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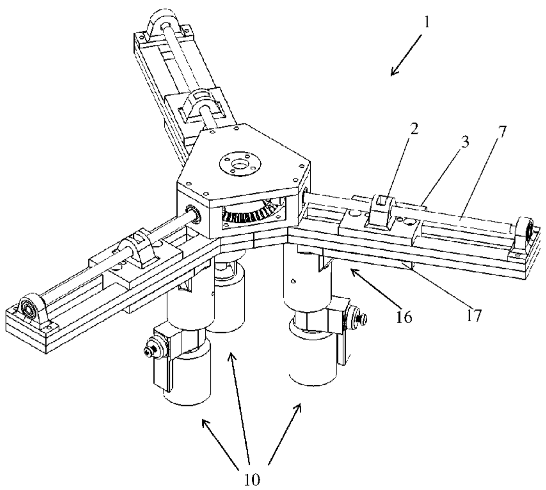
(54) **Title:** CONVERTIBLE FRICTIONLESS TO FRICTIONAL FINGERTIPS FOR A GRIPPER TO IMPROVE ROBOTIC GRASP ROBUSTNESS

Fig. 1



(57) **Abstract:** The present invention relates to a gripper system comprising fingers. The gripper fingers comprise a movable base element connectable to a gripper arm; a roller configured to spin around its central axis; a stopper configured to stop and/or prevent the spinning of the roller around its central axis. The present invention also relates to a method for grasping and displacing an object.

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CONVERTIBLE FRICTIONLESS TO FRICTIONAL FINGERTIPS FOR A GRIPPER TO IMPROVE ROBOTIC GRASP ROBUSTNESS

FIELD OF THE INVENTION:

The present invention relates to the field of mechanics. More particularly, the present invention relates to a mechanical gripper comprising fingertips providing a robust grasp.

BACKGROUND OF THE INVENTION:

Conventional mechanical grippers use several “fingers” that can be either rigid or non-rigid and that retract/close upon an object to form a grasp. The grasp geometry is usually predetermined, and in most cases grippers can only grasp specific objects by forming contact with specific points on it. Grippers that are meant to be versatile usually rely on redundancy (a large number of fingers), or soft, flexible fingers. Versatile grippers often lack the ability to withstand large external wrenches applied to the grasped object due to their flexible nature. Rigid grippers specified for specific object manipulation (such as those in an industrial assembly line) are good at withstanding external wrenches applied on the grasped object but in many cases cannot grasp even a slightly different object without corresponding hardware and/or software adaptation.

Fingertips of grippers are traditionally rigid, made of plastic, metal, hard rubber etc. The fingertips are designed to contact the object in a manner that does not harm it, while applying direct force and frictional force that suffice to manipulate the object and withstand external wrenches applied to it. The contact points are predetermined and often even predesigned to fit the fingertip for improved grasping.

While existing grippers are good at manipulating predetermined objects, there is a need for gripping devices that can grasp differently shaped objects without prior knowledge of their geometry, and manipulate them. The present invention is directed toward providing such a solution.

"Blind" closing of gripper fingers onto an object without predetermination of the contact locations can result in either:

A. An immobilizing grasp;

B. "Jamming" (an unstable, frictional grasp);

C. The object will escape and not be grasped.

If the fingers are retracted from what is known as a "caging" position, option C will not occur regardless of the finger type. Frictionless fingertips will result (in most cases) in option A. The fingers will close onto the object, which in turn will move within the retracting cage, until there is no further possible movement and the volume of the cage is zero, constituting an immobilizing grasp. Frictional fingertips will result (in most cases) in option B. The frictional contacts are likely to create a frictional grasp within the cage with positive non-zero volume, leaving room for the object to move if dislodged from the frictional contacts given a sufficient external wrench. Both A and B are considered feasible grasps, however they may be susceptible to external wrenches applied on the object, resulting in a loss of fingertip-object contact, or a “sliding” of the object along the fingertips. In case A this could occur due to the natural compliance and flexibility of the robotic gripper and of the object, and the lack of frictional forces to resist a sliding motion. In case B this could occur due to external wrenches dislodging the frictional contacts from their grasping positions, resulting in a freely-moving object (within the cage). A combination of an immobilizing grasp that is also a frictional grasp is the most robust to such external wrenches, but is difficult to obtain without engineering the contact in advance. Indeed, most manipulation applications utilize such grasps by exactly placing frictional fingertips in predetermined positions on the object that form an immobilizing grasp.

US2017/0036354 relates to a two-phase gripper. The gripper reorients and grasps an object while being picked up. The gripper includes a parallel jaw gripper including a pair of opposed, two-phase fingers, each finger including a cavity covered by an elastic strip wherein the elastic strip includes a point contact. Closure of the jaws of the gripper on as object at a first relatively lower force results in contact with lower friction between the point contact on the elastic strip on the fingers and the object allowing the object to rotate under gravity as the gripper is raised. Thereafter, closure of the jaws of the gripper on the object at a second relatively higher force causes the elastic strip to receded into the cavity resulting in multi-point contact with higher friction between the fingers and the object to securely grasp the object.

It is therefore an object of the present invention to provide a method and means for a robust versatile grasping of a variety of differently shaped objects.

It is a further object of the present invention to provide a method and means for a robust versatile grasping with minimal or no physical adaptation required to the manipulated objects.

Other objects and advantages of the present invention will become apparent as the description proceeds.

SUMMARY OF THE INVENTION:

The present invention relates to a gripping system comprising fingers that can be adjusted from being frictionless fingers to frictional fingers. When being frictionless, the object to be grasped can be reoriented to an improved position, an immobilizing position. When the improved position is reached the fingers are adjusted to be frictional fingers thus capable of carrying out a robust frictional immobilizing grasp.

Each gripper finger is mounted on a gripper arm and is mobile thereon along the arm. The arms are positioned such that the fingers may close on an object and engage it. A motor drives a movable member (to which the finger is attached to) along the arm.

The present invention relates to fingers capable of being used in said system. According to an embodiment of the present invention, the fingers comprise a rotatable cylinder thereon configured to be stopped (and configured to be prevented of being rotated) by a stopping element engageable therewith. Preferably, the deflection of the rotatable cylinder (in relation to its initial central axis) causes the engagement with the stopping element. A spring mechanism may be used to adjust the force needed to deflect the rotatable cylinder. The stopping mechanism may be associated with braking mechanism alignment by mechanical compliance. The present invention may allow braking by force thresholding regardless of surface orientation.

The present invention relates to a gripper finger comprising:
a movable base element connectable to a gripper arm;
a roller configured to spin around its central axis;
a stopper configured to stop and/or prevent the spinning of the roller around its central axis.

Preferably, the roller is mounted on a rod at its central axis;
wherein said rod is deflectable such that said roller is configured to engage the stopper.

Preferably, said finger further comprises an elongated portion extending along an axis perpendicular to the central axis of the roller, with an aperture provided at the bottom of said elongated portion, wherein the rod is mounted such that is passes through said aperture; and
wherein the stopper is connected to said elongated portion at a location distal to said aperture.

Preferably, the elongated portion is rotatable around an axis identical or parallel to the roller central axis and wherein the aperture is essentially elongated in the direction of the length of said elongated portion enabling the deflection of the rod.

Preferably, the elongated portion is rotatable around an axis parallel to the roller central axis such that there is an offset between the central axis of the roller and the rotation axis of said elongated portion.

Preferably, the central axis of the roller is distal to the central rotation axis of the elongated portion rotation.

Preferably, the elongated portion is hollow and wherein an elastic element is placed within the hollow portion, wherein the rod is responsive to compression of said elastic element.

Preferably, the elastic element is a spring.

Preferably, the gripper finger further comprises a nut and bolt mechanism configured to compress or expand the elastic element.

Preferably, the stopper comprises protrusions on its proximal side.

Preferably, the aperture comprises an elongated circle (or oval) shape.

Preferably, the base element comprises a hollow cylindrical tube extending therefrom;
wherein said finger further comprises a cylindrical portion connected to a proximal portion of the top of the elongated portion and inserted within said hollow cylindrical tube and rotatable therewithin;
wherein said hollow cylindrical tube and said cylindrical portion have a common central axis;
wherein said common central axis is the rotation axis of said elongated portion.

Preferably, the cylindrical portion comprises a bore extending from the inside of the hollow portion to within said cylindrical portion;
wherein said bore is substantially parallel to the rotation axis of said elongated portion;
wherein the rod is placed within said bore; and
wherein the stopper extends from a distal portion of the bottom of the hollow portion and is substantially parallel to the rotation axis of said elongated portion.

Preferably, the gripper finger further comprises a second rod mounted within the hollow tube and is placed perpendicularly to the rotation axis of the elongated portion;
wherein the cylindrical portion comprises a partial slot perpendicular to the rotation axis of the elongated portion;
wherein said second rod is located within said slot and configured to limit the rotation of said cylindrical portion.

The present invention relates to a method for grasping and displacing an object comprising:
engaging said object with a plurality of movable fingers;
optimizing the grip with a substantially frictionless engagement;
immobilizing said object by adjusting frictional properties of said fingers.

Preferably, the adjusting frictional properties is by increasing friction.

Preferably, the adjusting frictional properties comprises stopping the rotation of a roller.

Preferably, stopping the rotation of a roller is by deflecting the roller central axis and/or engaging said roller with a stopper.

The present invention relates to a gripper system comprising:
a plurality of arms wherein the proximal ends of each of the arms are at close proximity to each other, wherein each of said arms comprises a mobile member movable thereon;
a motor configured to drive said mobile member;
a control unit;
a plurality of gripper fingers as explained herein, each mounted on a corresponding mobile member of said mobile members.

Preferably, the gripper system further comprises one or more sensors selected from the group consisting of torque sensors, velocity sensors, orientation sensors, contact sensor, and force sensors.

Preferably, the gripper system comprises a lead screw and follower mechanism, wherein the system comprises a lead screw rotatable (rotatably driven) by the motor and the system comprises a follower element which is part of the mobile member.

BRIEF DESCRIPTION OF THE DRAWINGS:

The present invention is illustrated by way of example in the accompanying drawings, in which similar references consistently indicate similar elements and in which:

- Fig. 1 illustrates an embodiment of the system of the present invention.
- Fig. 2 illustrates an upside-down embodiment of the system of the present invention.
- Fig. 3A illustrates a gripper finger according to an embodiment of the present invention.
- Fig. 3B illustrates a side view of a gripper finger according to an embodiment of the present invention.
- Fig. 3C illustrates elements of the gripper finger according to an embodiment of the present invention.
- Fig. 3D illustrates another angle view of the gripper finger according to an embodiment of the present invention.
- Fig. 3E illustrates a bottom view of the rotator element according to an embodiment of the present invention.
- Fig. 4 illustrates a spring mechanism according to an embodiment of the present invention.

- Fig. 5 illustrates a demonstration of the offset according to an embodiment of the present invention.
- Fig. 6 illustrates a demonstration of the spring mechanism function.
- Fig. 7A-7B illustrate the half cup stopper element according to an embodiment of the present invention.
- Fig. 8 illustrates a sequence of closure of the gripper fingers on an object and reorientation according to an embodiment of the present invention.

DETAILED DESCRIPTION OF THE INVENTION:

The present invention relates to a gripping method and device. Particularly, the present invention relates to fingertips for a gripper that improves its gripping ability. Specifically, the invention relates to a novel concept of utilizing contact dynamics to improve grasp robustness. The present invention is also further applicable to object manipulation, tool operation and industrial assembly lines. The invention focuses on novel fingertips for multi-fingered mechanical grippers (and in some cases single-fingered grippers).

The present invention relates to a method and means for grasping with fingertips that are convertible from being nearly frictionless at a first stage and highly frictional at a second stage. The conversion is carried out through active or passive actuation. The friction-convertible fingertips allow a frictionless closing of the fingers onto an object, thus allowing relative movement (e.g. rotation and translation) of the object being gripped. The frictionless engagement of the fingers with the object may cause the grasped object to adapt its position to a "centralized" position such that the grasp connection points are locally minimally distanced from one another. Such a grasping position ensures that the geometry of the gripped object itself resists external wrenches, and is guaranteed to constitute a feasible grasp. Furthermore, since there are a finite, positive number of locally minimal distant contact configurations for a given gripper and object, the gripper is guaranteed to grasp the object at well-defined points, removing the need for object pose estimation after grasping.

Subsequently, the frictionless immobilizing grasp is then transformed into a more robust frictional immobilizing grasp by converting the fingertips into frictional fingertips. After conversion to friction contacts, the resulting grasp is more robust than either a frictionless immobilizing or jamming grasp. The contact points are such that the cage has zero-volume, and the geometry of the object itself resists external wrenches, therefore it cannot be dislodged as in the case of jamming. Unlike the case of frictionless contacts however, local “slipping” of the fingertips along the objects perimeter due to external wrenches and natural compliance is much less prone to occur, as the frictional contacts can create frictional forces that may counteract this slippage. Thus, the frictional contacts at an immobilizing grasp position offers qualities that are difficult to obtain with solely frictional or frictionless contacts.

The moment of friction conversion can be determined actively or passively. The final fingertip locations on the object perimeter can be derived from existing techniques, such as a graph search for locally minimal distant points conforming to a gripper shape (e.g. *Allen, Thomas, Joel Burdick, and Elon Rimon, "Two-fingered caging of polygons via contact-space graph search." Robotics and Automation (ICRA), 2012 IEEE International Conference on. IEEE, 2012.*), and upon recognition of such fingertip placements the frictional mode may be activated. Alternatively, one may recognize that an immobilizing grasp exists through the knowledge that further retraction is no longer possible. If the gripper attempts to retract the frictionless fingers further upon the object, and is unsuccessful, it is implied that the object is in an immobilizing grasp, because otherwise it would continue to rotate and translate within the cage, allowing further finger retraction. When frictionless retraction is completed an immobilizing grasp occurs, allowing a mechanical device portion to convert the fingertips into frictional fingertips without external stimuli.

According to a preferred aspect of the present invention, the conversion between frictionless and frictional fingertips is obtained by using a rolling mechanism. The fingertips comprise a roller which at a first stage is rotatable around its central axis. When lateral forces are applied between the roller and the object to be grasped, frictional forces do not occur therebetween, but rather the object may be movable along the roller which rotates accordingly. To convert the roller into a frictional body, a "brake" action is applied to the roller. This is similar to a car tire, which is free to roll along its axis and does not (ideally) create friction forces that slow the vehicle down, however when the brakes are applied, the tire is no longer free to roll, and creates friction forces. This type of roller can be cylindrical (as a tire), spherical, or any other axisymmetric shape or special shape that permits the application of this concept. Most preferably, the roller is cylindrical.

The "roller braking" may be applied actively using standard braking mechanisms or specialized braking mechanisms, based on predetermined time, location or other gripping based parameters that trigger the braking mechanism. Alternatively, braking may be applied through finger-object interaction, i.e. based on force applied to the fingertips with an internal mechanism that triggers the brakes when the force exceeds a predetermined threshold. Such a force would be applied when retraction/closure is completed and the object in an optimal position/orientation to be grasped. Then the fingertips in an immobilizing grasp position become frictional.

Fig. 1 illustrates an embodiment of the present invention comprising a gripping system **1** with three fingers **10** (but can actually be used with any single or plurality of fingers and corresponding arms). Fig. 2 illustrates an upside-down gripping system **1** in order to obtain a better understanding of the invention. The three fingers **10** are connected and movable along three corresponding arms **5** of the gripping system **1** that extend outwards from a central common point **6**. Optionally the arms **5** do not have to actually touch each other but their proximal ends must be at a close enough proximity to each other, to enable grasping a required object. Preferably the arms **5** are located on a common horizontal plane. When grasping an object, the three fingers close in on the object to be grasped by moving along the arms **5** from outwards towards inwards to the central point **6**. The fingers **10** comprise fingertip rollers **40** at their edges (the edges far from the arms **5**) that are configured to engage the object to be grasped. When the fingers **10** engage the object to be grasped, the fingers **10** fingertip rollers **40** roll upon pressures applied on them. At first the force required to move the fingers is near-zero, and only exists to overcome the gripper system’s energy losses (friction, heat, noise etc.), and to a certain degree to transfer kinetic energy to the object, enabling it to adjust its position/orientation until it reaches a steady state. This steady state is that in which no more energy is transferred to the object by the fingers, and they are both stationary (in an immobilizing grasp). Then, force may be applied from the enclosing fingers causing a reactive normal force from the object sides engaging the rollers **40**, pushing them back. This pushing of the rollers **40** causes the triggering of the roller braking mechanism (roller stopper) after the normal force of the pushing of the rollers **40** exceeds a certain force threshold. Then the rollers **40** cannot rotate and act as efficient frictional fingertips providing an efficient robust grasp.

Fig. 3A shows a preferred embodiment of one finger **10** of the gripping system **1**. For obtaining a better understanding of the present invention, the finger **10** and corresponding arm **5** will be explained as follows. For a single finger **10** the proximal direction is the horizontal moving direction when closing on an object to be grasped, i.e. the direction towards the central common point **6.** The distal direction is opposite to the proximal direction, i.e. towards the outward edge of arm **5.**

Finger **10** comprises a base element **16** configured to connect to the corresponding arm **5** and travel along it proximally and distally. The movement of base element **16** along arm **5** may be according to several mechanisms, e.g. according to a rack and pinion mechanism, a cable driven system, pneumatic/hydraulic cylinders etc. In Fig. 1, a lead screw/follower system is used to translate the base element **16.**

The base element **16** is configured to connect to a mobile member **3** (movable thereon) driven along arm **5** by a motor. The gripper system comprises a control unit (e.g. controller) coupled to the motor, that controls the gripping function. Optionally the controlling can be carried out manually by an operator which can input commands to activate the motor to drive the fingers along the arms **5,** to change the fingers from frictional to frictionless upon reaching an immobilizing position of an object and to finalize the grasp and maneuver the object. Alternatively, the controlling can be carried out automatically by the controller pre-programed by the operator with optional use of sensors to determine the steps of the grasping.

According to a preferred embodiment, the fingers are retracted by a lead screw and follower mechanism (shown in Figs. 1-2) where the follower **2** is part of the mobile member **3** (to which the base **16** of the finger is connected) and the screw **7** is rotated by a motor. The lead screws **7** are powered by a single motor with a torque sensor and an angular velocity sensor, both coupled to the control unit. The sensed torque can be used by the control unit to determine the force applied to each of the fingers. The sensed angular velocity can be used to determine the linear velocity of each of the fingers. While retracting the fingers (closing on an object), a minimal force is required to overcome the natural friction and other energy losses of the system, and therefore a minimal torque is sensed. When a finger impacts the body and transfers kinetic energy to it, the sensed torque rises somewhat (as a function of the transferred energy and motor speed). When the fingers reach an immobilizing grasp (after optimal reorientation of the object), the motor speed is naturally reduced to zero, and the torque rises drastically, until it reaches some user defined maximum. This torque maximum translates to the maximal force applied by the fingers to the object. The state of the gripper and the finger forces can therefore be derived by sensing the torque and speed of the driving motor. In addition, micro-switches or other contact sensors can be used to sense the enactment of the braking mechanism, giving the control unit further information regarding the state of the system. The control unit can control the gripping according to the sensed information according to preprogramed operating instructions. Ideally, manipulation of the object by the gripper occurs when the braking of all of the fingers is carried out, and when the desired force is applied to each of the fingers (which may be greater than the force required to enact the braking mechanism, as defined by the user).

Fig. 3B illustrates a side view of a gripper finger according to an embodiment of the present invention.

Fig. 3C shows the main elements of finger **10** disconnected and apart from each other for a better understanding of the invention. The distal portion of base element **16** comprises a flat portion **17**. The proximal end of base element **16** comprises a hollow tube **18** extending vertically downwards therefrom. Hollow tube **18** comprises two apertures **19** (only one shown) configured to receive a thin rod as will be explained hereinafter.

Finger **10** comprises a rotator element **30**. The rotator element **30** comprises an upper vertical cylindrical portion **31** comprising a horizontal partial slot **32**. The upper cylindrical portion **31** is inserted and fitted within tube **18** and rotatable therewithin.

Optionally, needle bearings **26** are inserted within tube **18** with a hollow cylindrical spacer **21** therebetween and cylindrical portion **31** is inserted within them (having a corresponding size). The needle bearings **26** reduce the friction of the rotation of cylindrical portion **31** therewithin. In this case spacer **21** also comprises two apertures **22** (only one shown) configured to receive a thin rod **25** passing through the apertures **22** (its final connection will be explained hereinafter).

Optionally, tube **18** may have needle bearings to assist cylindrical portion **31** rotation. The cylindrical portion **31** in this case has a corresponding size to tube **18**.

The upper cylindrical portion **31** is inserted within spacer **21** such that apertures **22** are aligned with apertures **19** and thin rod **25** is inserted therethrough and within slot **32** (in case without the needle bearings and spacer the rod **25** is inserted through apertures **19** only, mutatis mutandis). Thus the rotation of rotator element **30** is limited according to the slot **32** structure such that the rotation may be stopped by rod **25** at both rotation directions. Thus the rotator is rotatable around the central axis of cylindrical portion **31** about a limited angle. This angle limitation can be set to any value (0 degrees to endless turns). In the device depicted in Fig. 1 the angle is limited to 90 degrees, or ±45 degrees from the central position (wherein the rod **25** is perpendicular to the proximal-distal direction). The angle limitation is designed to ensure that the locking mechanism (stopper **37** explained hereinafter) does not contact the grasped body during finger retraction. The upper part of slot **32** rests on rod **25** maintaining rotator element **30** in place vertically.

The rotator element **30** further comprises an elongated hollow portion **35** attached to the bottom of cylindrical portion **31** and extending distally therefrom in a horizontal manner. The elongated hollow portion **35** indeed extends distally being parallel to the flat portion **17** but since the rotator element **30** is rotatable, it can be positioned at an angle from the direction of flat portion **17** such that the center of the rotatable angle is when parallel to flat portion **17**. In any case the general direction/position that elongated hollow portion **35** extends to is distally with a possible side deviation (due to the rotation). Other elements attached thereto will also be defined herein as having a general distal orientation with possible side deviations.

The rotator element **30** further comprises a stopper element **37** extending vertically downwards from the distal end of elongated hollow portion **35**. The stopper element **37** comprises protrusions **36** on its proximal side configured to stop the roller **40** upon contact therewith (and/or prevent it from spinning), as will be explained hereinafter.

The finger **10** further comprises the roller **40** mounted on a lower portion of a vertical rod **41**. The roller **40** comprises a central bore where the rod **41** is inserted therethrough. The roller **40** is rotatable around the rod which is at its central axis. Two mountable bearings **42** are mounted and attached to the rod **41**, holding and keeping the roller **40** in place while allowing rotation with minimal friction. The top and bottom surfaces of the roller **40** may comprise recesses **45** and the bearings **42** may be placed within the recesses **45**.

The rotator element **30** comprises a central bore **38** extending vertically upwards from a proximal portion of elongated hollow portion **35** ending at a portion within cylindrical portion **31**. Typically, the bottom of the proximal portion of elongated hollow portion **35** comprises an aperture **39** parallel to the bore **38** (with the hollow part therebetween). The bore **38** and aperture **39** have an elongated length portion (along the proximal-distal axis) such that the rod **41** can be positioned vertically with an option to be deviated distally such that the roller **40** can engage the protrusions **36** of stopper element **37.** Thus the bore **38** (and aperture **39**) may have an elongated circle cross section with the major axis in the proximal-distal direction. A top view of rotator **30** can be seen in Fig. 3E showing bore **38** and aperture **39.** The rod **41** does not normally move within the bore **38** due to force applied by a compressed spring **55** through a pushing surface **56** that pushes the rod **41** against one side of the bore **38.** Movement of the rod **41** within bore **38** is only possible when an opposing force overcomes the force of the compressed spring **55,** as in the case of the activation of the braking mechanism that will be explained hereinafter.

According to this embodiment the stopping of the rotation/spinning of roller **40,** i.e. its "braking", is implemented by using a spring mechanism. The roller rotation stopping is carried out when a force threshold is exceeded. When the fingers **10** close on an object by moving proximally (each finger **10** along its corresponding arm **5** towards the connecting center point **6**) and when engaging the object, the object orientates itself to an optimal grasp position and then ceases to orientate itself. Then the rollers are therefore placed at the most optimal engaging points of the object. Then, the continuation of the application of force by the fingers **10** proximally causes a normal force from the object surface to the rollers **40** according to Newton's third law of motion.

The roller **40** is connected to the finger **10** in the following manner. As said, rod **41** is inserted in bore **38.** A spring mechanism is inserted within elongated hollow portion **35.** The spring mechanism includes a slot **50** (shown in Fig. 3A) at the distal end of elongated hollow portion **35.** A nut **51** (as shown also enlarged in Fig 4) is inserted within slot **50,** and a corresponding mating bolt **52** is threaded therethrough (the head **52h** of the bolt **52** being on the distal side and the shank and thread **52t** on the proximal side). The nut **51** having a thickness corresponding to slot **50** thickness, is maintained stationary, while the bolt may be turned and screwed causing proximal and distal motion. The proximal end of the thread **52t** engages a pushing surface **53** placed proximally to it and an elastic element (e.g. spring, wherein according to this specific embodiment - coil spring **55**) is placed proximally to the pushing surface **53.** A second pushing surface **56** is placed proximal to the spring **55.** The pushing surface **56** comprises an inner vertical bore **56b** where the rod **41** is inserted therethrough. Thus the spring mechanism works as will be explained hereinafter.

The finger **10** is constructed such that rod **41** (placed in bore **38**) being the central vertical axis of roller **40** (which it spins about) is placed at an offset from the central vertical axis of cylindrical portion **31** of rotator element **30** (i.e. they are not aligned). The offset is shown in a top view in Fig. 5. Since stopper element **37** rotates according to rotator **30** (which it is part of) and since the roller **40** is fixed to cylindrical portion **31** at a slight offset - mechanical conditions are formed where upon contact of the roller with the object surface, torque is created that strives to orient the stopper element **37** in a direction normal to the object pushing side surface (the direction of elongated portion **35** is perpendicular to the object pushing side surface). In other words, the normal force from the object to be grasped pushing side pushes the roller **40** in the normal force direction causing the rod **41** to push the bore **38** (and aperture **39**) distal end in the normal force direction. Since the bore **38** (and aperture **39**) distal end is in the same direction of the stopper element **37**, the stopper element **37** is actually pushed in the normal force direction and thus the stopper element **37** is rotated until it faces the object pushing side orientation (both being perpendicular to the normal force direction).

When the normal force increases (due to the system force applied to finger **10** to move proximally along arm **5** and thus Newton's third law) the roller **40** is pushed such that it deviates in the normal force direction and engages the stopper element **37** which stops its ability to rotate. The protrusions **36** engagement with the roller **40** causes friction with the roller **40** body making it stationary and un-rotatable thus the roller **40** becomes a frictional fingertip that can provide a robust grasp.

At its regular state before being pushed by the normal force, the roller **40** is oriented such that the rod **41** is maintained vertically by the spring mechanism. The pushing surface **56** is pushed proximally by the spring such that rod **41** is maintained in a vertical position. Since the nut **51** is stationary in slot **50**, the bolt **52** may be adjusted proximally such that the pushing surface **53** (being pushed by the bolt proximal end) may push the spring **55** distal end causing it to contract and thus increasing the normal force threshold needed to stop the roller rotation. This is because more normal force will be needed to push the roller (and thus the rod **41** to which it is connected and thus the pushing surface **56** to which the rod passes therethrough) to overcome the spring force. Alternatively, the bolt **52** may be adjusted distally such that the pushing surface **53** may retract distally causing the spring **55** to expand (and thus decreasing the normal force threshold needed to stop the roller rotation). This is because less normal force will be needed to push the roller (and thus the rod **41** to which it is connected and thus the pushing surface **56** to which the rod passes therethrough) to overcome the spring force. Thus the force of the pushing surface **56** pushing the rod **41** therewithin may vary according to the spring contraction/expansion length. According to this, a user may determine and adjust the threshold of the normal force that is required to change the fingertip from frictionless to frictional, i.e. that causes the roller to stop rotating. Additional springs of different lengths and stiffness may be added between pushing elements **53** and **56** to increase the threshold normal force range required for "braking" the roller **40**. Of course a user can further adjust different force thresholds required to "brake" the rollers by replacing the spring with another that is more stiff or less stiff or by adding or removing additional springs.

Fig. 5 shows the roller **40** contacting a surface creating a torque that rotates the stopper element **37**. In the left image, the roller **40** contacts a surface in the NW-SE direction. In the right image the roller **40** contacts a surface in the SW-NE direction. In both cases, the stopper element **37** is parallel to the surface (with the normal force perpendicular to both).

Fig. 6 describes the mechanical compliance that enables the varying threshold force. The top left image shows the roller **40** in a "relaxed" position (the spring **55** is uncompressed or minimally compressed, pushing rod **41**). The bottom left image shows the roller **40** after the spring **55** is additionally compressed by the bolt **52**. The top right image shows the roller **40** in a breaking position when the spring is relatively in a relaxed position thus a mere small force was needed to cause the braking. The bottom right image shows the roller **40** in a braked position, where enough force was applied to overcome the preloading force caused by the bolt compressing the spring (the compression as in bottom left image).

Orientation sensors such as optical encoders or potentiometers (coupled to the system controller) can be used to determine the relative angle between the rotating stopper element **37** and the distal-proximal direction (e.g. the direction of arm **5**). By measuring this relative angle one can derive the surface angle (contact surface orientation) of the object being grasped at the point of contact with the fingertip roller **40** at any stage of gripping. The orientation information can be used to determine the object's pose during finger retraction and upon grasping, in order to estimate grasping progress and detect placement errors. Fig. 3C shows an example of a potentiometer **60** connectable to a protrusion **62** (shown in Figs. 3C and 3D) extending vertically upwards from the center of the top of cylindrical portion **31** and thus rotates in accordance to the rotation of cylindrical portion **31**.

Braking can be detected by means of a physical contact sensor, such as a microswitch or other means of closing an electric circuit by contact between the roller **40** and the stopper element **37**. The physical contact sensor is coupled to the system control unit. This detection may assist the system in determining the grasp state. Fingers that are determined as "braked" by means of this sensor are friction contacts, while fingers that are not determined as "braked" are frictionless contacts (enabling the rollers to spin). One embodiment of the contact sensor is a button attached to the proximal side of stopper element **37**. When the roller engages stopper element **37** the button is pressed indicating braking to the control unit. Another embodiment includes a metal strip attached around the roller such that when it contacts a corresponding circuit attached to the proximal side of stopper element **37** a circuit is closed and thus indicating braking to the control unit.

Optionally, the system comprises force sensors attached to the stopper element **37** or on the roller **40** (and coupled to the control unit) used to determine the normal force applied by each finger to the object (or the normal force applied to each finger by the object).

Fig. 8 shows the engagement and orientation of an object by the gripper fingers of the present invention. Five images are shown sequentially from top to bottom, wherein the rollers engage a triangular object and reorient the object to the optimal steady state position for an immobilizing grasp. After reaching the optimal position (bottom image) the fingers become frictional thus obtaining a robust frictional immobilizing grasp.

Fig. 7A shows a different embodiment of the present invention. This embodiment does not comprise a rotating stopper, rather a stationary half cup element stopper **137.** The roller, the elongated hollow element and spring mechanism may be similar like explained hereinabove. The roller **140** is mounted on a rod passing through the elongated hollow element into an elongated bore (enabling rod deflection), the bore being within an elongated portion **118** (e.g. tube) extending (e.g. vertically) from a base element **116.** The half cup element stopper **137** has a half cylindrical shape initially parallel to the roller **140** and its inner side (which is its proximal side) is placed facing the roller **140** distal side. When the rod is deflected due to the normal force of the object on the roller **140,** the roller **140** engages the stopper **137** inner (proximal) side and thus ceases to rotate and is stopped. The stopper **137** inner side comprises protrusions **136** that apply friction with the roller **140** causing it to stop and/or prevent it from spinning. Fig. 7B shows the half cup element stopper **137.**

The gripper hand may be made mostly of aluminum and plastic (3d printed or laser-cut) preferably with some steel components. The fingers are preferably made mostly of plastic (3d printed), a coating of latex on the rollers, and some steel components.

The base element **16** is preferably between 15 and 75 mm long, more preferably between 25 and 65 mm long, for example between 40 and 50 mm). The base element **16** may comprise plastic, steel, aluminum, etc.

The hollow tube **18** is preferably between 20 and 60 mm long and preferably has an inner diameter between 15 and 25 mm. Its height is preferably between 25 and 55 mm, and its diameter is preferably between 10 and 30 mm). The hollow tube **18** may comprise plastic, steel, aluminum, etc.

Cylindrical portion **31** is preferably between 60 and 95 mm long with an outer diameter of preferably between 10 and 20 mm. Cylindrical portion **31** may comprise plastic, brass, steel, etc.

The bore **38** is preferably between 2 mm and 4 mm in diameter.

The slit is preferably of diameter equal to the bore **38**, with an arc preferably between 2 and 6 degrees and a depth of between 25 mm and 45 mm.

The rod **41** should preferably be of equal diameter to the bore **38**, with a clearance fit. The rod **41** may comprise steel.

The elongated portion **35** should preferably have a cross section of between 10x7 mm^2 and 20x17 mm^2, with a length of between 20 and 40 mm. The elongated portion **35** may comprise plastic, brass, steel, etc.

The length of springs **55** can vary greatly depending on the users force threshold requirements, however the compressed spring length should preferably not exceed the half the length of the elongated portion **35**. The springs **55** may comprise steel.

The pushing elements **53**, **56** should preferably have a diameter equal or greater than the diameter of the springs **55**, and preferably comprise plastic.

The roller **40** is preferably between 20 mm and 30 mm in diameter, with a preferable height of between 20 mm and 40 mm. The roller **40** preferably comprises plastic, or preferably comprises aluminum coated with rubber or latex.

The stopper **37** should preferably have a height that is between half the height of the roller **40**, and the full height of the roller **40**. The stopper **37** preferably comprises rubber coated steel, or preferably comprises plastic or rubber coated brass.

Arms **5** should preferably have a length of between 50 mm and 250 mm depending on the required extension. The arms **5** preferably comprise aluminum.

The roller coefficient of friction depends on the object to be grasped. A typical value of the coefficient of friction between rubber and steel (such as the contact between the roller and a steel object) is 0.7. A typical value of a rubber on rubber contact (the roller with the stopping element for example) is 1.15, etc. The higher the coefficients of friction is, the better. A good value would be anything above 0.5 (ballpark estimate).

The offset distance between the central axis of the roller and the rotation axis of the elongated portion is preferably between 1 and 5 mm. The larger the offset is the moments created to align the stopper with the object to be gripped (one facing and parallel to the other) are greater.

The present invention relates to a method for grasping and displacing an object using the system as explained herein.

The present invention relates to a method for grasping and displacing an object comprising:
engaging said object with a plurality of movable fingers;
optimizing the grip with a substantially frictionless engagement;
immobilizing said object by adjusting frictional properties of said fingers.

The adjusting frictional properties may be carried out by increasing friction.

The adjusting frictional properties may comprise stopping the rotation of a roller (as explained herein).

Preferably, the stopping of the rotation of a roller is by deflecting the roller central axis and/or engaging said roller with a stopper.

While some of the embodiments of the invention have been described by way of illustration, it will be apparent that the invention can be carried into practice with many modifications, variations and adaptations, and with the use of numerous equivalents or alternative solutions that are within the scope of a person skilled in the art, without departing from the spirit of the invention, or the scope of the claims.

CLAIMS

1. A gripper finger comprising:
a movable base element connectable to a gripper arm;
a roller configured to spin around its central axis;
a stopper configured to stop and/or prevent the spinning of the roller around its central axis.

2. The gripper finger according to claim 1, wherein the roller is mounted on a rod at its central axis;
wherein said rod is deflectable such that said roller is configured to engage the stopper.

3. The gripper finger according to claim 2, wherein said finger further comprises an elongated portion extending along an axis perpendicular to the central axis of the roller, with an aperture provided at the bottom of said elongated portion, wherein the rod is mounted such that is passes through said aperture; and
wherein the stopper is connected to said elongated portion at a location distal to said aperture.

4. The gripper finger according to claim 3, wherein the elongated portion is rotatable around an axis identical or parallel to the roller central axis and wherein the aperture is essentially elongated in the direction of the length of said elongated portion enabling the deflection of the rod.

5. The gripper finger according to claim 4, wherein the elongated portion is rotatable around an axis parallel to the roller central axis such that there is an offset

between the central axis of the roller and the rotation axis of said elongated portion.

6. The gripper finger according to claim 5, wherein the central axis of the roller is distal to the central rotation axis of the elongated portion rotation.

7. The gripper finger according to claim 6, wherein the elongated portion is hollow and wherein an elastic element is placed within the hollow portion, wherein the rod is responsive to compression of said elastic element.

8. The gripper finger according to claim 7, wherein the elastic element is a spring.

9. The gripper finger according to claim 7, further comprising a nut and bolt mechanism configured to compress or expand the elastic element.

10. The gripper finger according to claim 2, wherein the stopper comprises protrusions on its proximal side.

11. The gripper finger according to claim 4, wherein the aperture comprises an elongated circle shape.

12. The gripper finger according to claim 6, wherein the base element comprises a hollow cylindrical tube extending therefrom;
wherein said finger further comprises a cylindrical portion connected to a proximal portion of the top of the elongated portion and inserted within said hollow cylindrical tube and rotatable therewithin;

wherein said hollow cylindrical tube and said cylindrical portion have a common central axis;
wherein said common central axis is the rotation axis of said elongated portion.

13. The gripper finger according to claim 12, wherein the cylindrical portion comprises a bore extending from the inside of the hollow portion to within said cylindrical portion;
wherein said bore is substantially parallel to the rotation axis of said elongated portion;
wherein the rod is placed within said bore; and
wherein the stopper extends from a distal portion of the bottom of the hollow portion and is substantially parallel to the rotation axis of said elongated portion.

14. The gripper finger according to claim 12, further comprising a second rod mounted within the hollow tube and is placed perpendicularly to the rotation axis of the elongated portion;
wherein the cylindrical portion comprises a partial slot perpendicular to the rotation axis of the elongated portion;
wherein said second rod is located within said slot and configured to limit the rotation of said cylindrical portion.

15. A method for grasping and displacing an object comprising:
engaging said object with a plurality of movable fingers;
optimizing the grip with a substantially frictionless engagement;

immobilizing said object by adjusting frictional properties of said fingers.

16. The method according to claim 15, wherein the adjusting frictional properties is by increasing friction.

17. The method according to claim 15, wherein the adjusting frictional properties comprises stopping the rotation of a roller.

18. The method according to claim 17, wherein stopping the rotation of a roller is by deflecting the roller central axis and/or engaging said roller with a stopper.

19. A gripper system comprising:
a plurality of arms wherein the proximal ends of each of the arms are at close proximity to each other, wherein each of said arms comprises a mobile member movable thereon;
a motor configured to drive said mobile member;
a control unit;
a plurality of gripper fingers according to claim 1, each mounted on a corresponding mobile member of said mobile members.

20. The gripper system according to claim 19, further comprising one or more sensors selected from the group consisting of torque sensors, velocity sensors, orientation sensors, contact sensor, and force sensors.

21. The gripper system according to claim 19, comprising a lead screw and follower mechanism, wherein the system comprises a lead screw rotatable by the motor and the

system comprises a follower element which is part of the mobile member.

Fig. 1

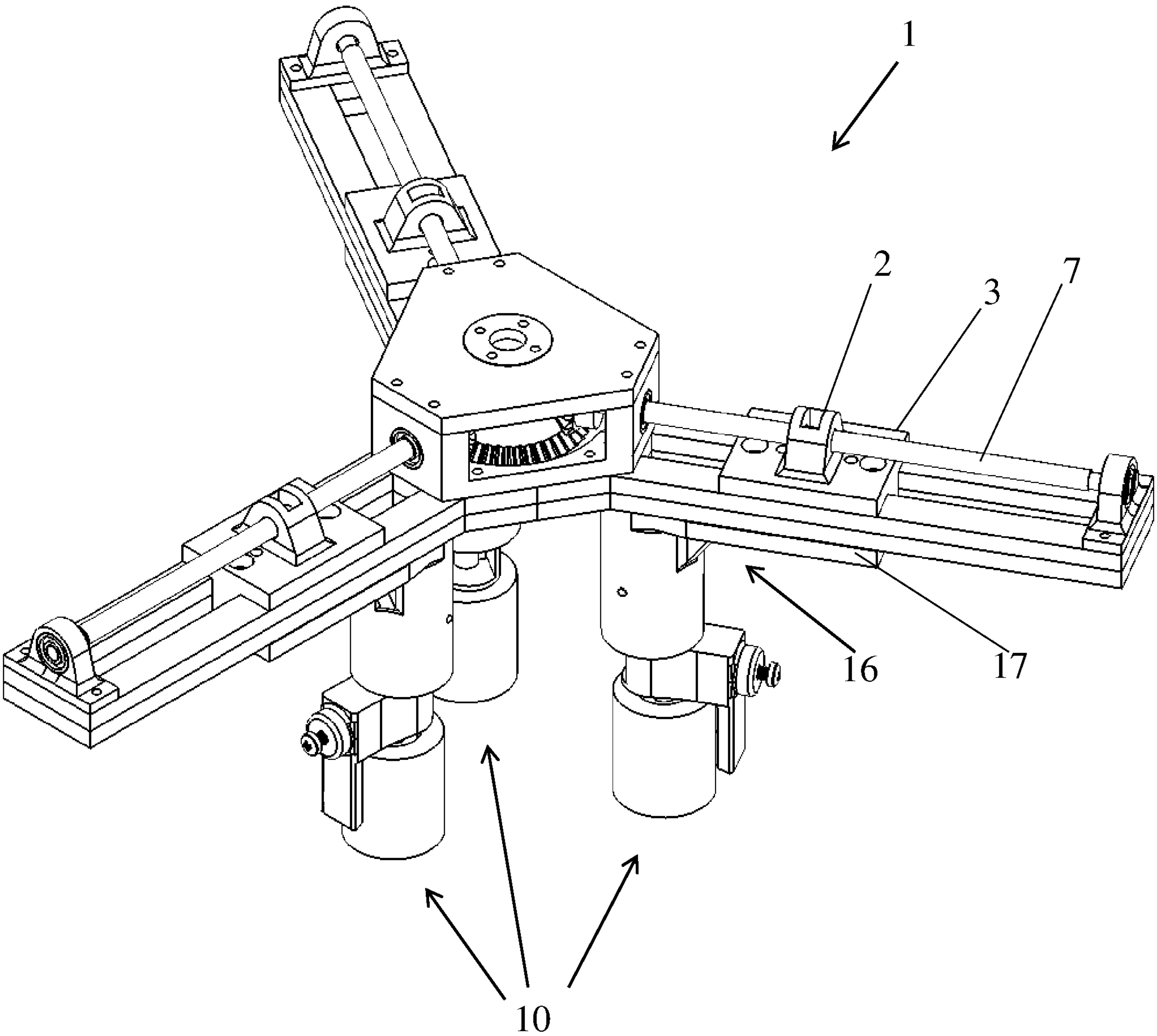


Fig. 2

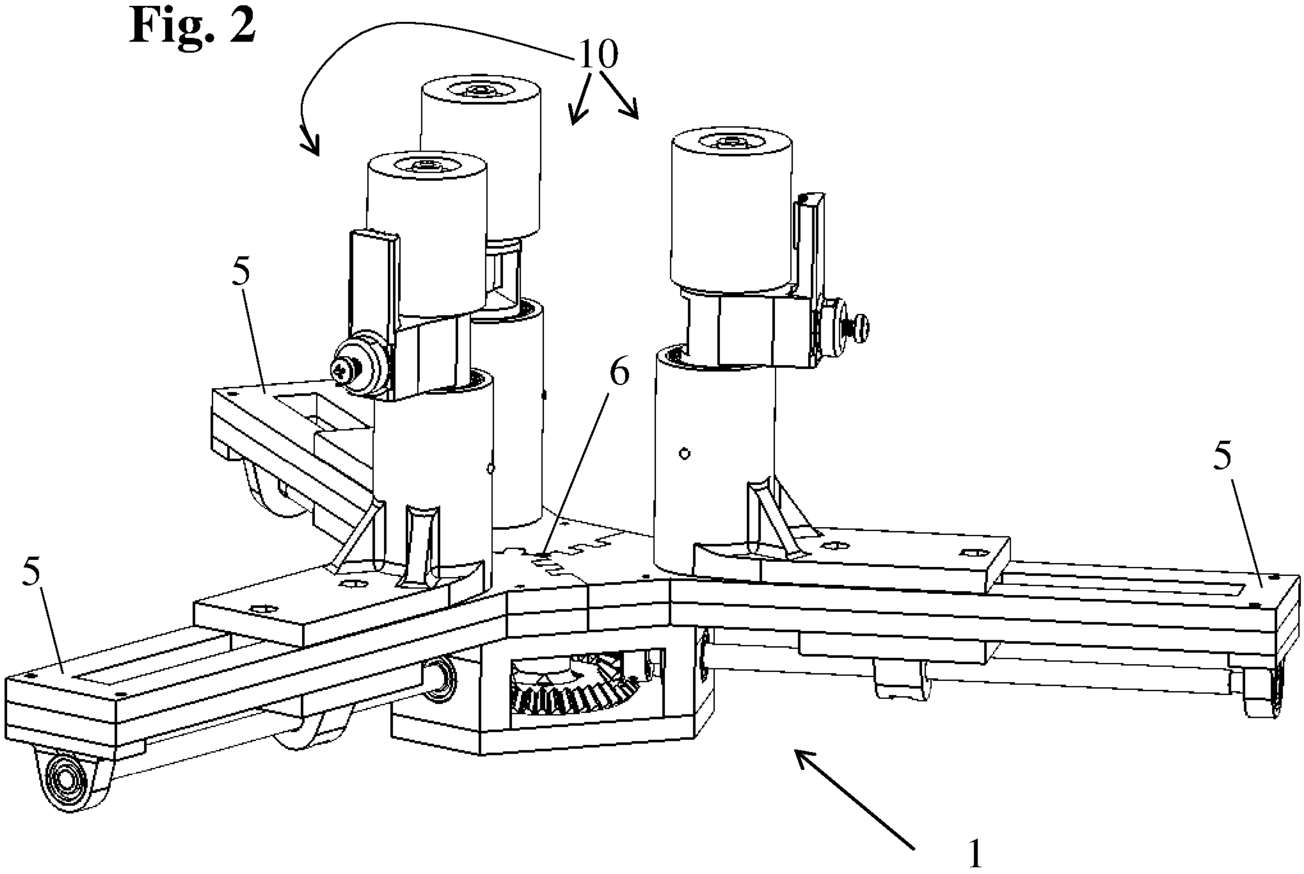


Fig. 3A

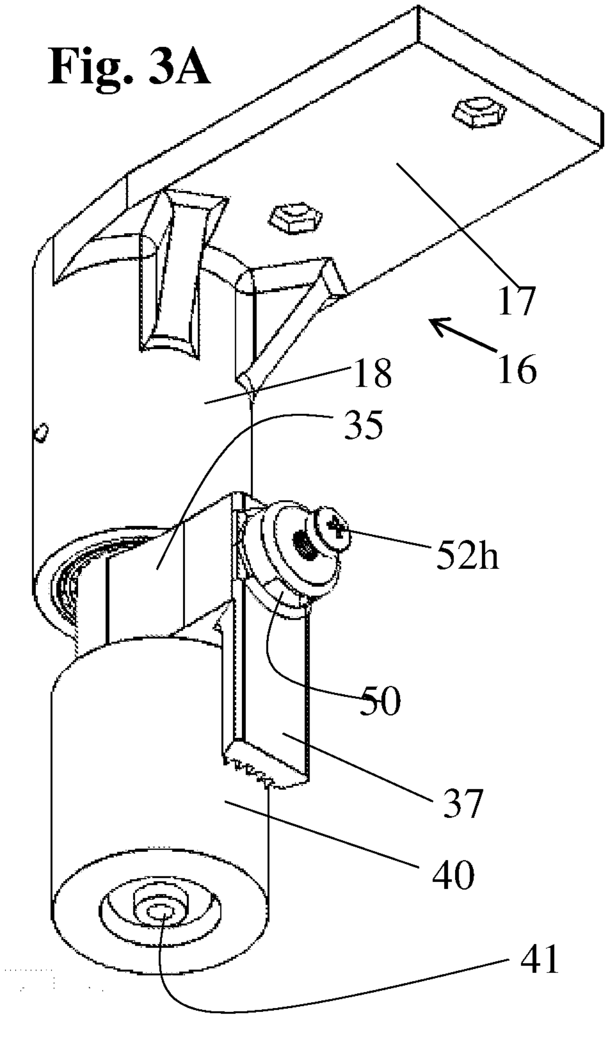


Fig. 3B

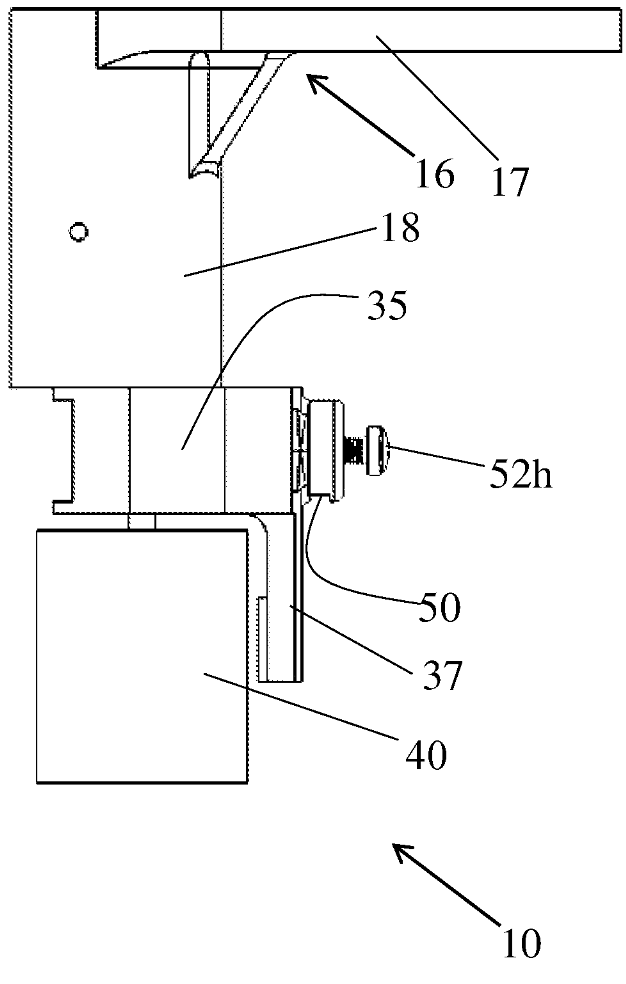
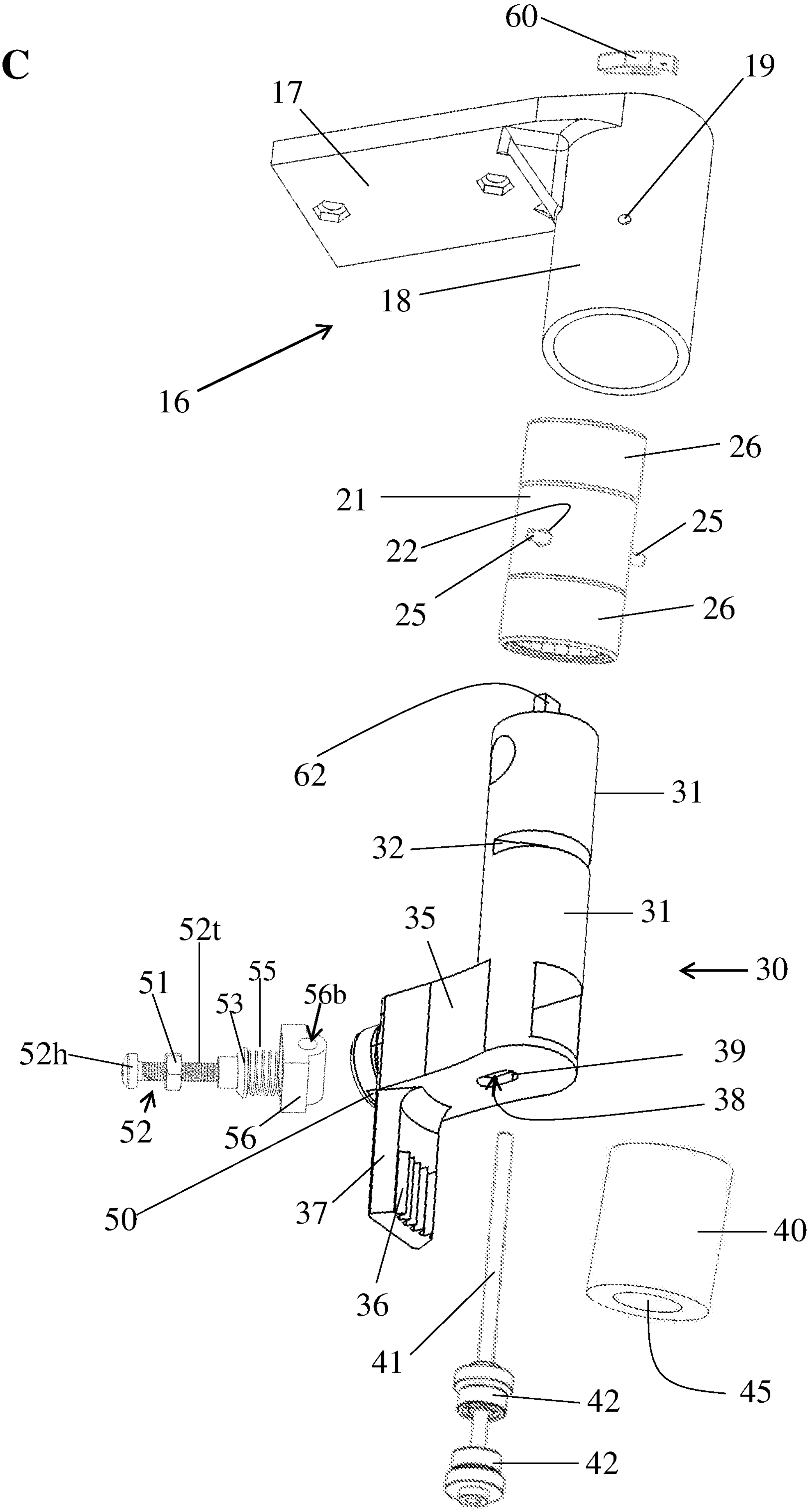


Fig. 3C


60
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62
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32
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52t
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56b
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Fig. 3D

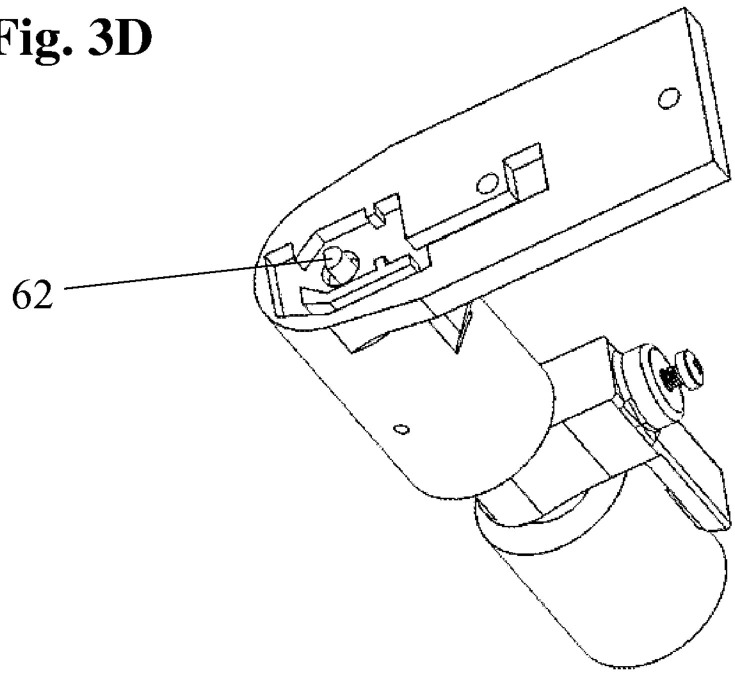


Fig. 3E

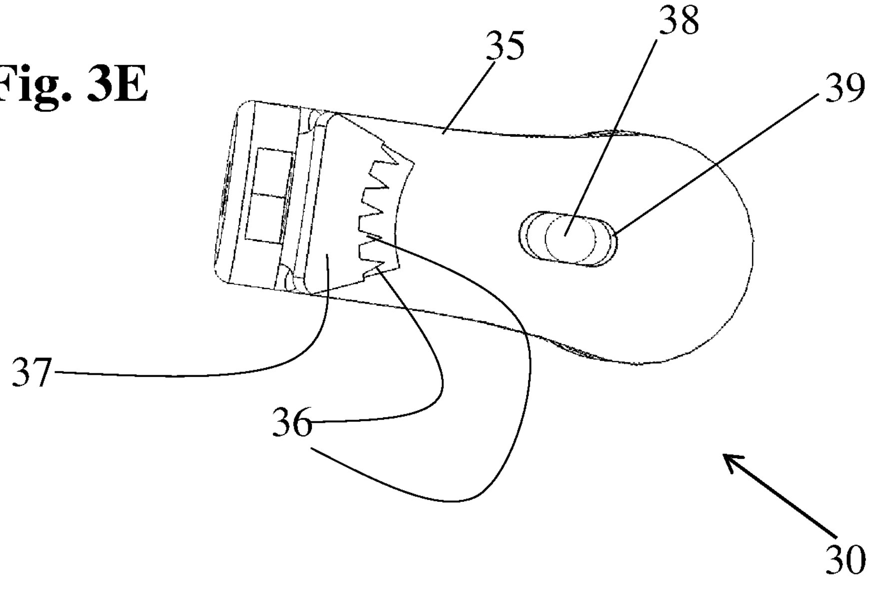


Fig. 4

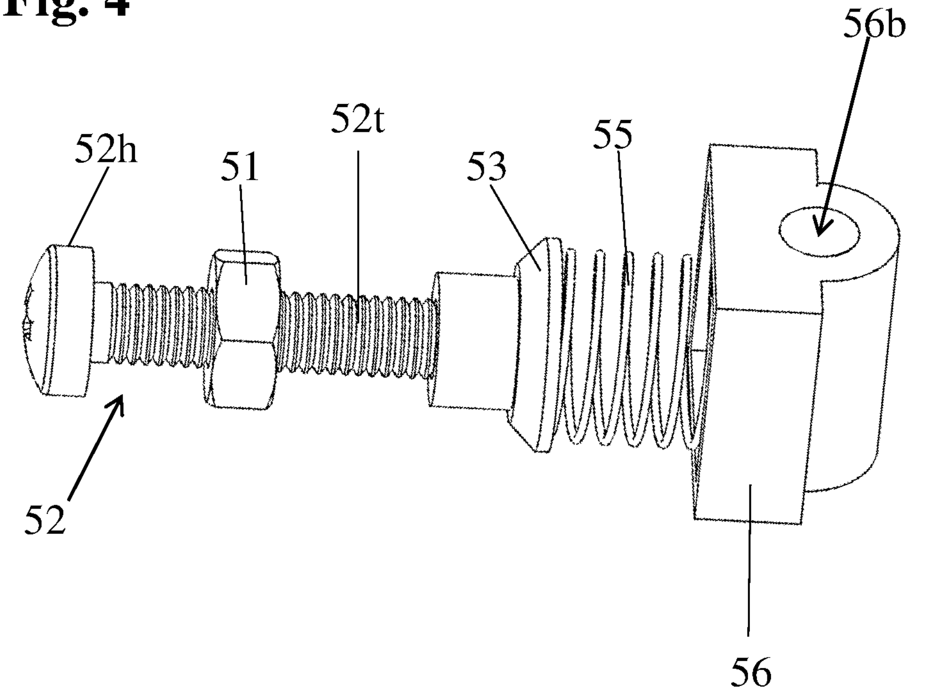
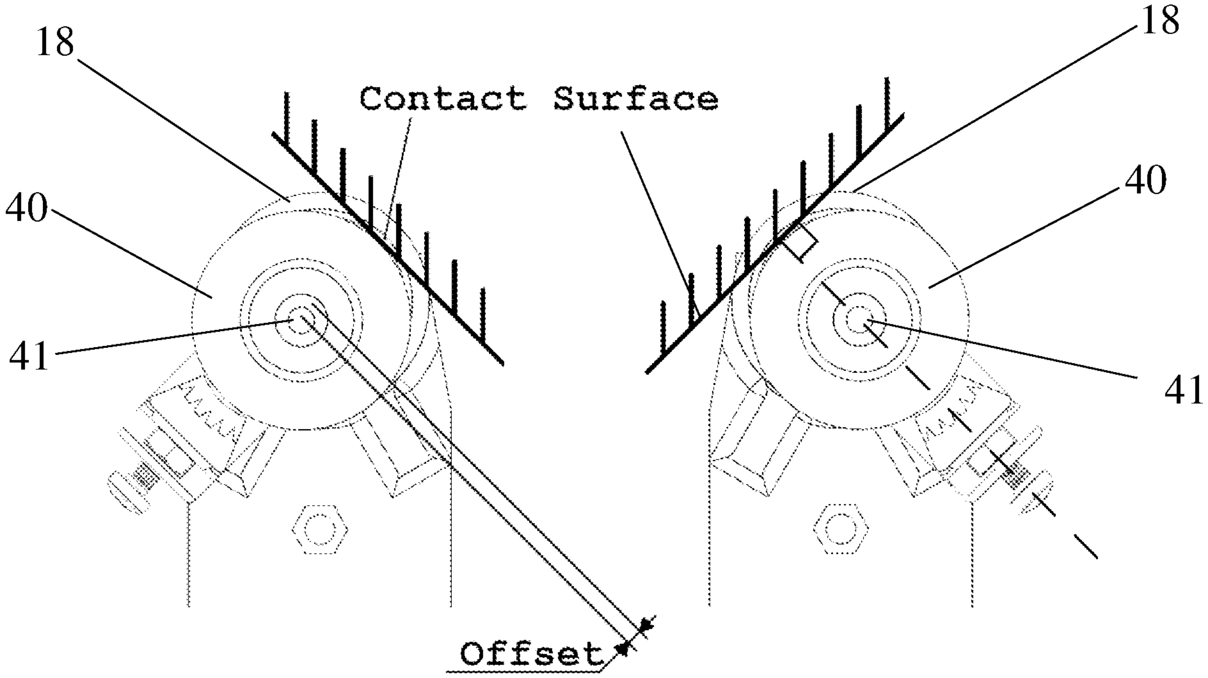
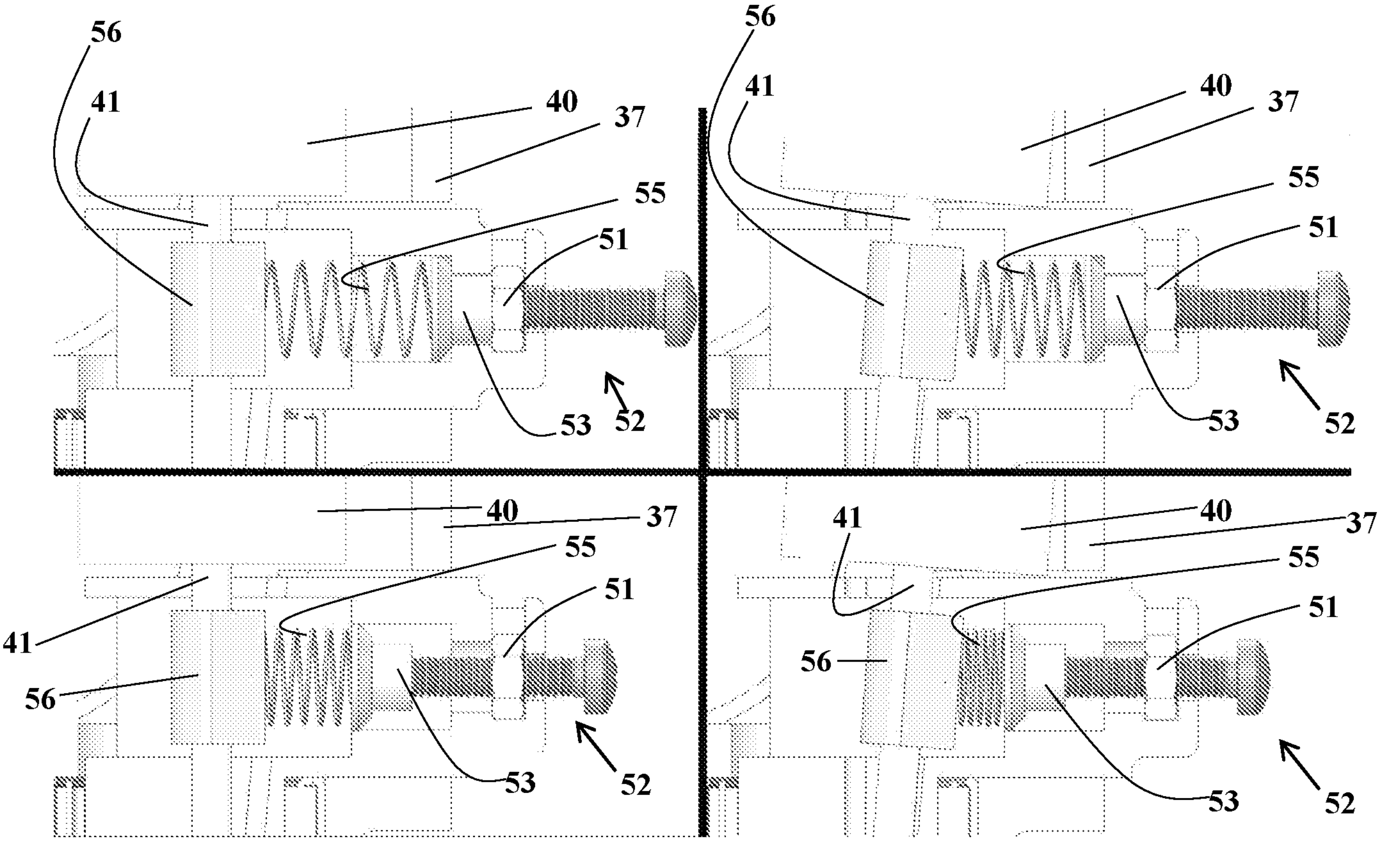


Fig. 5



Mechanical compliance for braking alignment

Fig. 6



Spring loading mechanism to change force required to brake

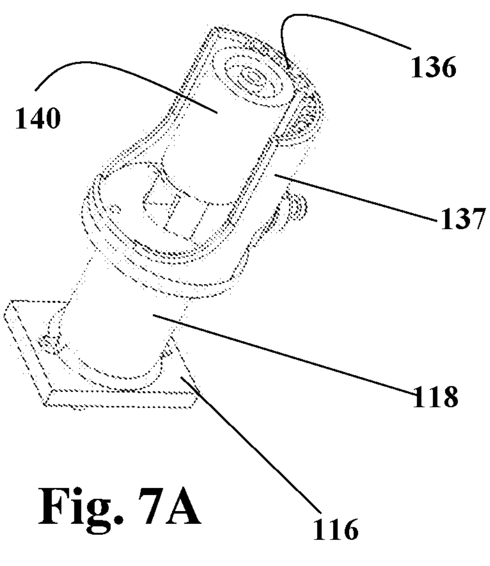


Fig. 7A

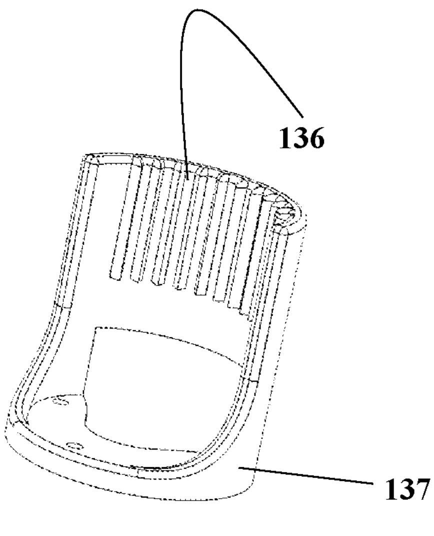


Fig. 7B

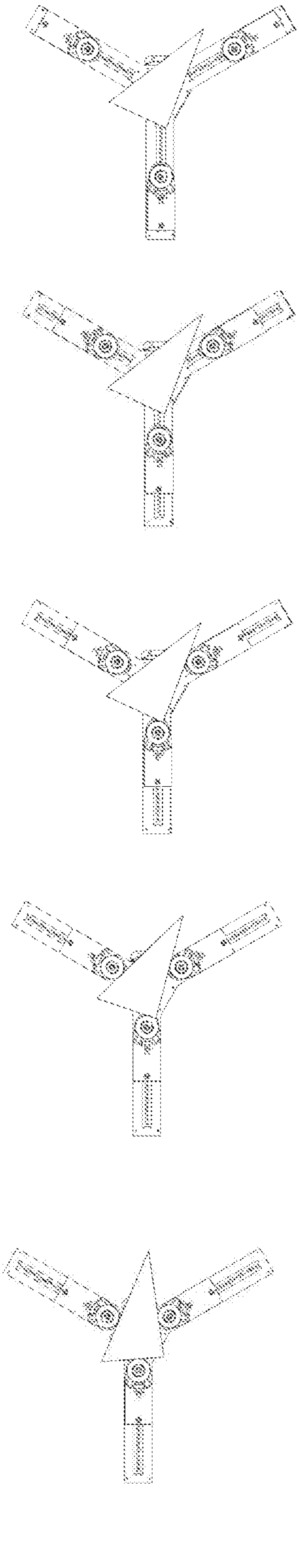


Fig. 8

INTERNATIONAL SEARCH REPORT

International application No.
PCT/IL2017/050532

A. CLASSIFICATION OF SUBJECT MATTER
IPC (2017.01) B25J 15/10, B25J 15/02

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC (2017.01) B25J

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
Databases consulted: Google Patents, PatBase
Search terms used: Grip/grasp, finger, roller, stopper/brake, base, axis, rotate/spin, immobilize, pivot, elongated, spring, cylinder.

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2014/0255129 A1 Kenner 11 Sep 2014 (2014/09/11) The entire document.	1,2,10,15-21
A	The entire document.	3-9,11-14
A	US 4653793 A Guinot et al. 31 Mar 1987 (1987/03/31) The enttire document.	1-21
A	US 2015/0151438 A1 Hecht et al. 04 Jun 2015 (2015/06/04) The entire document.	1-21
A	US 2003/0102640 A1 Saito 05 Jun 2003 (2003/06/05) The entire document.	1-21

☐ Further documents are listed in the continuation of Box C. ☒ See patent family annex.

* Special categories of cited documents:
"A" document defining the general state of the art which is not considered to be of particular relevance
"E" earlier application or patent but published on or after the international filing date
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
"O" document referring to an oral disclosure, use, exhibition or other means
"P" document published prior to the international filing date but later than the priority date claimed
"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
06 Sep 2017	11 Sep 2017

Name and mailing address of the ISA:	Authorized officer
Israel Patent Office Technology Park, Bldg.5, Malcha, Jerusalem, 9695101, Israel Facsimile No. 972-2-5651616	SIGALOV Olga Telephone No. 972-2-5651781

INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.
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