25 FIG 6 shows a mode state machine 400 for patient transfer 410 with high-force HF capabilities, patient assistance 420 with high-speed HS capabilities, fall prevention 440 to catch the patient when falling and fall recovery 430 to lift the patient after falling. The main operating modes, high force HF mode and high-speed HS mode can be changed manually as shown in FIG 6. The patient lifting system 300a, 300b also needs to automatically transfer from HS mode

to HF mode if the patient was to fall (fall prevention), to support the full weight of the patient and stop the fall (fall recovery).

Transitions between HF and HS mode is made by opening or closing the variable locking mechanism 30 smoothly and seamlessly. If a fall is detected
5 in HS mode, the variable locking mechanism 30 and second motor 20 work simultaneously to decelerate the patient before downshifting the speed. The first motor 10 applies a downward velocity to help downshifting faster. Once the velocity of second motor 20 is zero, the variable locking mechanism 30 closes to its maximal braking force and the patient lifting system 300a, 300b
10 transfers into HF mode. To help the patient recover and continue his activity, the patient lifting system 300a, 300b then lifts him to the position where the fall was detected. In the following, each operating mode is further explained:

- Patient Transfer mode 410:

To transfer a patient 200, the patient lifting system 300a, 300b needs to
15 hoist the full weight of the patient 200. This requires the patient lifting system 300a, 300b to be in HF mode utilizing the highly geared first motor 10. The controller is a velocity command sent to the first motor 10 based on a user up-down input on a remote. This is the base functionality of currently available patient lifts.

- Patient Assistance mode 420:

To assist a patient 200 for daily activities, the patient lifting system 300a, 300b needs to unload a certain amount of weight of the patient 200 while following their movements. This requires the patient lifting system 300a, 300b to be in HS mode and to control the force at the output rather
25 than the position or velocity as in transfer mode. Aspects of a force control algorithm 500 is presented in FIG 7a-e. FIG 7a shows an open-loop current control, FIG 7b shows a friction compensation algorithm, FIG 7c shows a friction compensation algorithm with an offset on the speed, FIG 7d shows a PID current controller and FIG 7e shows a
30 disturbance observer (DOB).

The motor torque is obtained by knowing the motor constant (k_t) and adjusting the current of the second motor 20, shown in FIG 7a. This works well for lightly geared electric motors but the friction can induce an undesired error on the force output. This error can be measured in terms of speed. A dry and viscous
 5 friction model can be estimated using a linear equation (using the absolute value for symmetry) multiplied by a hyperbolic tangent function:

$$\text{Friction Model} = (a|v_0| + b)\tanh(v_0) \quad (8)$$

The friction estimation can then be subtracted to the desired force to compensate for the friction error and help improving the force quality, as shown
 10 in FIG 7b. One issue with friction compensation is when trying to compensate near zero speed, since a more complex friction model would be necessary for considering hysteresis. With a dual-motor actuator 100, the first motor 10 can run at a constant speed while the second motor 20 is applying a constant force, as shown in FIG 7c. This offsets the speed of the second motor 20 from the
 15 output speed, which reduces the time the second motor 20 is at zero speed, since the patient 200 is often near zero speed (when they're standing still or sitting down). In one embodiment, the force-fidelity, in rehabilitation mode, i.e. fall recovering mode, is improved by using the second motor 20 to offset the velocity of the first motor 10 to avoid the stick-slip behavior about zero-velocity.
 20 In one aspect, a load cell is required on patient lifting system 300a, 300b for measuring patient's weight, the measured force can be sent to a simple closed-loop PID controller, as shown in FIG 7d. A disturbance observer is implemented to compare a different more elaborate control law, as shown in FIG 7e.

- 25 - Fall prevention 440 and recovery 430: There are two goals to the fall prevention algorithm: first, stopping the fall of a patient 200 safely and comfortably, and second, helping the patient 200 resume their daily activity afterwards. To ensure the safety of the patient, the patient lifting system 300a, 300b must never let the patient 200 reach the ground

during a fall. As for the comfort, it is dependent on the patient's acceleration. To apply a desired deceleration (v_0) to the patient 200, the torque needed from the variable locking mechanism 30 can be calculated knowing the weight of the patient 200, see equation 9 shown in FIG. 8. The variable locking mechanism 30 is controlled by a servo motor, not shown, thus only a discrete amount of force can be applied by the variable locking mechanism 30 and a certain delay is introduced by the time the servo motor moves to the desired angle. To improve the accuracy and response time of the patient lifting system 300a, 300b, the second motor 20 applies a torque proportional to the error on the desired speed. The contribution algorithm 600, shown in FIG. 8, is used by the second motor 20 during fall prevention 440.

FIG. 9 shows an aspect of a complete fall sequence with the output speed, V_0 , the speed contribution, $W_2 r/R_2$, $W_1 r/R_1$, of the first and second motor 10, 20, the output Force, the Servo angle and the output position, Height, with a 90 kg weight at 2 m/s^2 . Starting at a height of 1 m, the weight begins to fall at (a), until it reaches 90 cm/s (b), at which point the system detects the fall and moves the variable locking mechanism 30 to get the desired braking force. To help downshifting faster, the first motor 10 applies its maximum downward velocity when the fall is detected. Once the speed of the second motor 20 reaches 2 cm/s (c), the variable locking mechanism 30 fully locks to transfer the control to the first motor 10 which can then finish the deceleration at a constant rate until the fall is fully stopped (d). The first motor 10 then lifts the patient 200 to the height at which the fall (e) was detected to help the patient stand up and continue his activity.

By measuring the height at the detection of the fall and at the lowest point, it is possible to find the fall distance x . The average acceleration during the fall is calculated with $a = v_f^2/(2x)$ with v_f being the velocity of the mass at the detection of the fall, and the average force is found with $F = m(g + a)$. The acceleration was the parameter that was adjusted and is related to the patient's comfort.

The fall distance is more intuitive to understand and is linked to the patient's safety since it indicates the minimal falling distance that the patient needs. The force roughly corresponds to the braking capabilities of the patient lifting system 300a, 300b.

- 5 At the beginning of the braking sequence, only the second motor 20 applies a torque to slow the mass. Since the second motor 20 can only lift up to 59 kgf, when the mass of the patient is low, the contribution of the second motor 20 is more important relative to the patient's weight and the patient lifting system 300a, 300b can apply the desired braking torque from the beginning. This
10 means the patient lifting system 300a, 300b can decelerate the mass on a shorter distance. As the mass gets higher, the influence of the second motor 20 becomes smaller and the patient lifting system 300a, 300b takes more distance to brake the patient. For patients under 90 kg, the patient lifting system 300a, 300b can brake their fall comfortably (at 1 m/s²) and safely (on
15 less than 40 cm). For heavier patients, the patient lifting system 300a, 300b needs to brake at a higher deceleration value to ensure the safety of the patient.

- In one embodiment, the variable locking mechanism 30 and control scheme allow to "down-shift" to transfer mode (for instance to catch a falling patient)
20 despite any velocity/external forces at the system output.

- In one embodiment, a patient lifting system 300a, 300b capable of patient transfer, patient assistance and fall prevention by using a dual-motor actuator 100 is provided. The patient lifting system 300a, 300b is configured to lift a patient of up to 318 kg at 4.6 cm/s during transfer mode 410, and unload up to
25 59 kg off the patient at a maximum speed of 55 cm/s during assistance mode 420. The force tracking error during the patient assistance mode is 12% at high speed and 7.8% at low speed with a friction compensation algorithm and utilizing both motors 10, 20, which is similar to the performances of a traditional close loop controller. For the fall prevention algorithm 440, it is possible to

control the deceleration of the patient by using the variable locking mechanism 30 to apply a desired amount of force to dissipate energy.

The terminology used herein is for the purpose of describing particular embodiments only and is not intended to be limiting of the invention. As used
5 herein, the singular forms "a", "an" and "the" are intended to include the plural forms as well, unless the context clearly indicates otherwise. It will be further understood that the terms "comprises" "comprising," "includes" and/or "including" when used herein, specify the presence of stated features, integers, steps, operations, elements, and/or components, but do not preclude
10 the presence or addition of one or more other features, integers, steps, operations, elements, components, and/or groups thereof.

Unless otherwise defined, all terms (including technical and scientific terms) used herein have the same meaning as commonly understood by one of ordinary skill in the art to which this invention belongs. It will be further
15 understood that terms used herein should be interpreted as having a meaning that is consistent with their meaning in the context of this specification and the relevant art and will not be interpreted in an idealized or overly formal sense unless expressly so defined herein.

The foregoing has described the principles, preferred embodiments and
20 modes of operation of the present invention. However, the invention should be regarded as illustrative rather than restrictive, and not as being limited to the particular embodiments discussed above. The different features of the various embodiments of the invention can be combined in other combinations than those explicitly described. It should therefore be appreciated that variations
25 may be made in those embodiments by those skilled in the art without departing from the scope of the present invention as defined by the following claims.

Reference numbers

10	first motor
20	second motor
30	a variable locking mechanism
40	planetary gearbox
40a	Sun gear
40b	planet gear
40c	Planet carrier
40d	ring gear
41	first planetary gearing input shaft
42	second planetary gearing input shaft
43	planetary output shaft /output strap
R ₁	first gear ratio
R ₂	second gear ratio
50	drum
51	load bearing member
60	control system
100	lifting module/ dual-motor actuator
200	patient
300a, b	patient lifting system

310	patient hoist assembly
320	patient lift support
330	patient support mounting device
340	connecting unit
350	track
360	attachment elements
370	mast
380	frame
HS	high speed
HF	high force
400	Mode state machine
410	Transfer mode
420	Assistance mode
430	Fall recovery mode
440	Fall prevention mode
500	Force control algorithm
600	Contribution algorithm

CLAIMS

1. A lifting module (100) for a patient lifting system (300a, 300b), the lifting module (100) being coupled to a drum (50) of the patient lifting system, wherein the lifting module comprising:
 - 5 - a first electric motor (10) configured to drive the drum (50),
 - a second electric motor (20) configured to drive the drum (50),
 - a planetary gearbox (40) connecting the first (10) and second motor (20) to the drum (50), the planetary gearbox (40) being configured to transfer torque from the first (10) and/or second (20)
10 motor to the drum (50), and
 - a variable locking mechanism (30),wherein the locking mechanism (30) is configured to being coupled to the second motor (20), wherein the variable locking mechanism (30) is configured to provide controlled deceleration of an output shaft (43) of
15 the planetary gearbox (40), and
 wherein, by utilizing the first motor (10), the second motor (20 and the variable locking mechanism (30), the lifting module (100) is configured to adjust the gear ratio of the planetary gearbox (40) in real time for ensuring seamless transitions between the different operational
20 modes (HS, HF, 410, 420, 430, 440) of the patient lifting system regardless of movement of the patient (200).
2. The lifting module (100) according to claim 1, wherein the operational modes includes a high-speed operational mode (HS), which includes
25 patient assistance mode (420), a high force operational mode (HF), which includes patient transfer mode (410) and transition mode, which includes fall prevention (440) and fall recovery (430).
3. The lifting module (100) according to claim 2, comprising a control
30 system (60) configured to synchronizes the operation of the first and second electric motors (10, 20) during the transition between the

different operational modes (HS, HF, 410, 420, 430, 440) for optimizing the performance of the lifting module (100).

4. The lifting module according to claim 1, wherein the first electric motor (10) is connected to a first input shaft (41) of the planetary gearbox (40) and the second electric motor (20) is connected to a second input shaft (42) of the planetary gearbox, and wherein the output shaft (43) of the planetary gearbox is associated with the load bearing member (51) for movement of the patient (200).
5. The lifting module (100) according to claim 1, wherein the first electric motor (10) is configured as a highly geared electric motor and the second motor (20) is configured as a lightly geared electric motor.
6. The lifting module (100) according to claim 1, wherein the planetary gearbox (40) is configured to switch between a high-gear ratio for a high force operational mode and a light-gear ratio for high-speed operational mode.
7. The lifting module (100) according to claim 1, wherein the lifting module (100) is configured for allowing precise control of the output force and speed for controlling deceleration movement and enhancing patient comfort and safety during transition between the different operational modes (HS, HF, 410, 420, 430, 440).
8. The lifting module (100) according to claim 1, wherein the variable locking mechanism (30) is a disc brake.
9. The lifting module (100) according to claim 1, wherein the drum (50) being configured to control a vertical movement of a patient support mounting device (330) of the patient lifting system (300a, 300b) via a load bearing member (51).

10. The lifting module (100) according to claim 9, wherein the load bearing member (51) is any one of lifting strap or cable, the strap being extendable or retractable as the drum rotates.

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11. The lifting module according to any one of claim 1-10, wherein the patient lifting system is anyone of a ceiling based patient lifting system (300a) and a floor-based patient lifting system (300b).