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(54) **MECHANICAL END EFFECTOR**

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(72) Inventors: **Jake Goldsmith**, Sunnyvale, CA (US); **Michael Stevens**, Sunnyvale, CA (US)

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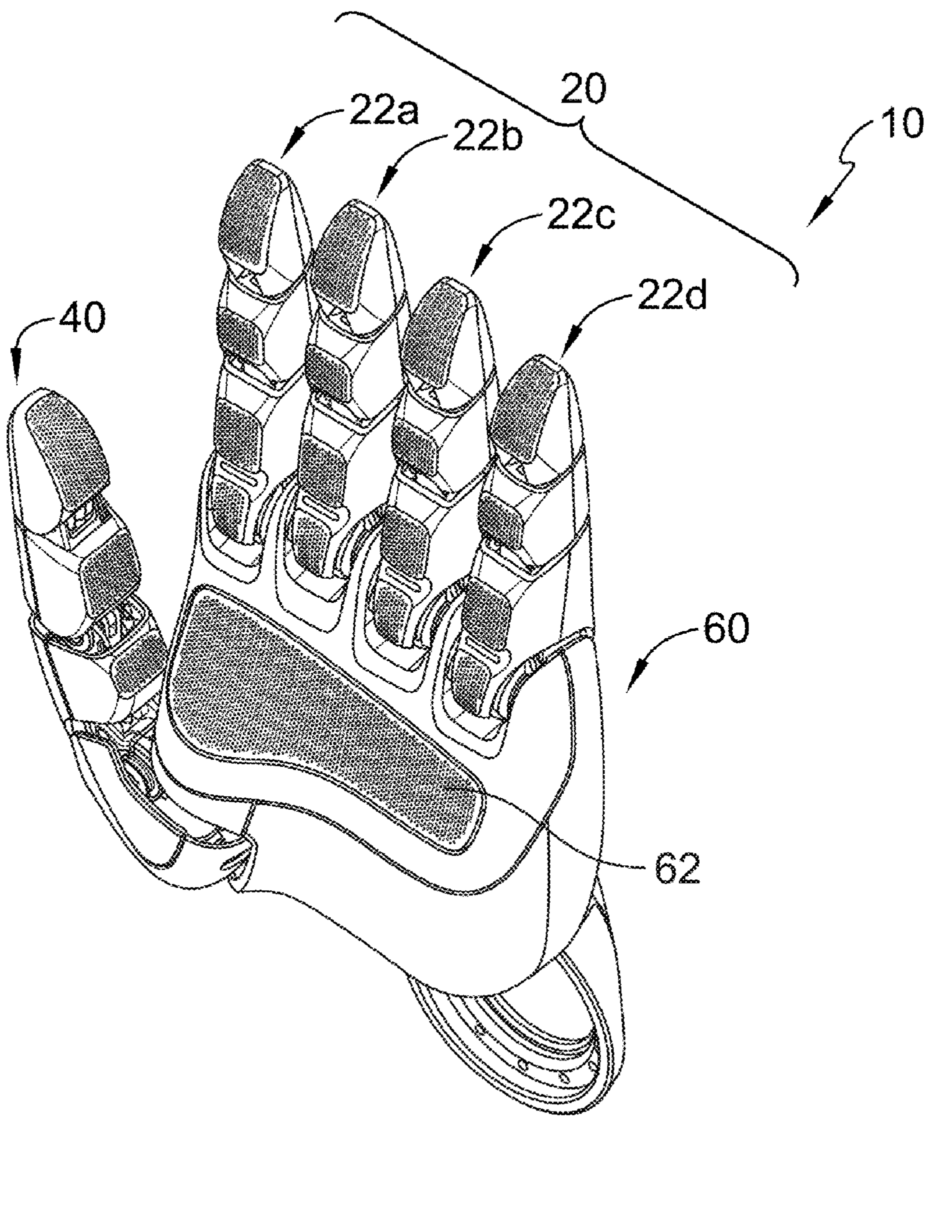
B25J 9/10 (2006.01)

(52) **U.S. Cl.**
CPC ***B25J 15/10*** (2013.01); ***B25J 9/106*** (2013.01)

(57) **ABSTRACT**

A mechanical end effector for a humanoid robot includes a plurality of identical finger assemblies. Each of the finger assemblies is removably connected to a frame. Each of the finger assemblies is fully self-contained and operable independently of every other one of the finger assemblies and independently of every other component connected to the frame. Each of the finger assemblies includes a single electric motor and is configured to be fully operable using only the single electric motor.



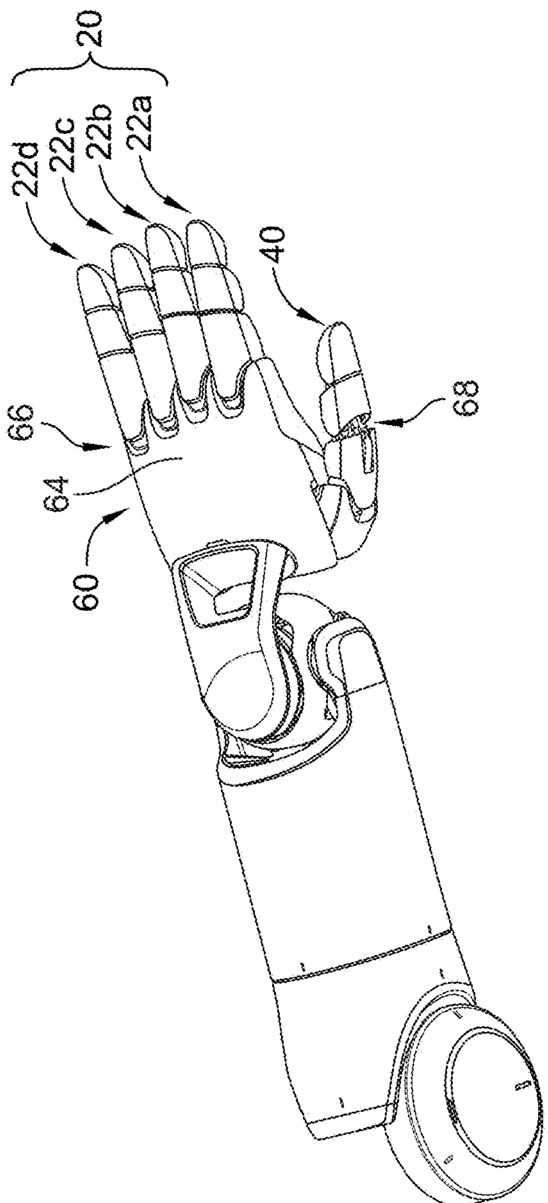


FIG. 2

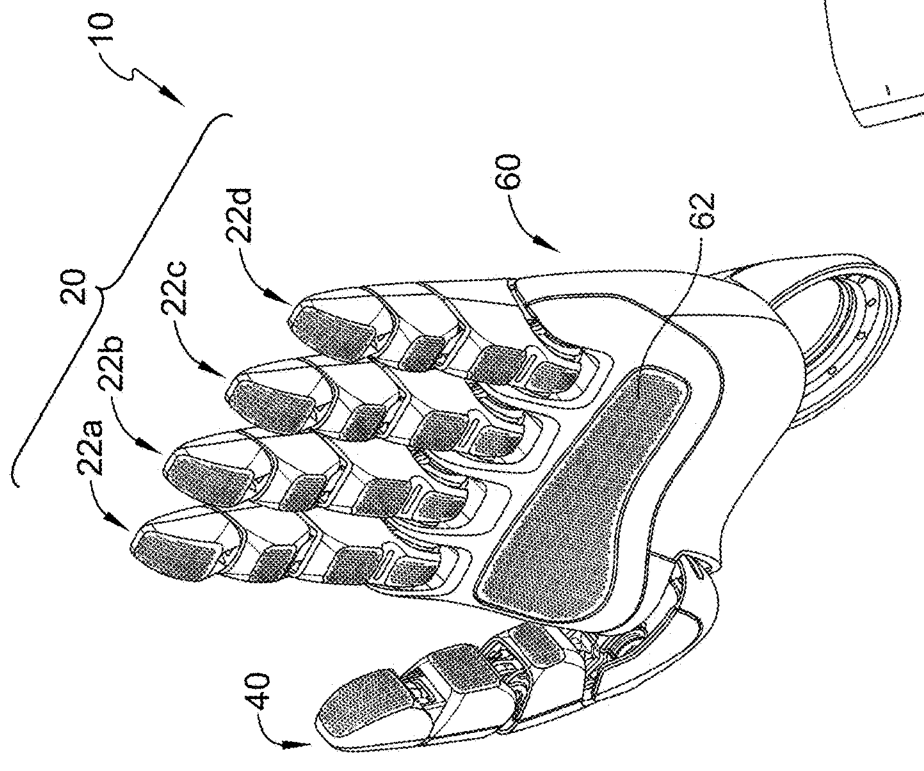


FIG. 1

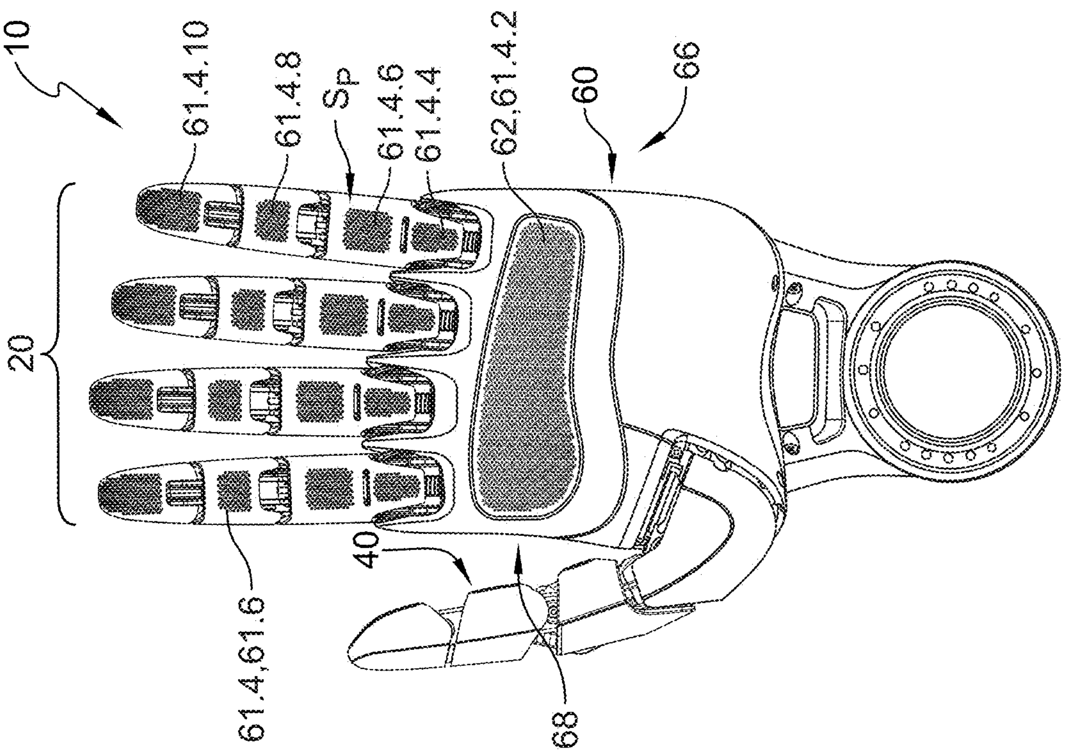

10
20
61.4.10
61.4.8
S_P
61.4.6
61.4.4
62,61.4.2
60
66
40
61.4,61.6
68

FIG. 3

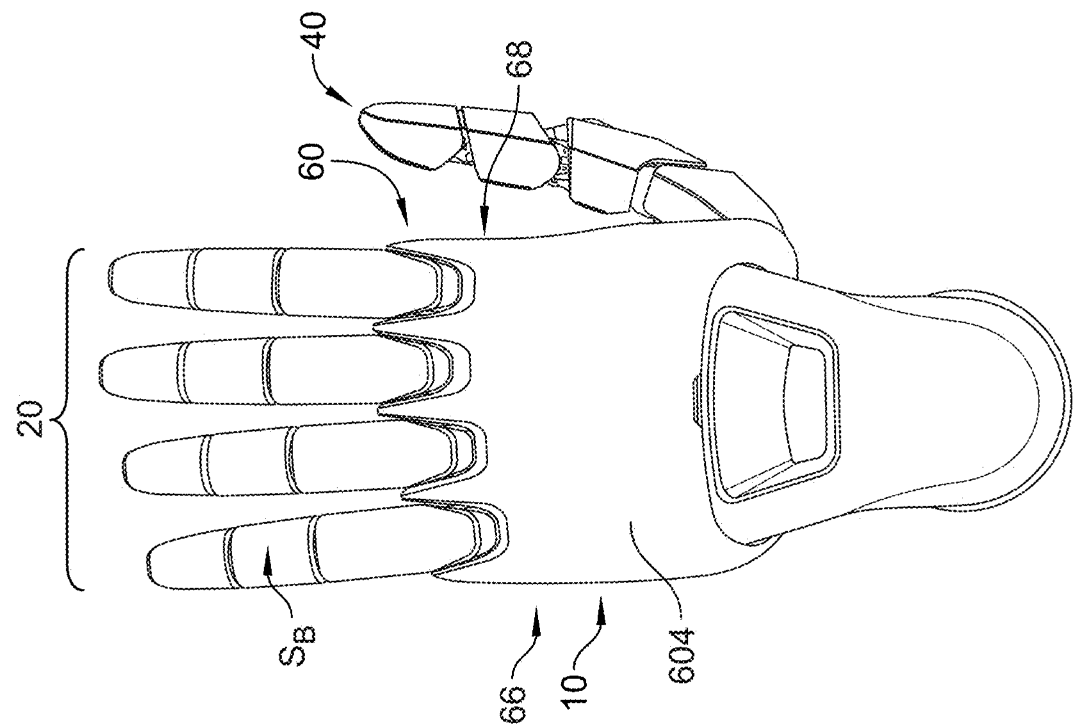

20
40
68
60
S_B
66
10
604

FIG. 4

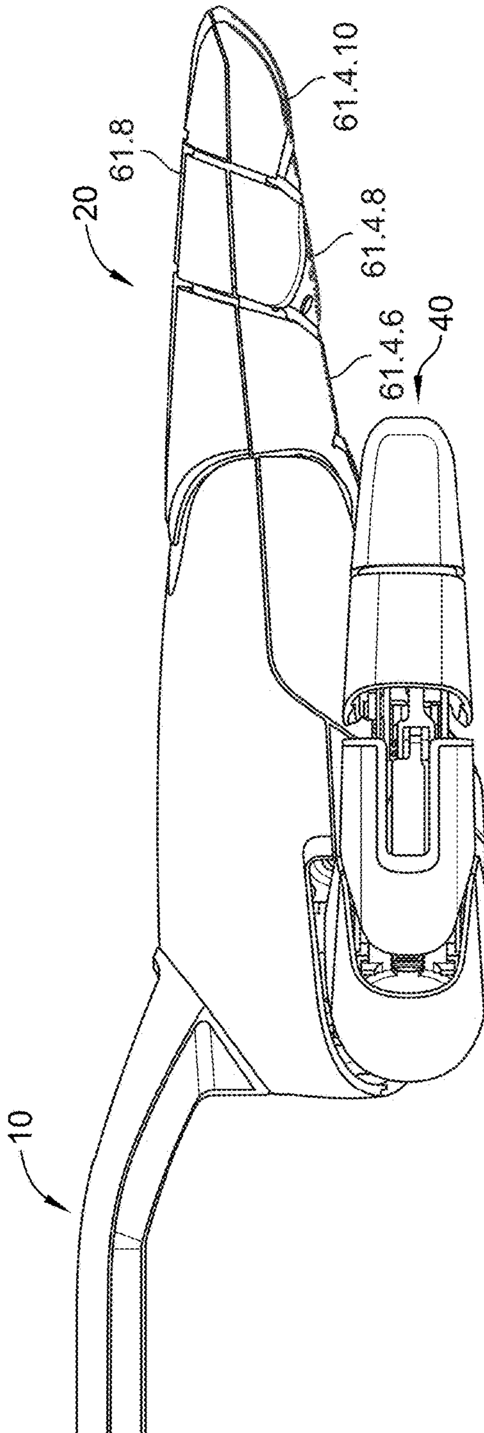

20
61.8
61.4.10
61.4.8
61.4.6
40
10

FIG. 5

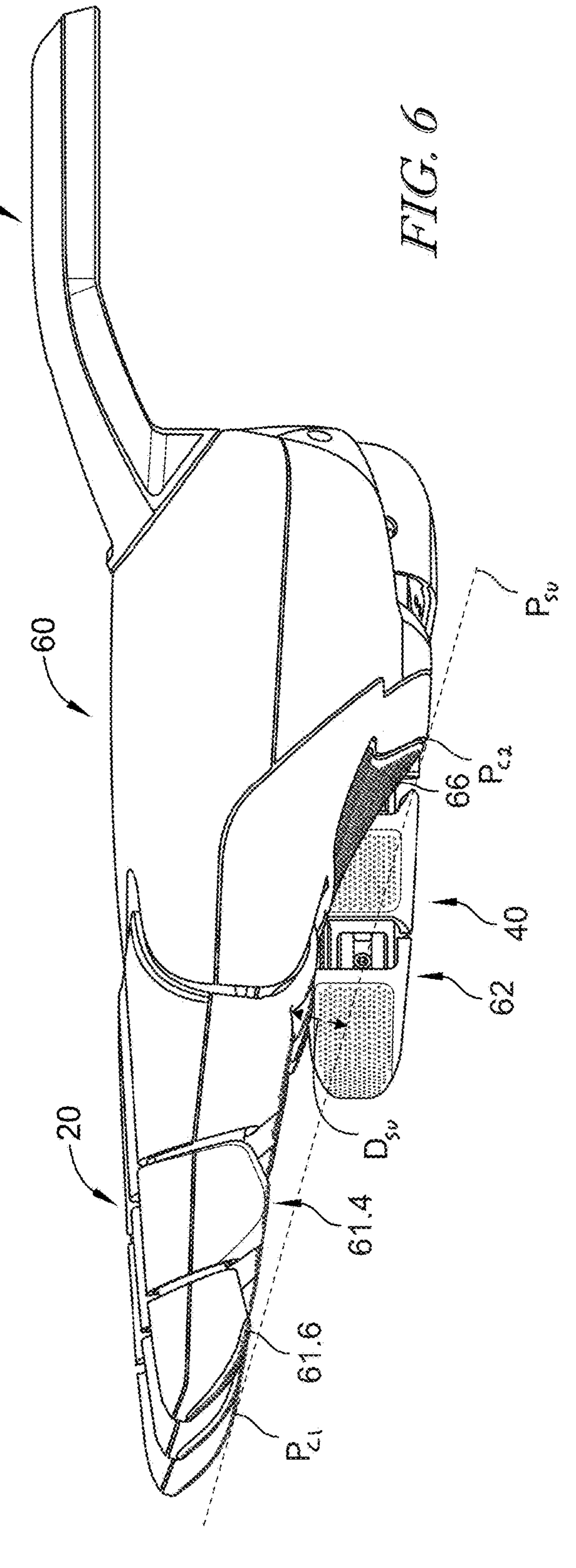

10
60
P_{sv}
P_{c2}
66
40
62
D_{sv}
20
61.4
61.6
P_{c1}

FIG. 6

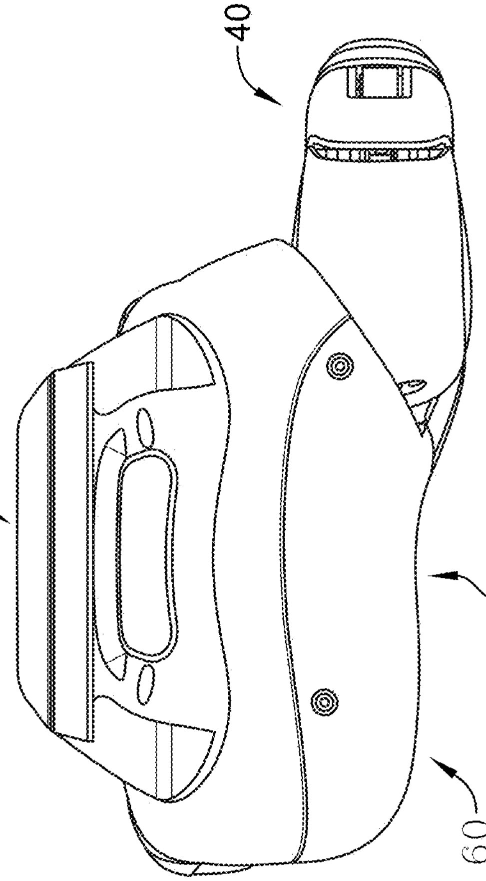


FIG. 7

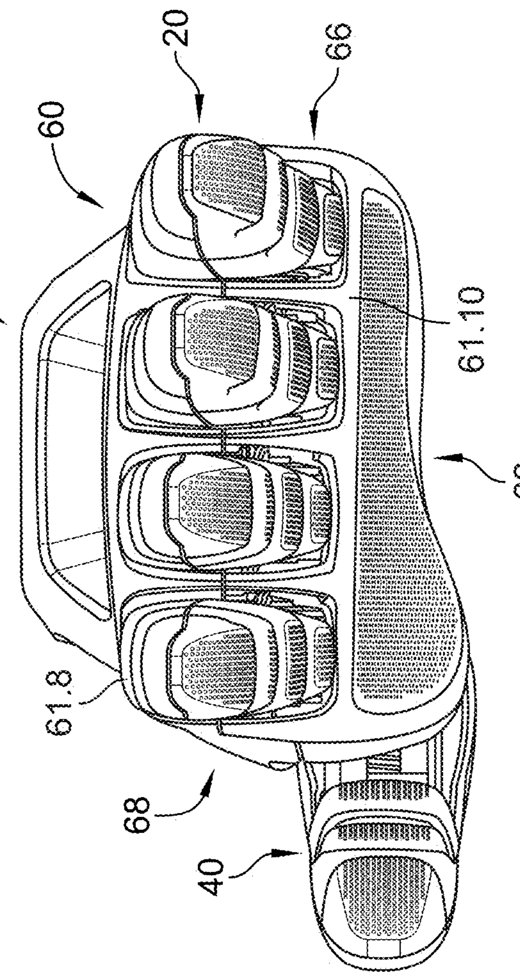


FIG. 8

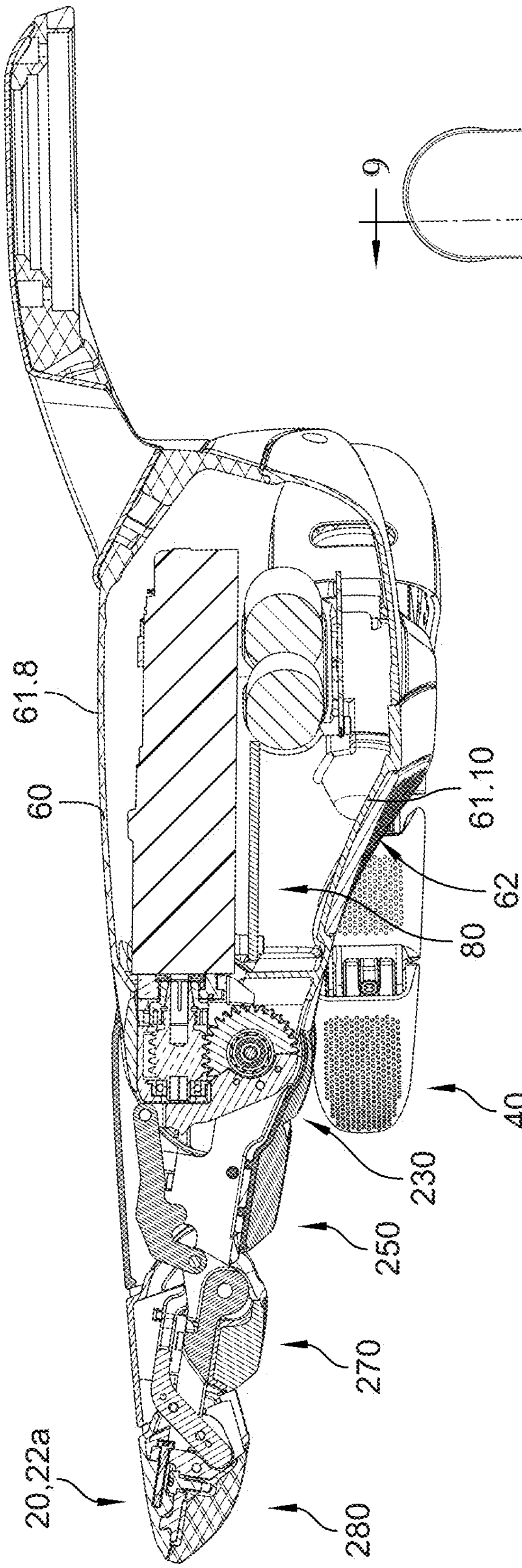


FIG. 9

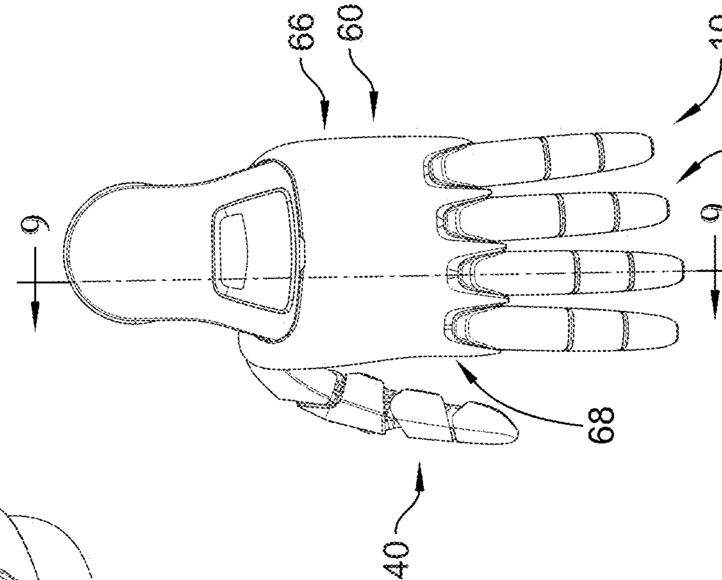


FIG. 10

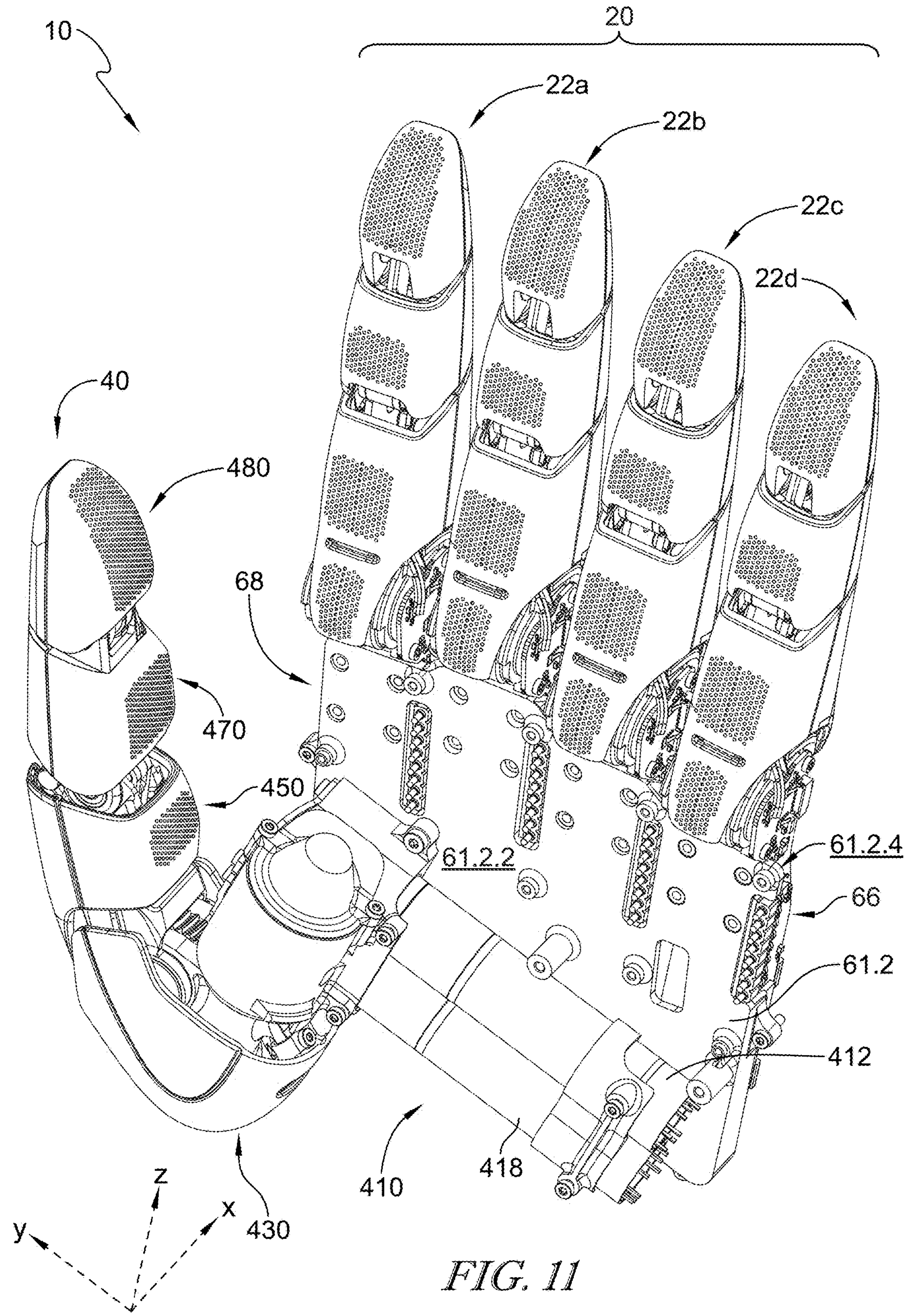

10
20
22a
22b
22c
22d
40
480
470
450
68
61.2.2
61.2.4
66
61.2
412
410
418
430
z
x
y

FIG. 11

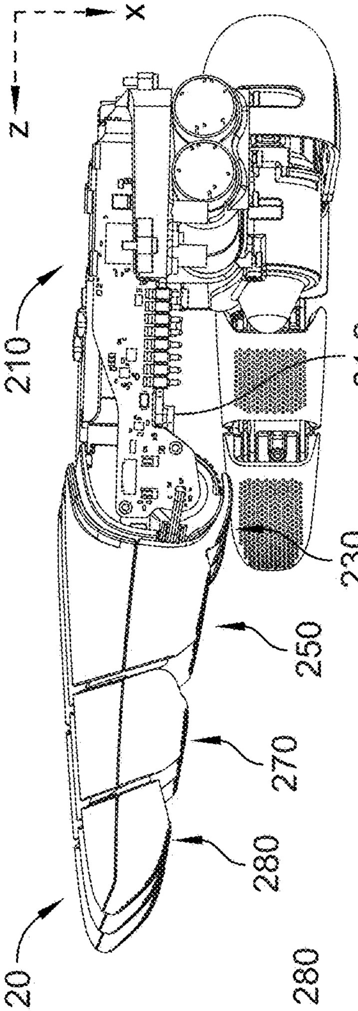

x
z
210
61.2
40
230
250
270
280
20

FIG. 13

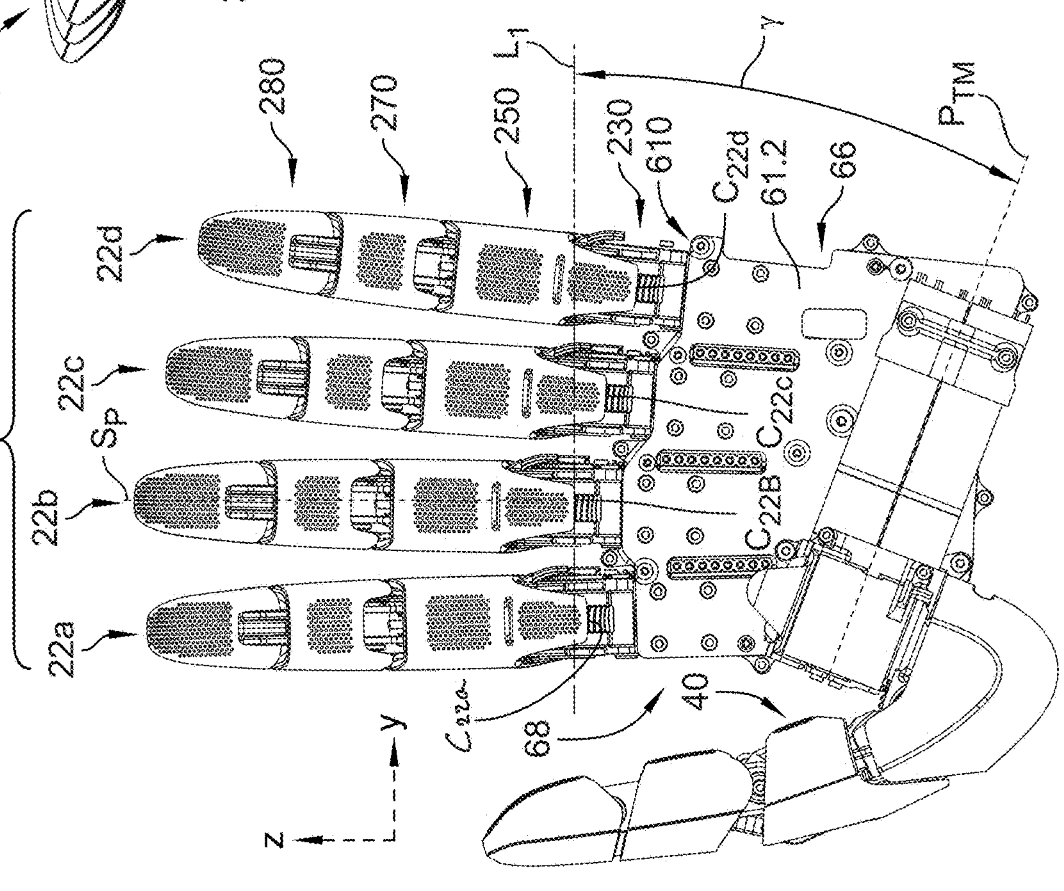
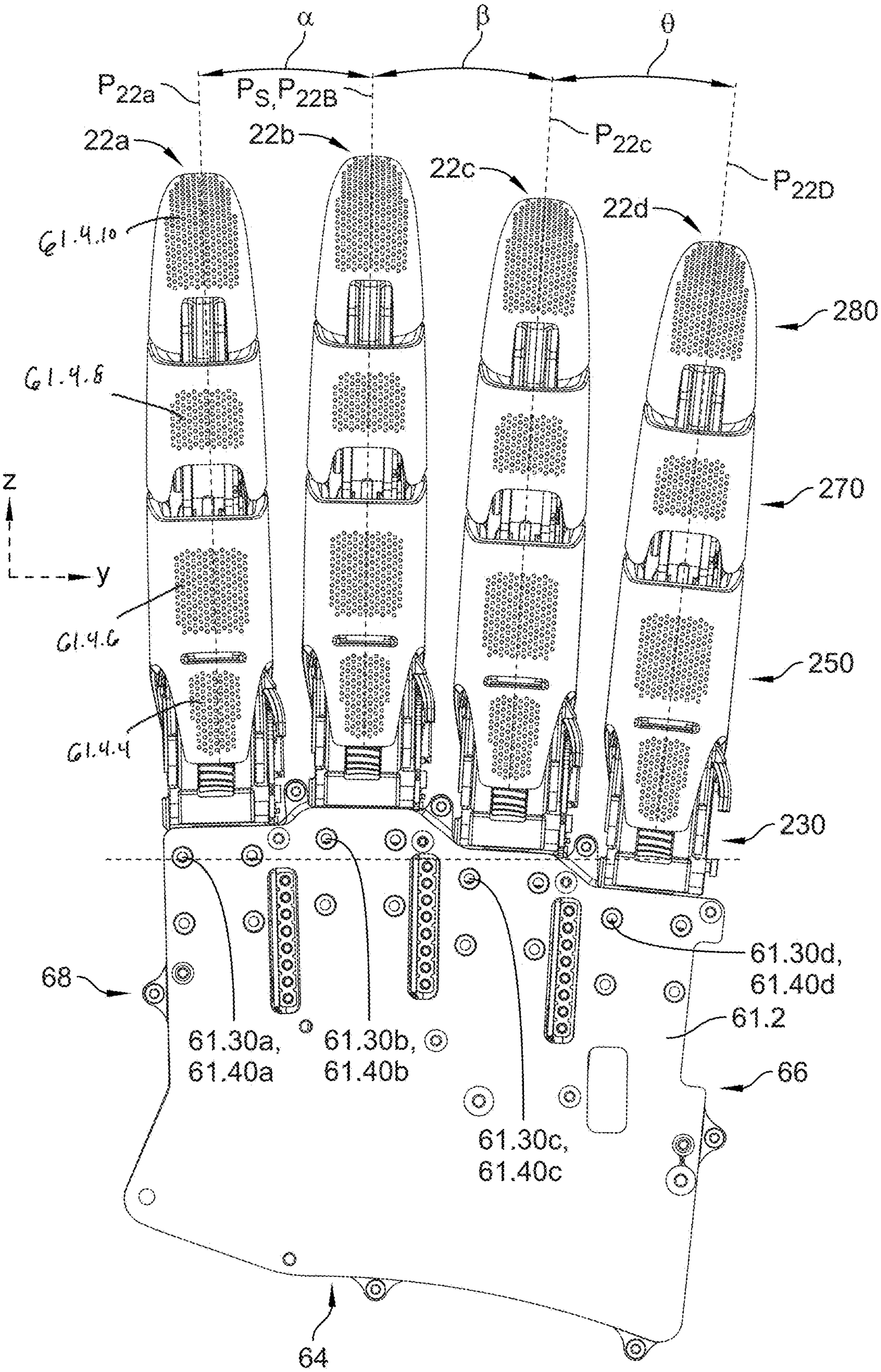
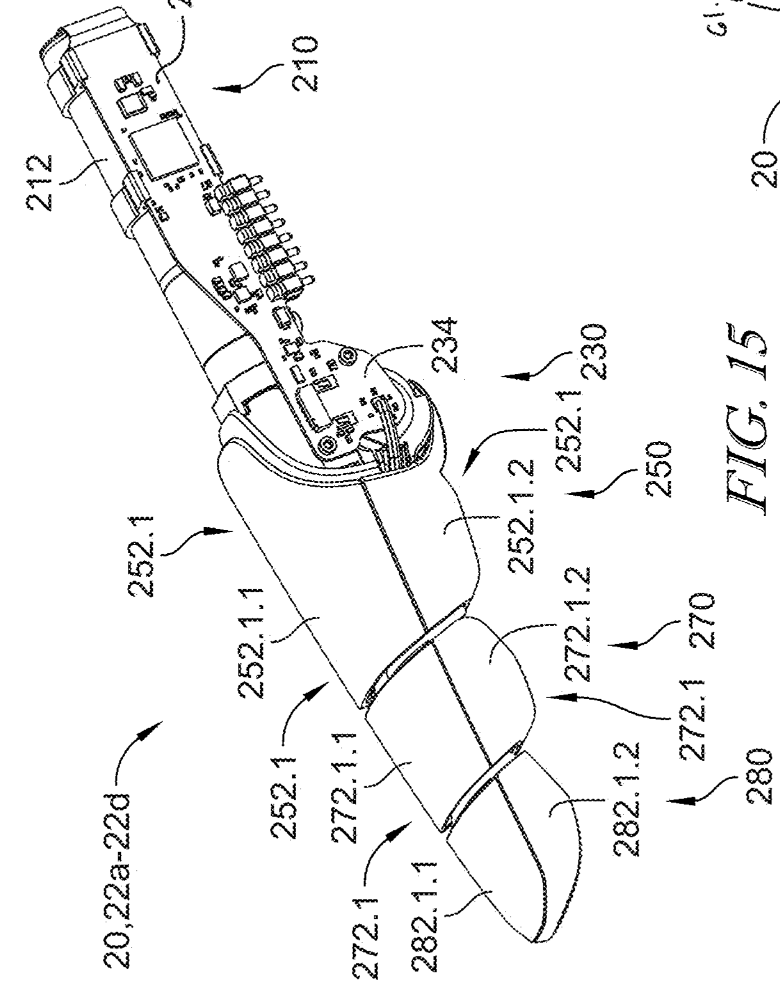

20
22a
22b
22c
22d
S_P
280
270
250
230
610
L_1
γ
P_{TM}
C_{22d}
61.2
66
C_{22c}
C_{22B}
C_{22a}
68
40
y
z

FIG. 12



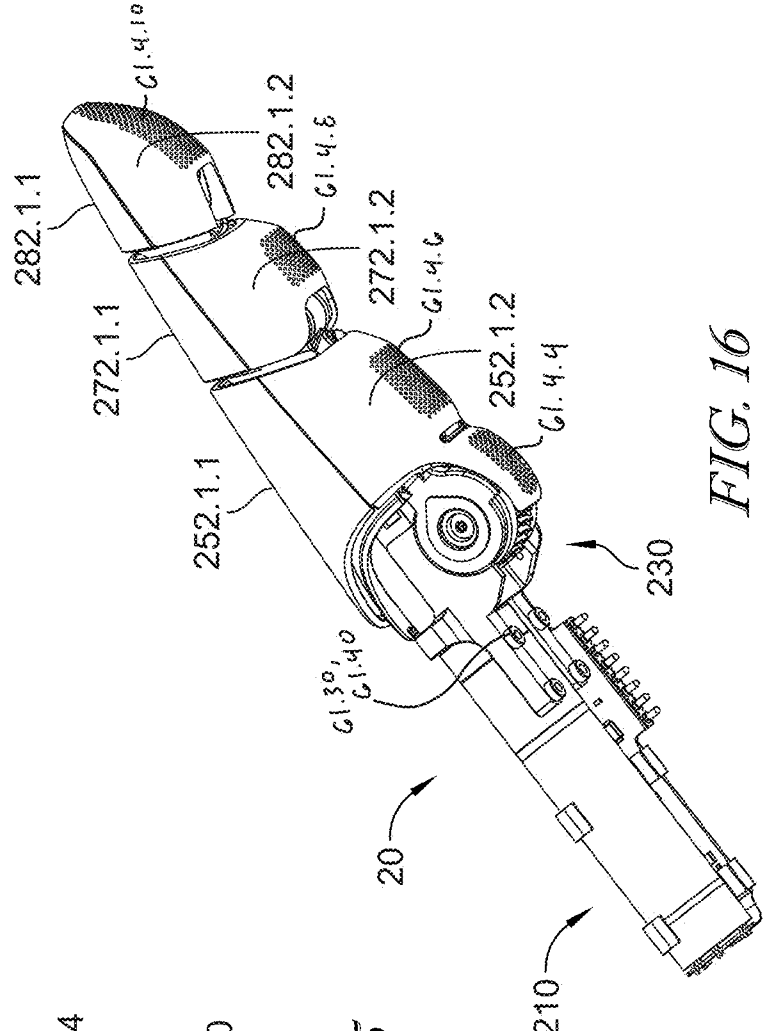
α
β
θ
P_{22a}
P_S, P_{22B}
P_{22c}
P_{22D}
22a
22b
22c
22d
61.4.10
61.4.8
61.4.6
61.4.4
280
270
250
230
z
y
68
61.30a,
61.40a
61.30b,
61.40b
61.30c,
61.40c
61.30d,
61.40d
61.2
66
64

FIG. 14



20,22a-22d
212
214
210
234
230
252.1
252.1.1
252.1.2
250
270
272.1
272.1.1
272.1.2
280
282.1.1
282.1.2

FIG. 15



G1.4.10
282.1.2
G1.4.8
282.1.1
272.1.2
G1.4.6
272.1.1
G1.4.4
252.1.2
252.1.1
230
G1.30,
G1.40
20
210

FIG. 16

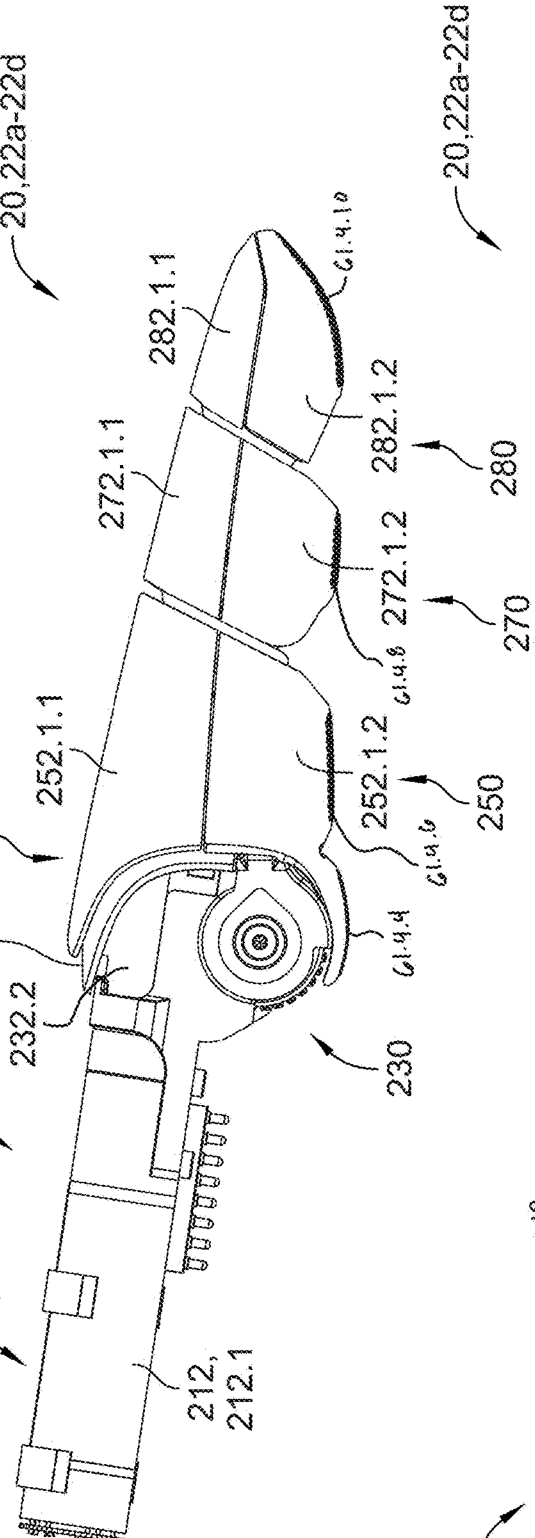


FIG. 17

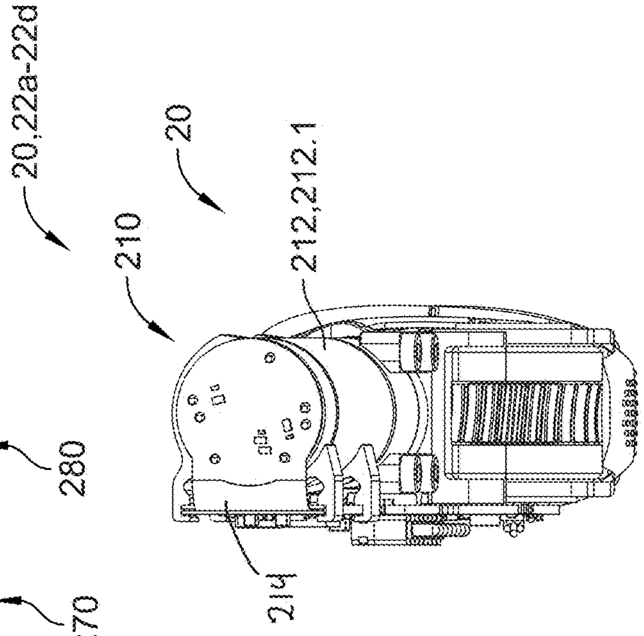


FIG. 19

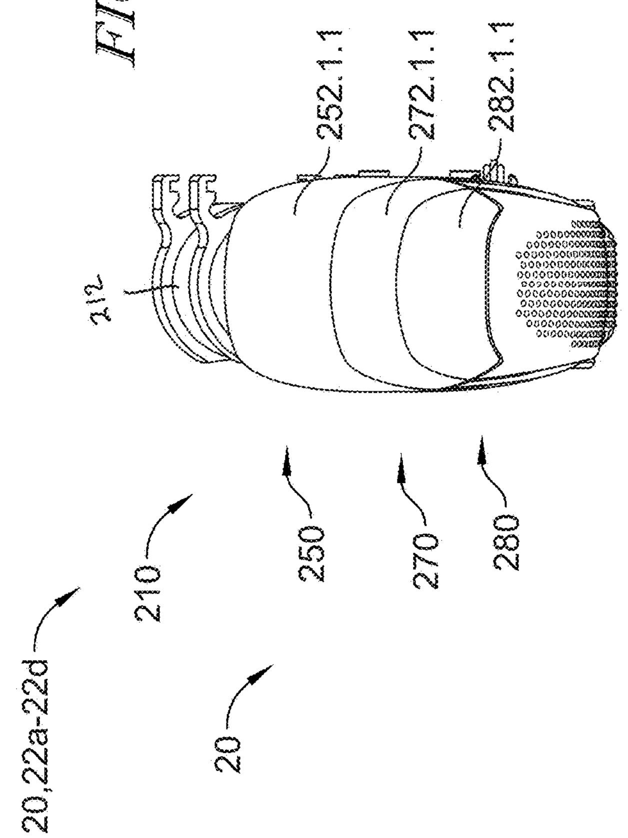
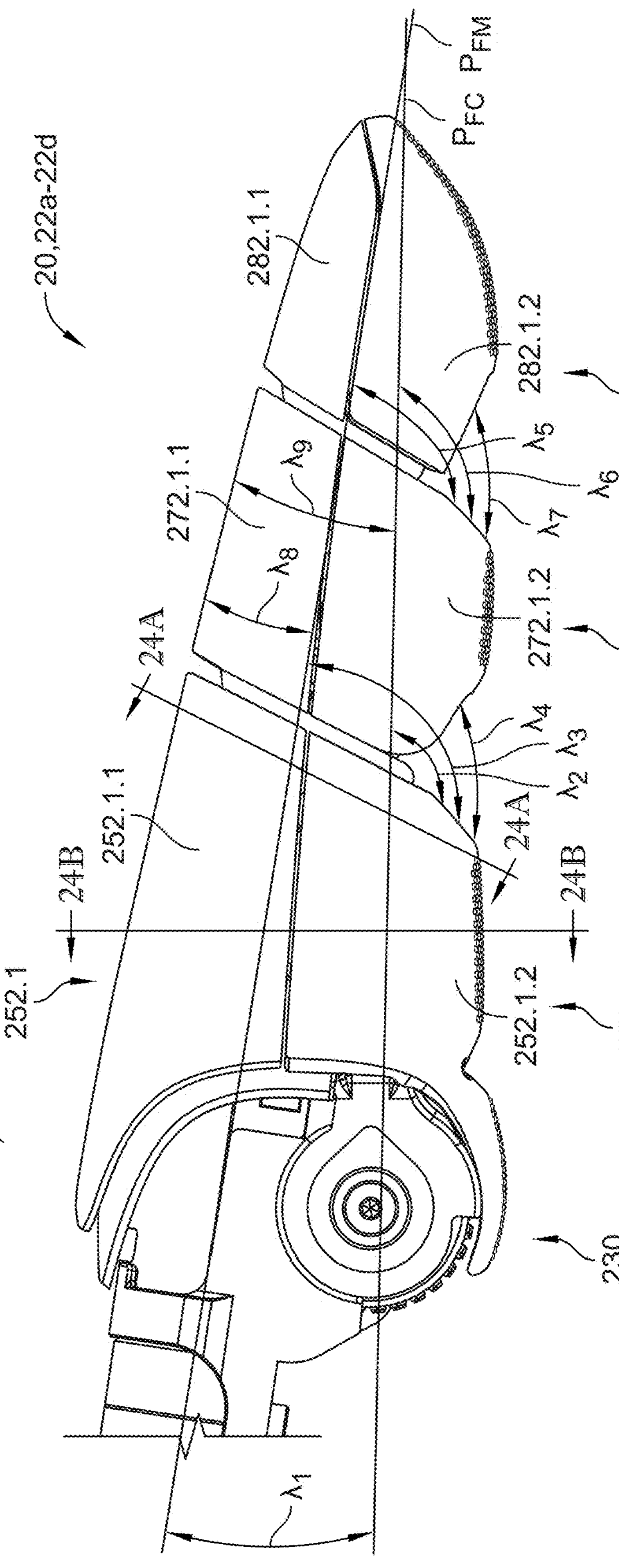


FIG. 18



20,22a-22d
P_{FC} P_{FM}
282.1.1
282.1.2
280
λ_5
λ_6
λ_7
λ_9
272.1.1
λ_8
272.1.2
270
24A
λ_4
λ_3
λ_2
24A
252.1.1
24B
24B
252.1
252.1.2
250
20
230
λ_1

FIG. 20

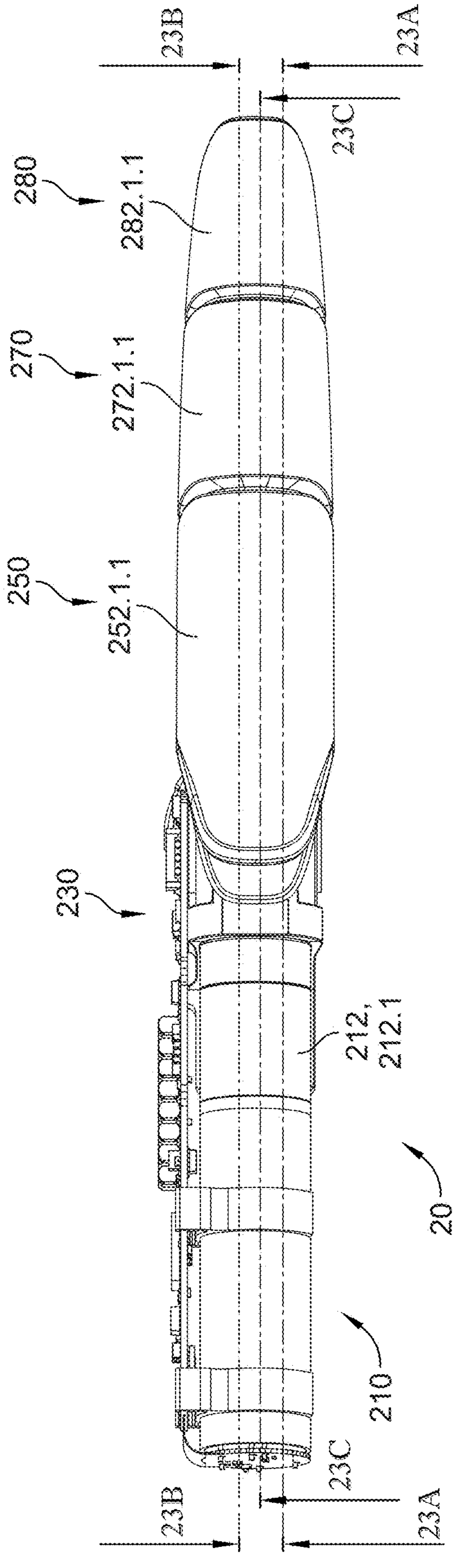

23B
23A
23C
280
282.1.1
270
272.1.1
250
252.1.1
230
212,
212.1
20
210
23C
23B
23A

FIG. 21

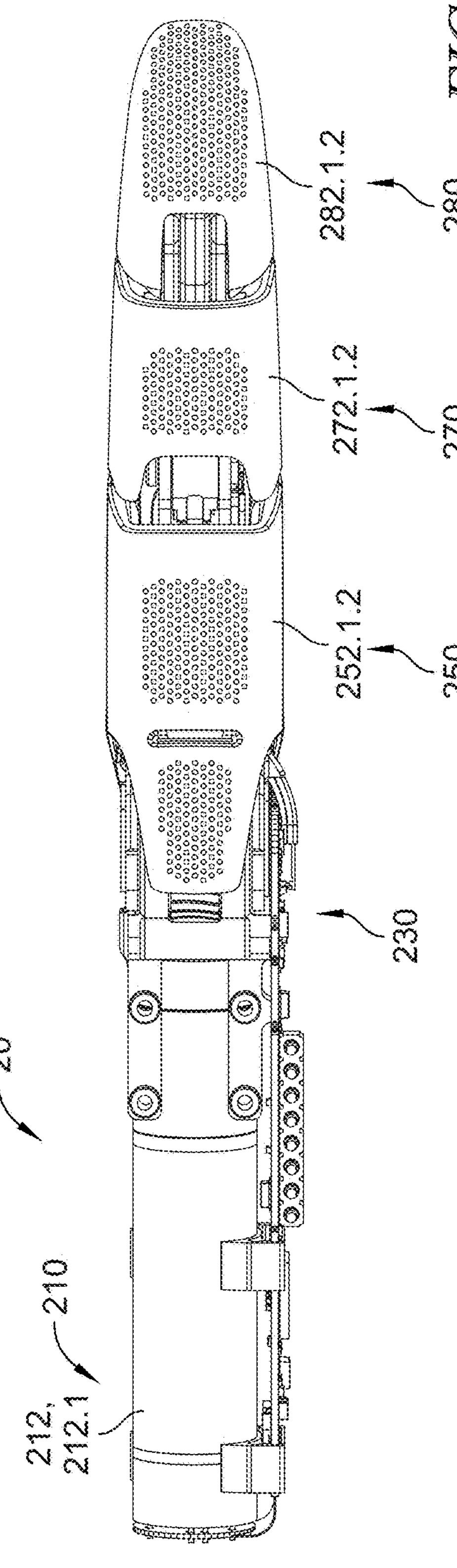

282.1.2
280
272.1.2
270
252.1.2
250
230
20
210
212,
212.1

FIG. 22

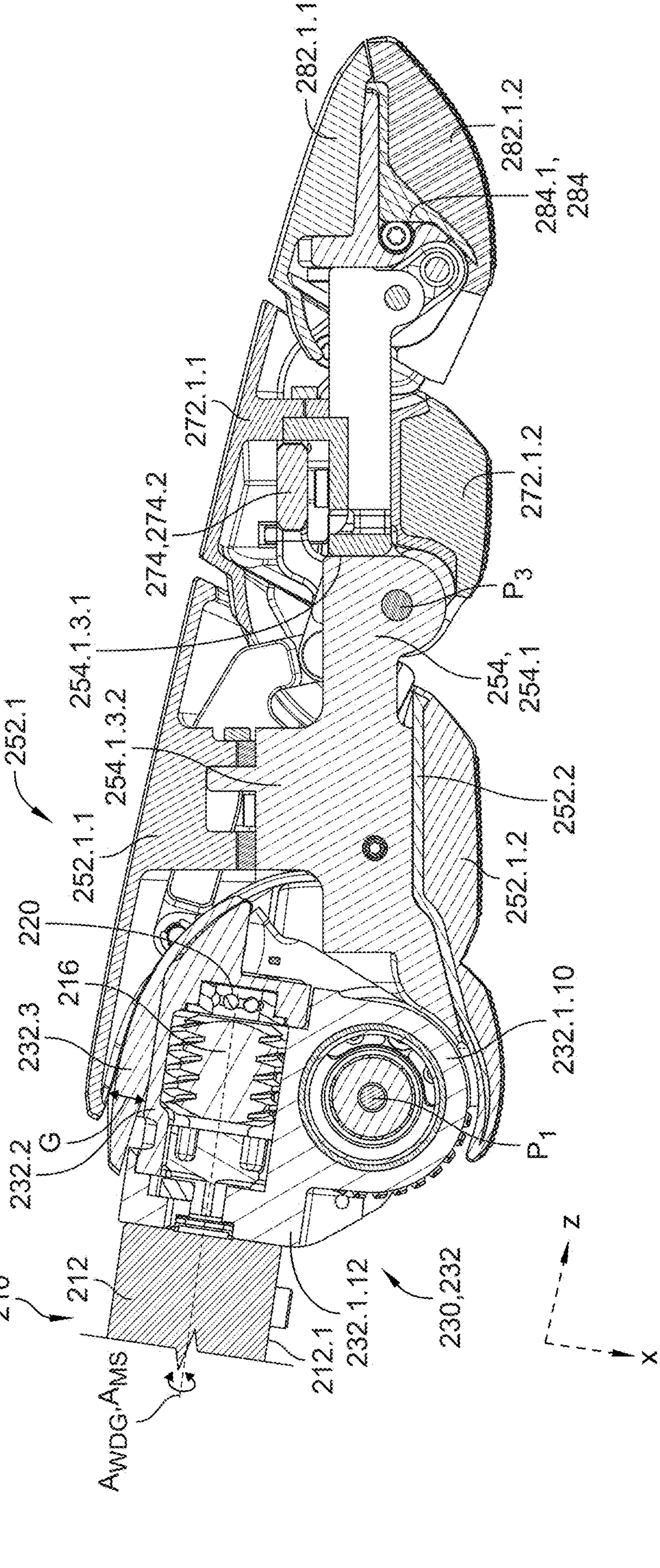
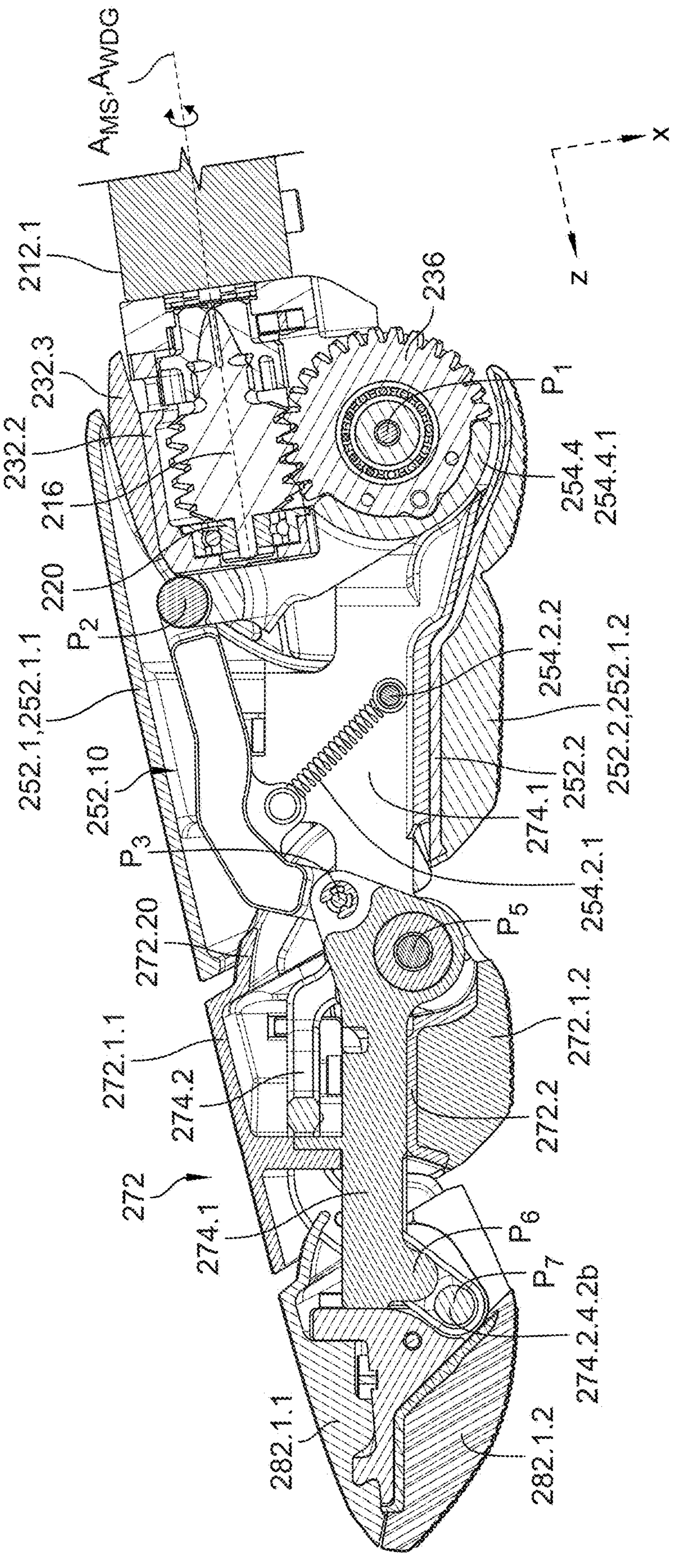

282.1.1
282.1.2
282.1.2
284.1,
284
272.1.1
272.1.2
274,274.2
P3
254.1.3.1
254,
254.1
254.1.3.2
252.1
252.1.1
252.2
252.1.2
220
216
232.3
232.1.10
232.2
G
P1
z
210
212
232.1.12
230,232
x
212.1
AWDG,AMS

FIG. 23A



A_{MS}, A_{WDG}
x
z
212.1
236
232.3
232.2
216
220
P_1
254.4
254.4.1
P_2
252.1,252.1.1
254.2.2
252.2,252.1.2
252.10
252.2
274.1
P_3
254.2.1
P_5
272.20
272.1.2
272.1.1
274.2
272.2
272
274.1
P_6
P_7
274.2.4.2b
282.1.1
282.1.2

FIG. 23B

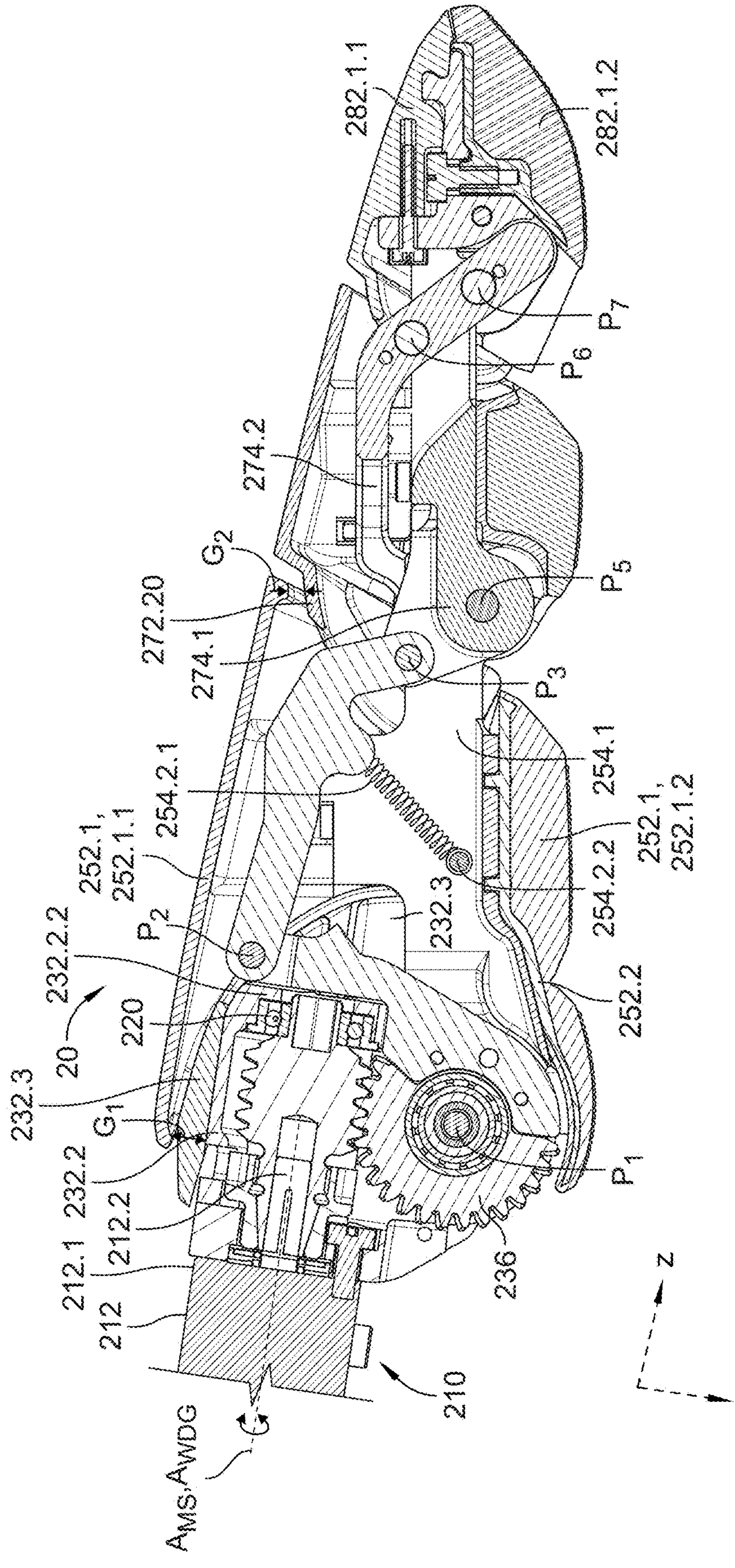

282.1.1
282.1.2
P_7
P_6
274.2
G_2
P_5
272.20
274.1
P_3
254.1
254.2.1
252.1,
252.1.1
252.1,
252.1.2
254.2.2
232.3
P_2
232.2.2
20
220
252.2
232.3
G_1
P_1
232.2
212.2
212.1
236
212
z
210
x
A_{MS},A_{WDG}

FIG. 23C

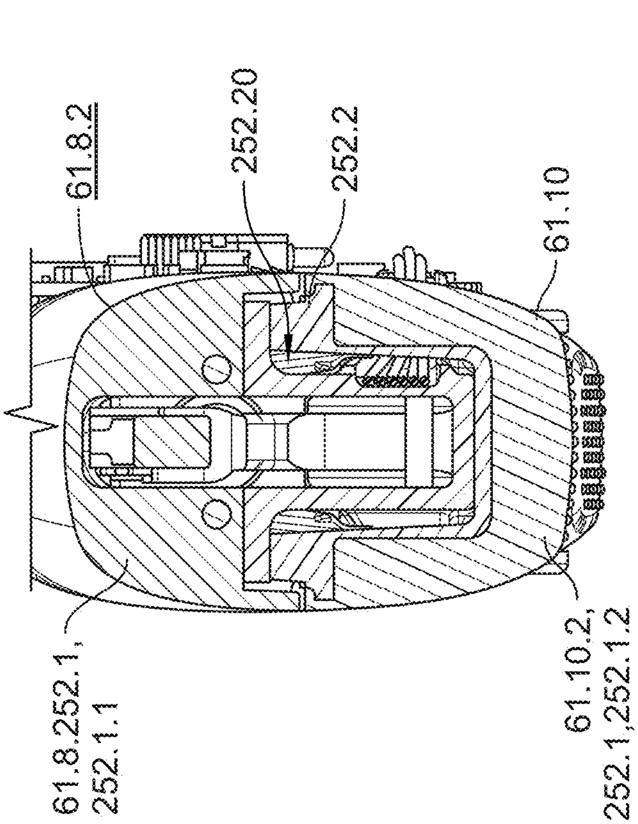


FIG. 24B

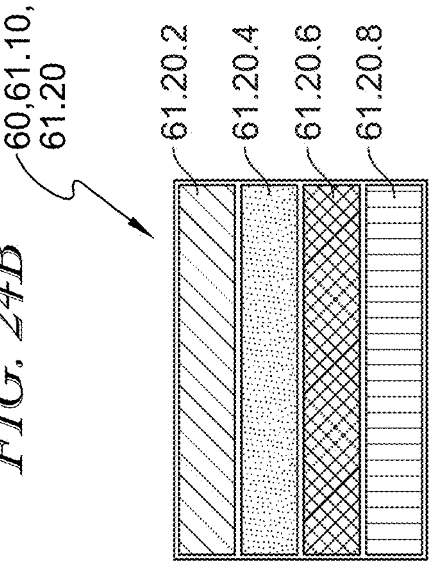


FIG. 25

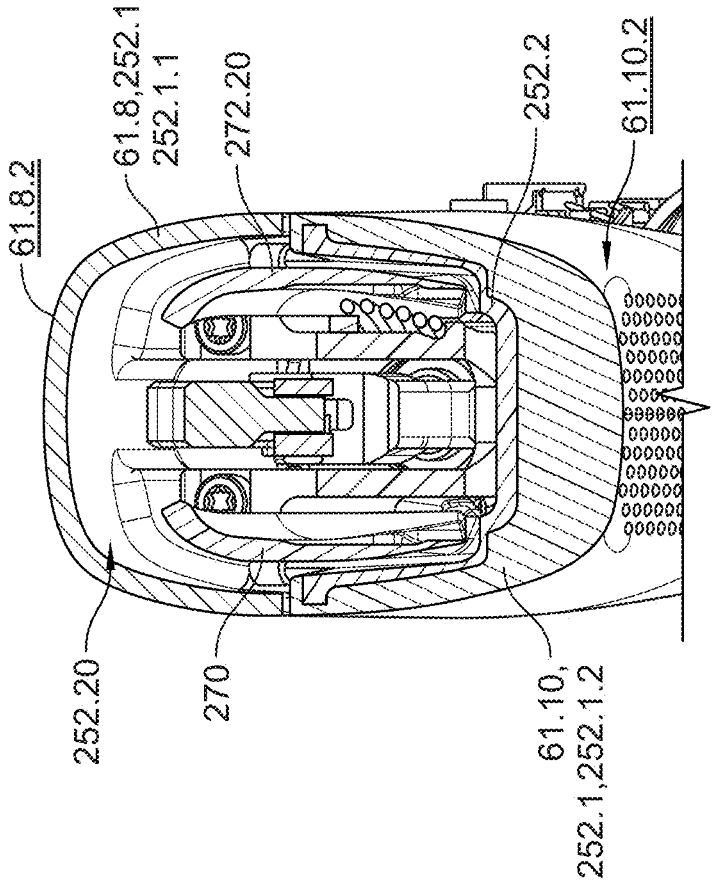
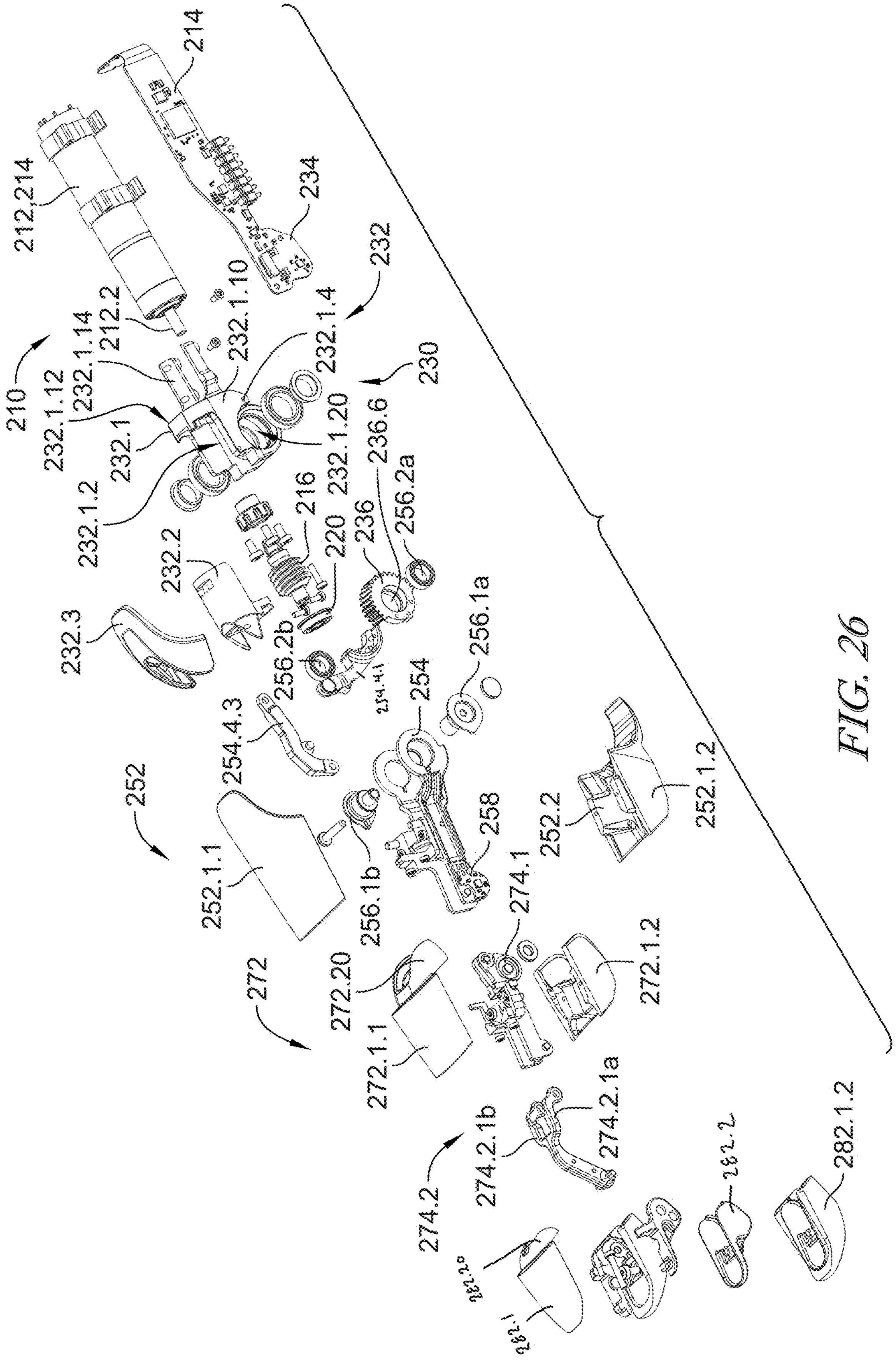


FIG. 24A



210
212.214
214
234
232
232.1.10
232.1.4
212.2
232.1.14
232.1.12
232.1
232.1.2
232.1.20
230
236.6
236
256.2a
216
220
232.2
232.3
256.2b
254.4.1
256.1a
254
254.4.3
252
252.1.1
256.1b
258
252.2
252.1.2
274.1
272
272.20
272.1.1
272.1.2
274.2.1a
274.2.1b
274.2
282.2.0
282.1
282.2
282.1.2

FIG. 26

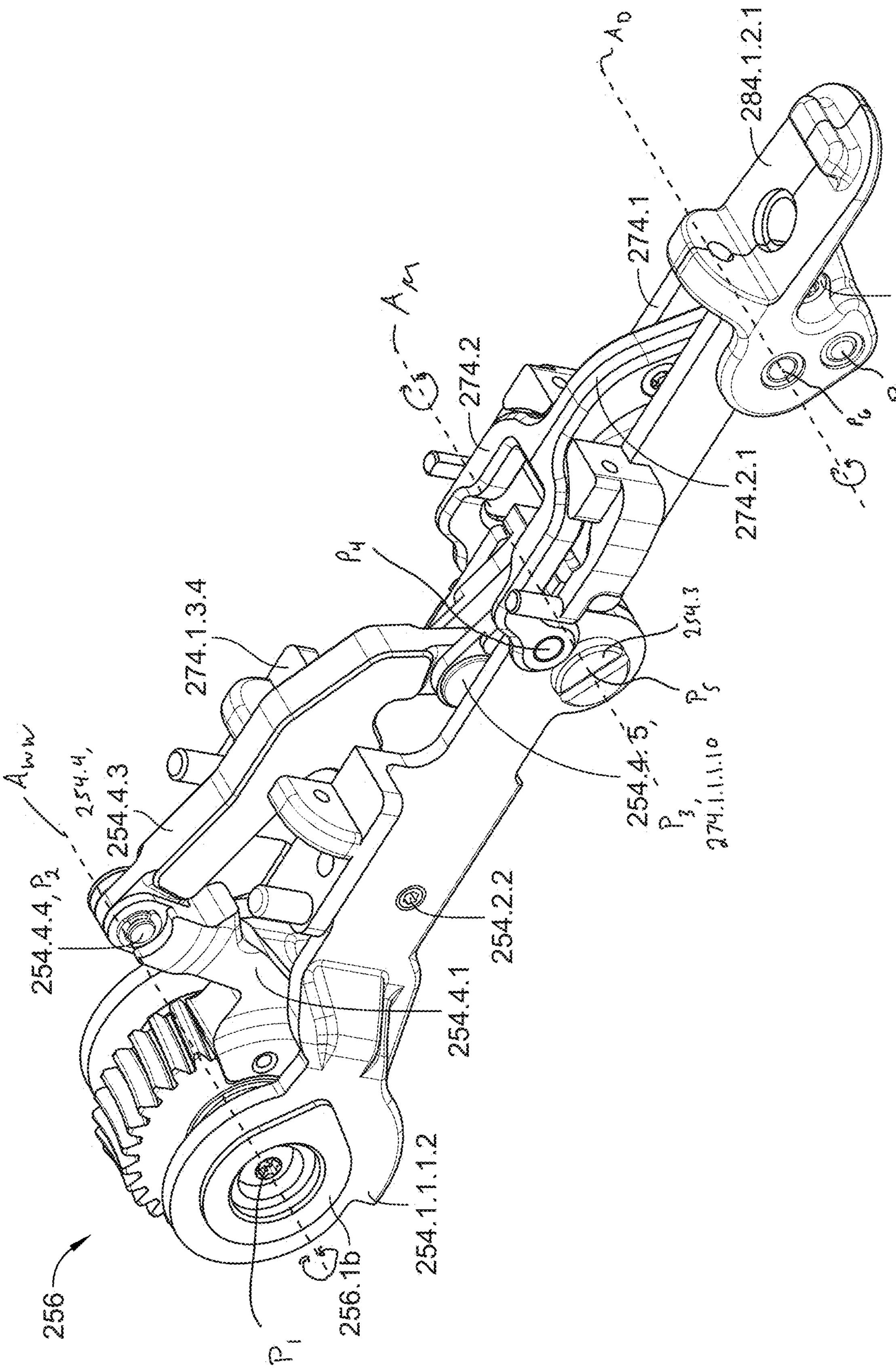

256
256.1b
254.1.1.1.2
254.4.1
254.4.4, P2
254.2.2
254.4.3
254.4,
274.1.3.4
254.4.5,
274.2
274.2.1
274.1
284.1.2.1
284.1.2.2
254.3

FIG. 27

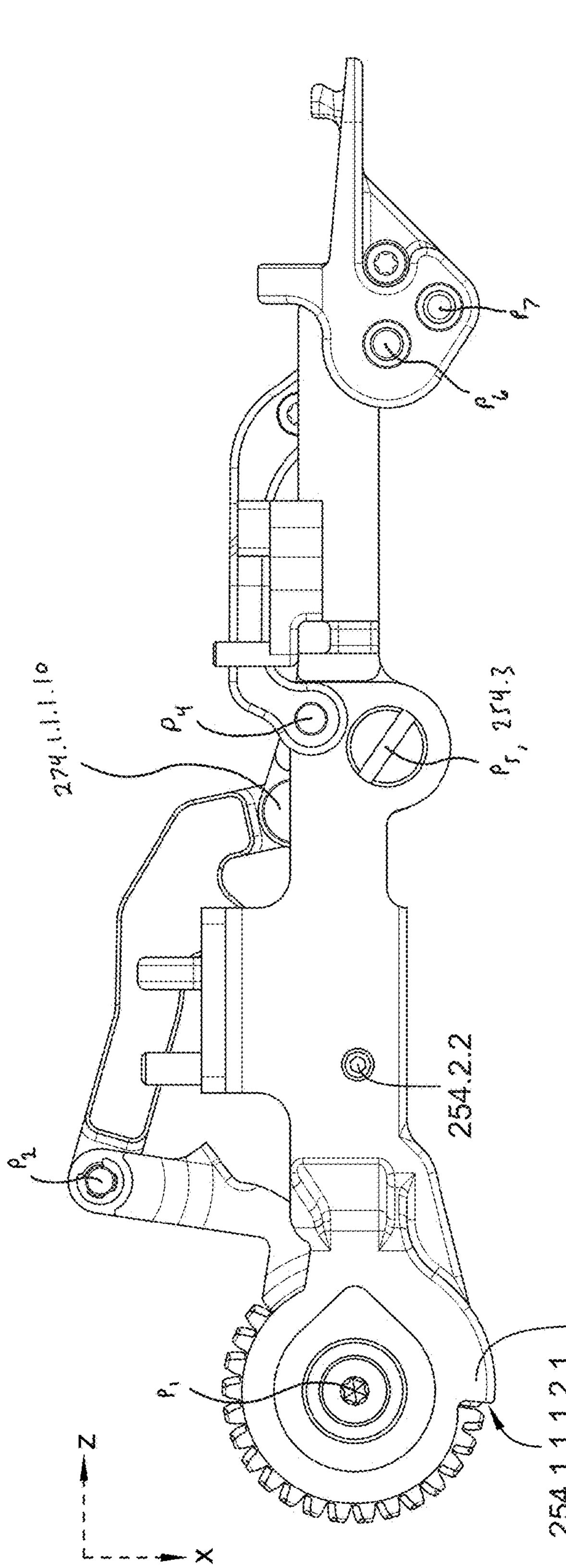

254.2.2
z
x

FIG. 28

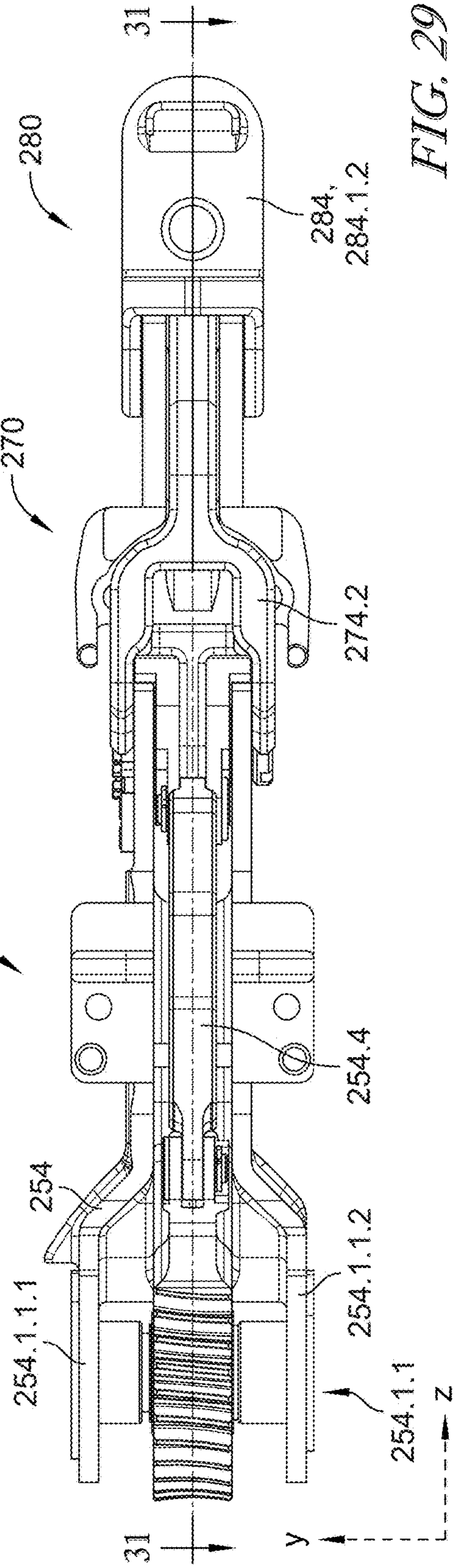

31
280
284,
284.1.2
270
274.2
250
254.4
254
254.1.1.2
254.1.1.1
254.1.1
z
y
31

FIG. 29

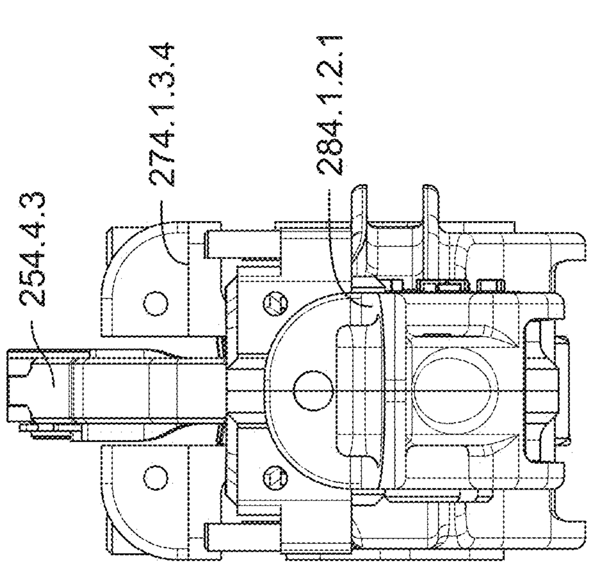

254.4.3
274.1.3.4
284.1.2.1

FIG. 30

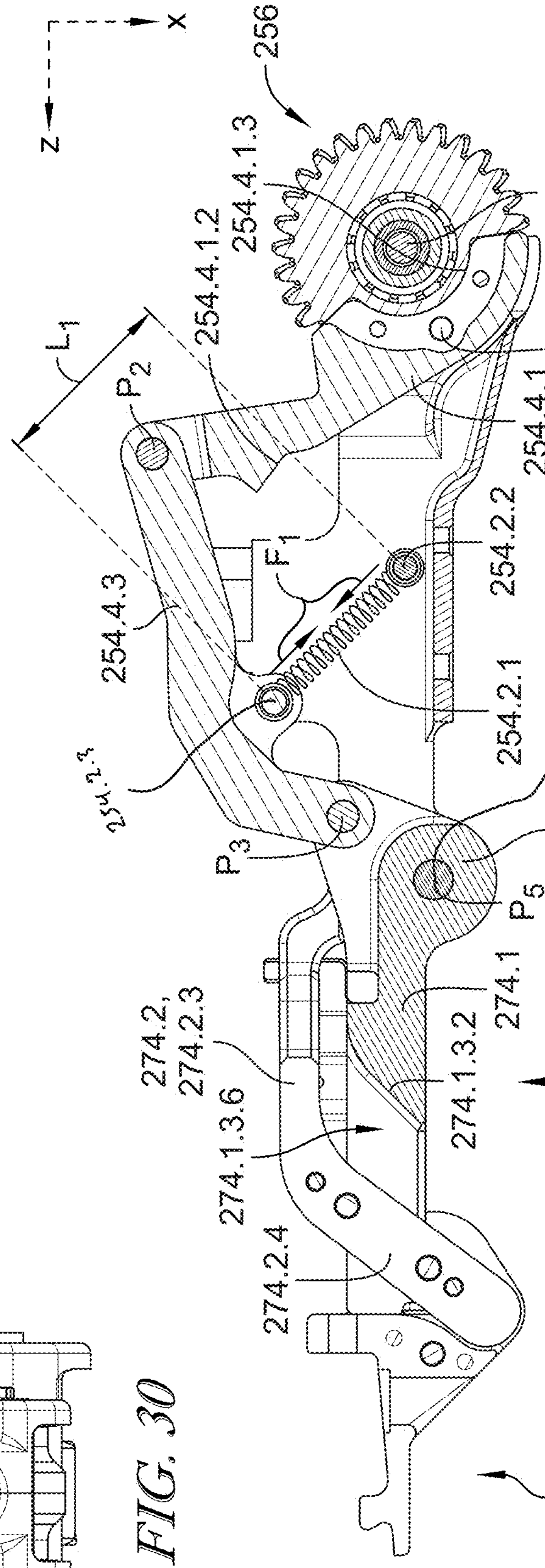

X
Z
256
254.4.1.3
254.4.1.2
P_1
L_1
P_2
254.4.2
254.4.1
254.2.2
F_1
254.4.3
254.2.1
254.3
254.2.3
P_3
274.1.1
P_5
274.1
274.2,
274.2.3
274.1.3.2
274.1.3.6
274
274.2.4
284

FIG. 31

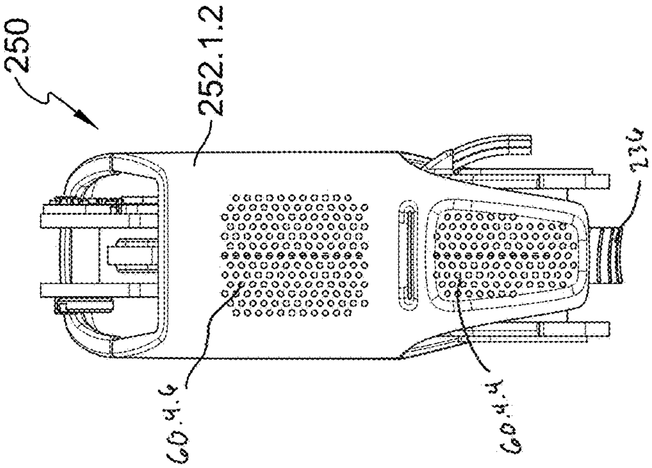


FIG. 33

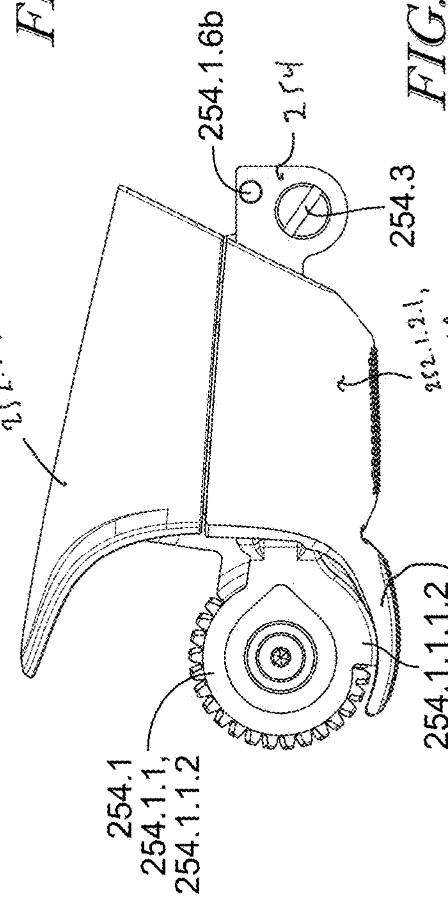


FIG. 34

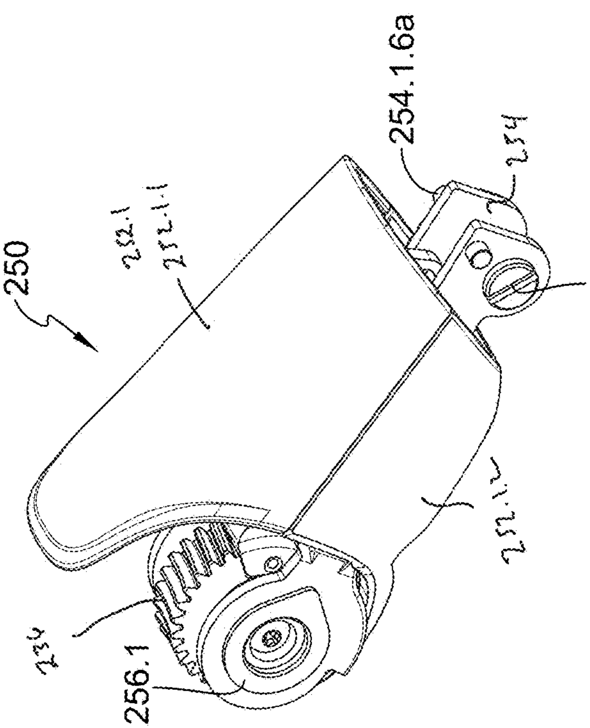


FIG. 32

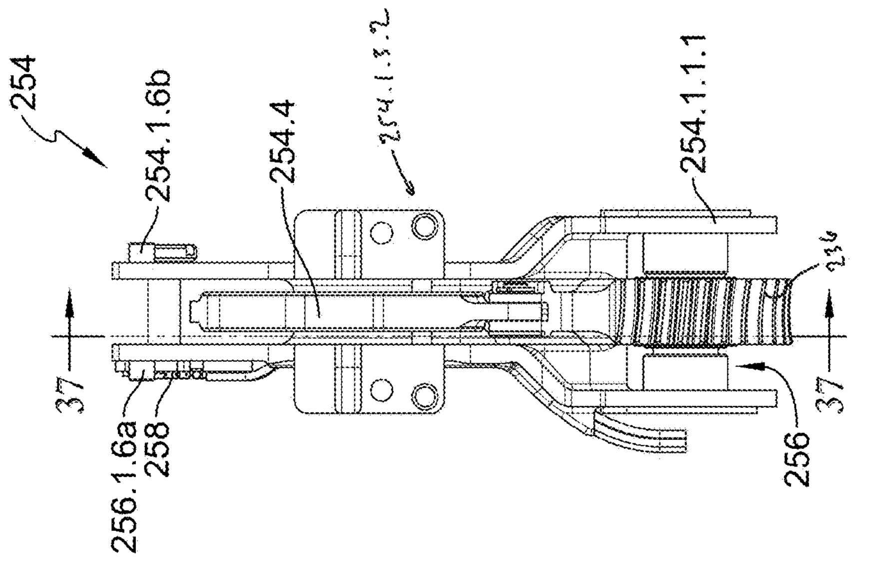


FIG. 36

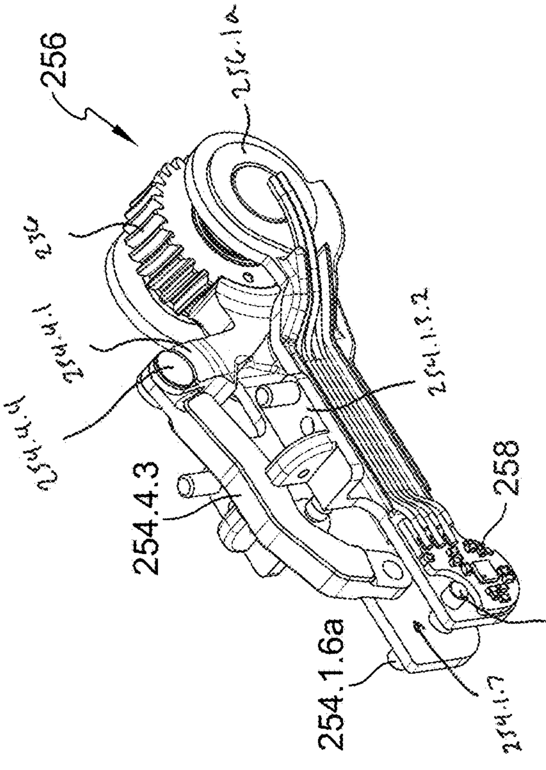


FIG. 35

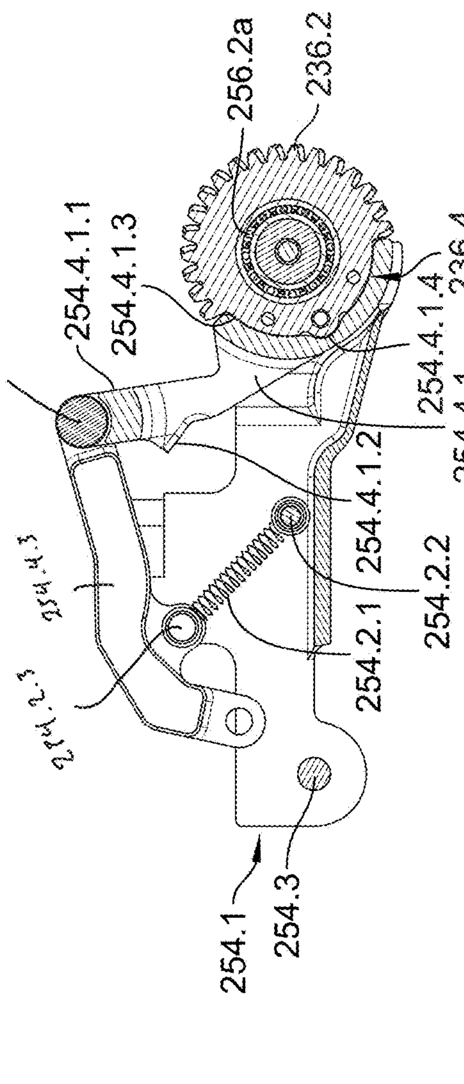


FIG. 37

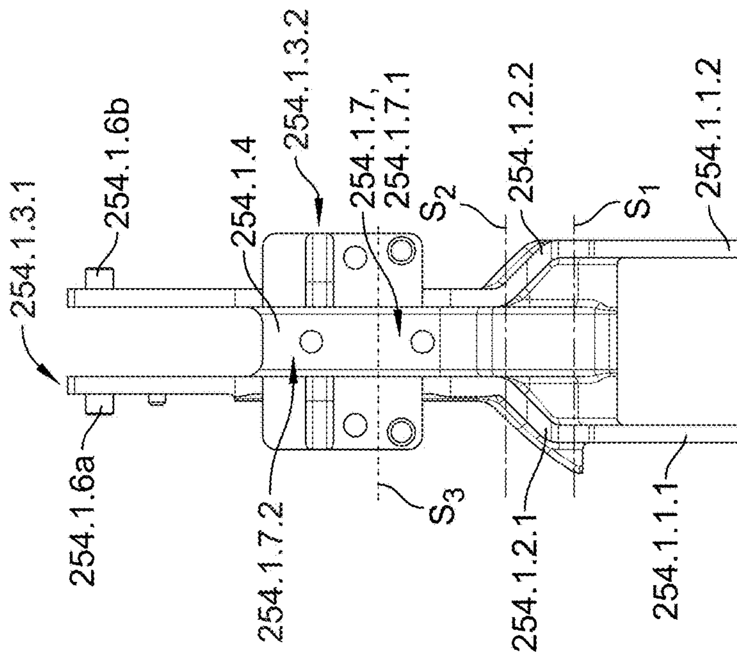


FIG. 39

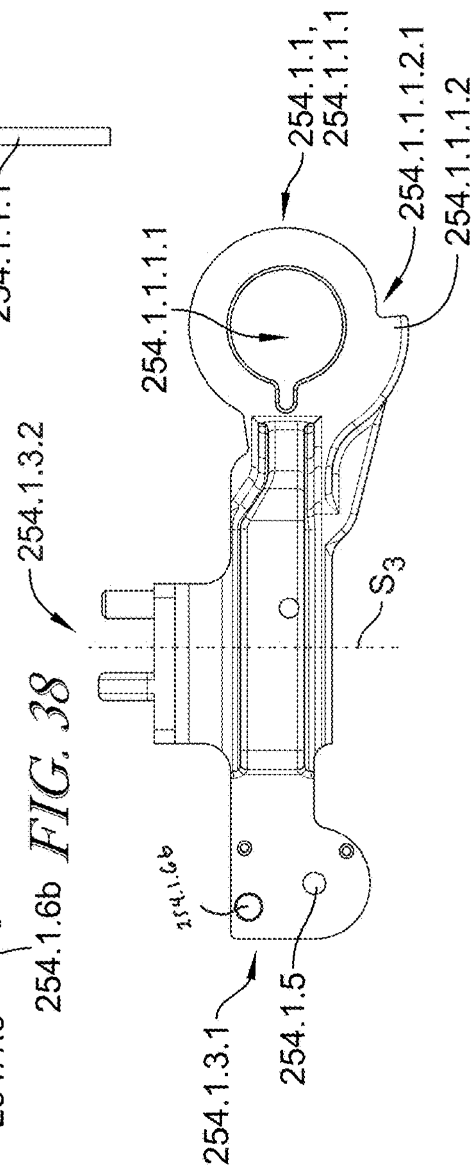


FIG. 40

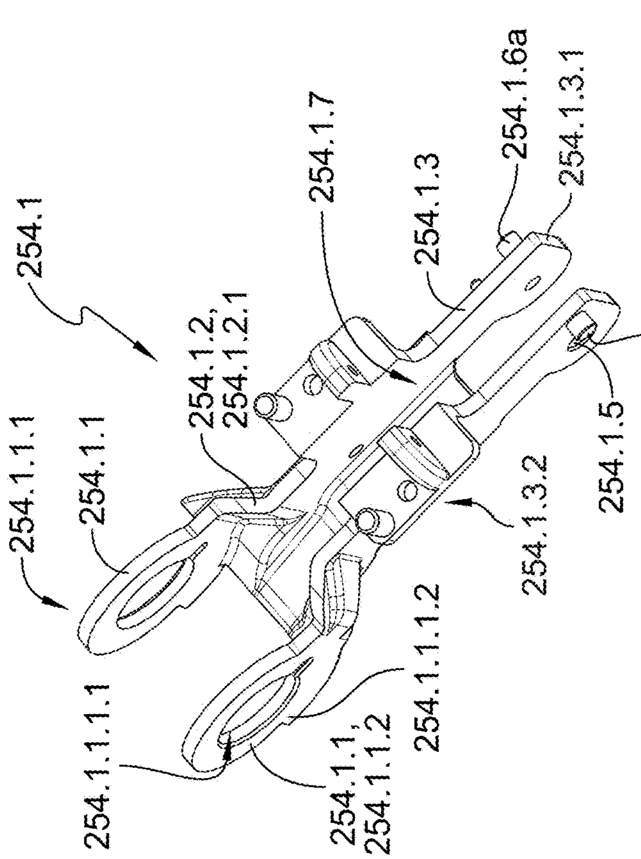


FIG. 38

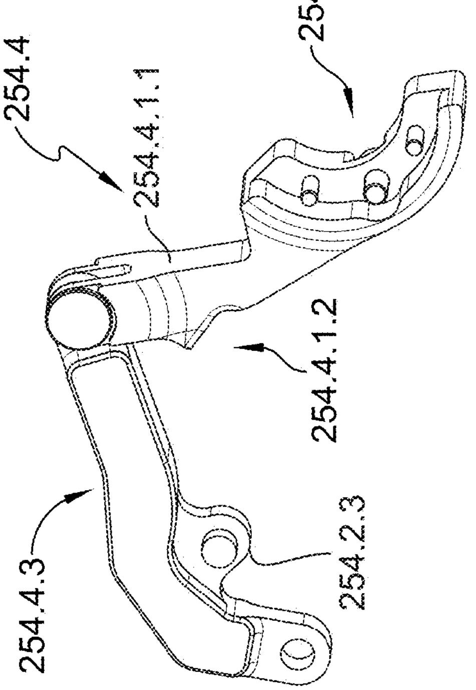

254.4
254.4.1.1
254.4.1.3
254.4.1.2
254.4.3
254.2.3

FIG. 41

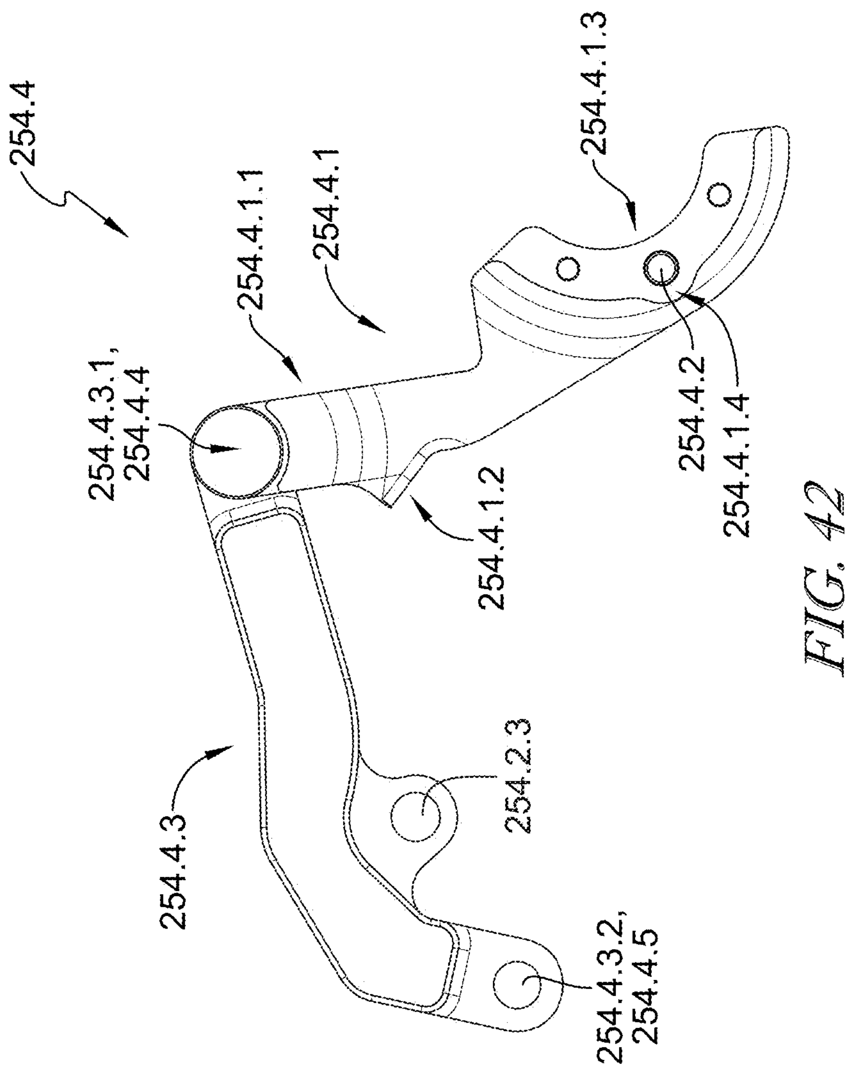

254.4
254.4.1.1
254.4.1
254.4.1.3
254.4.3.1,
254.4.4
254.4.1.2
254.4.2
254.4.1.4
254.4.3
254.2.3
254.4.3.2,
254.4.5

FIG. 42

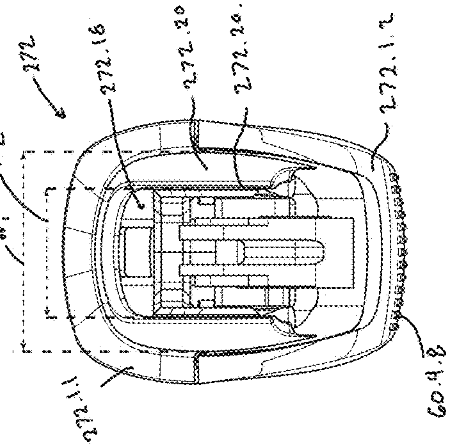


FIG. 44

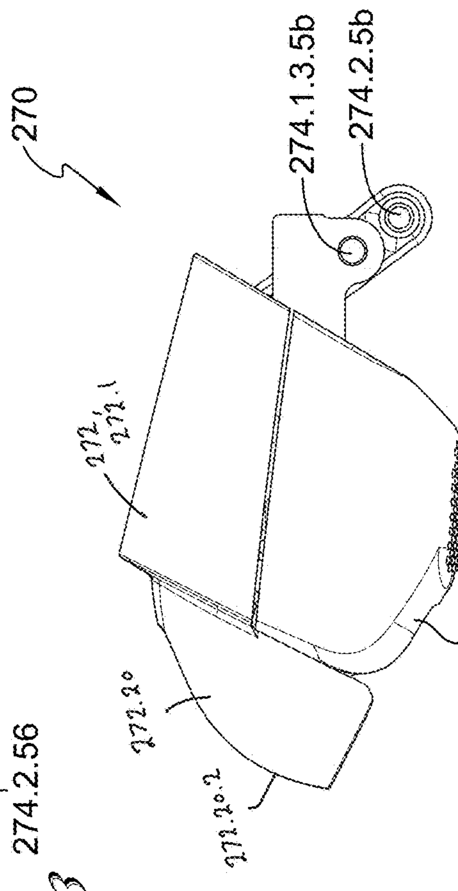


FIG. 45

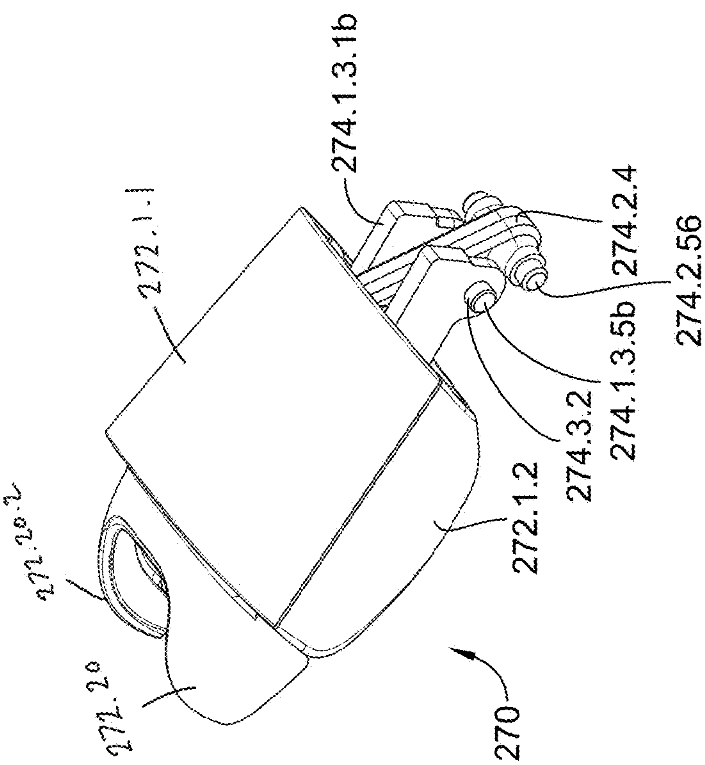
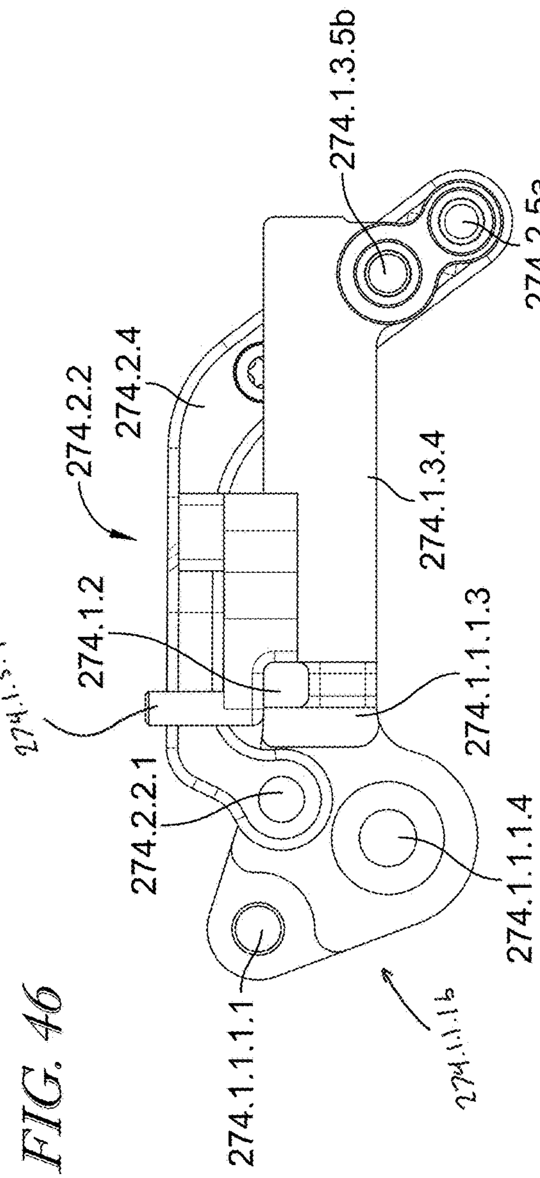


FIG. 43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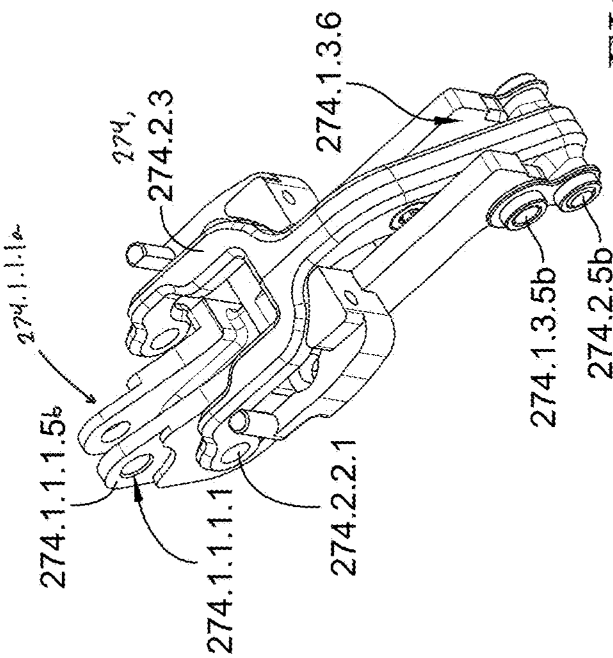
274.2.5a
274.2.2
274.2.4
274.1.3.4
274.1.2
274.1.3.4
274.1.1.1.3
274.2.2.1
274.1.1.1.4
274.1.1.1.1
274.1.1.1b

FIG. 47


274.1.1.1a
274,
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274.2.2.1
274.1.3.5b
274.2.5b

FIG. 46

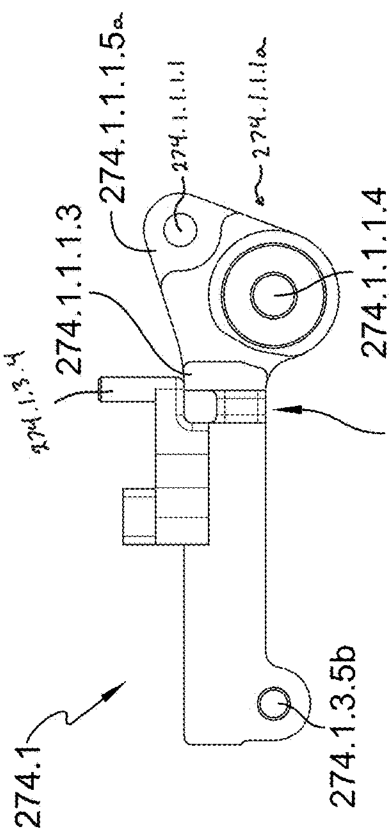


FIG. 49

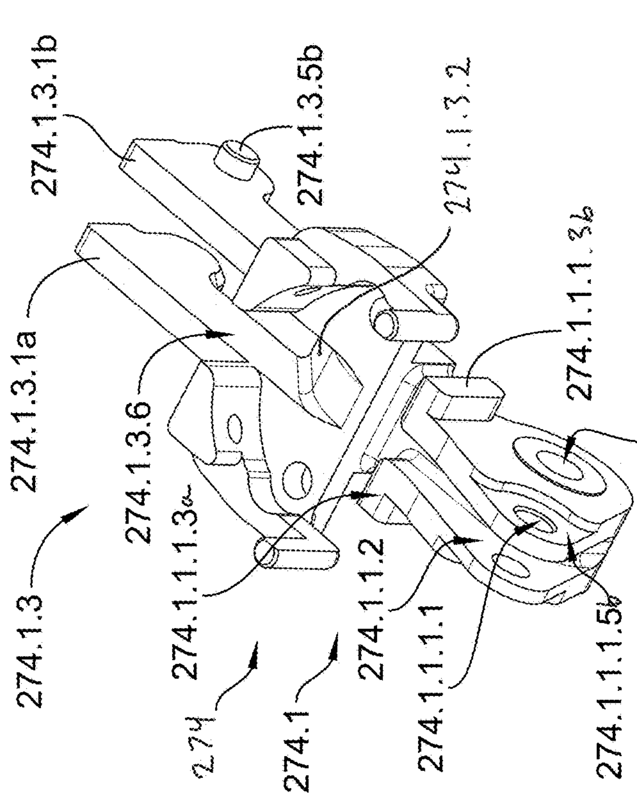


FIG. 50

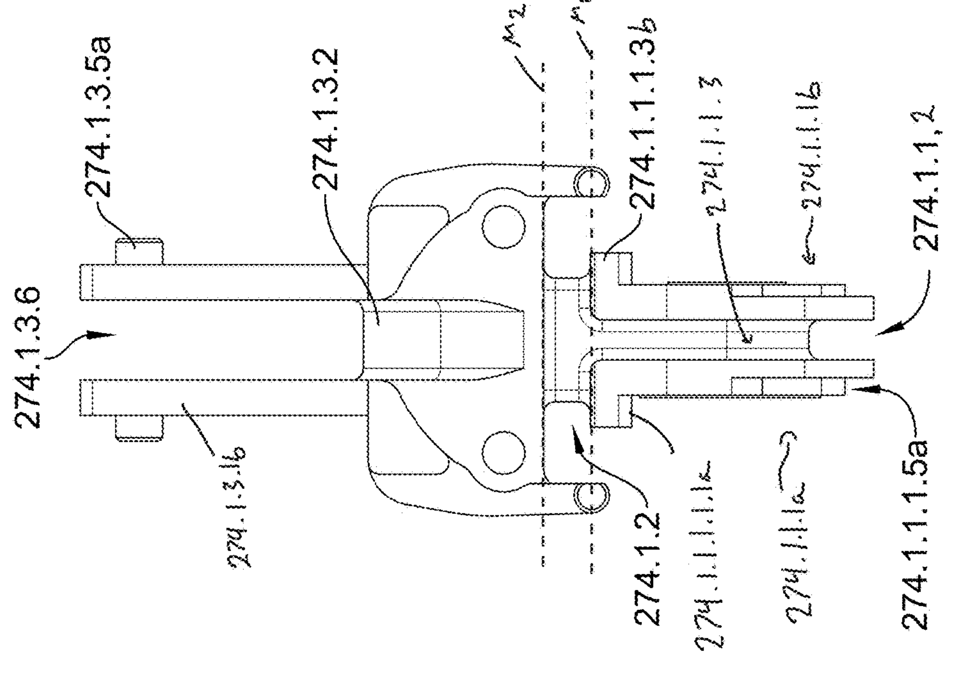


FIG. 48

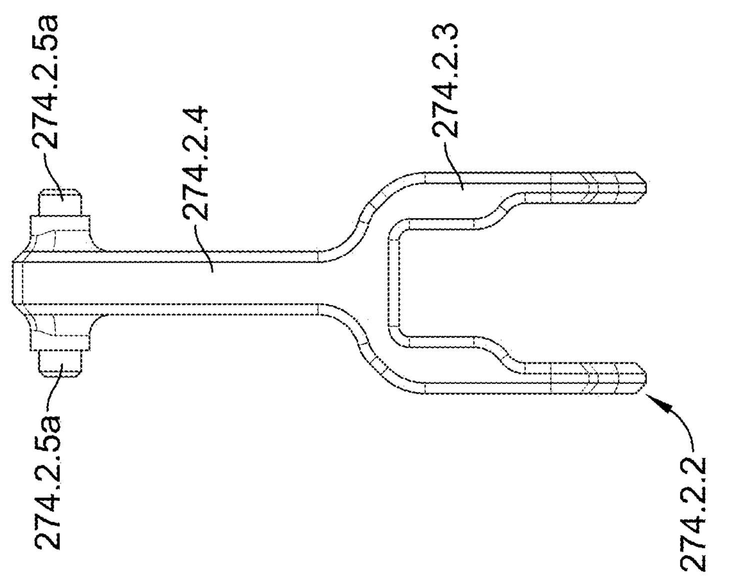


FIG. 52

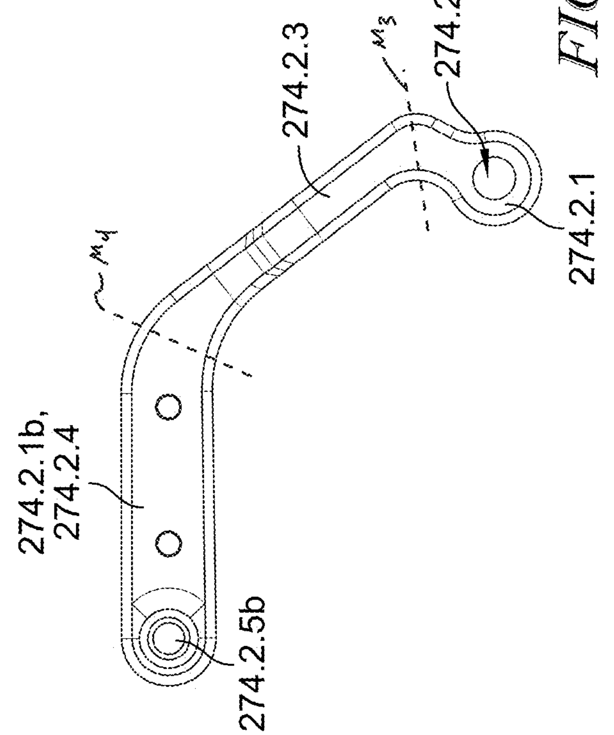


FIG. 53

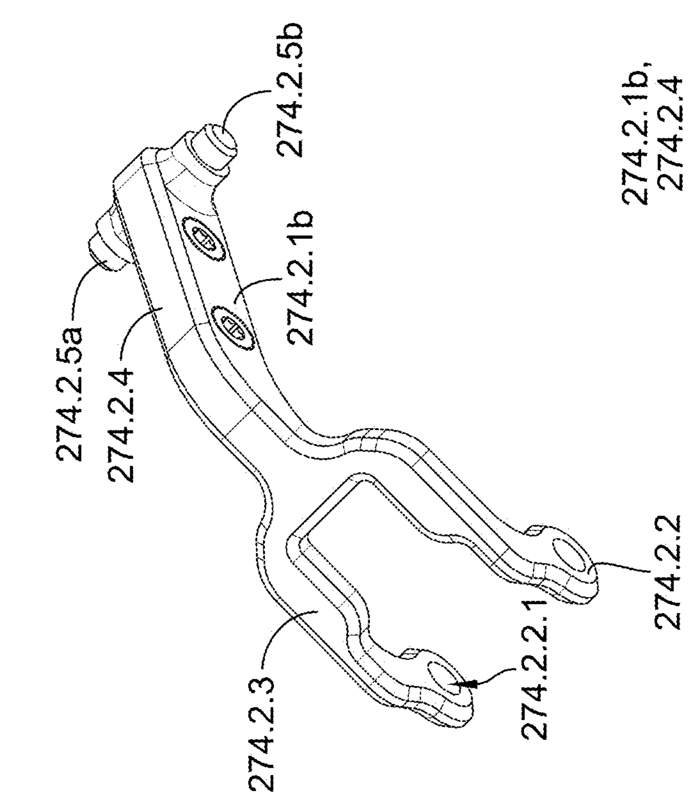


FIG. 51

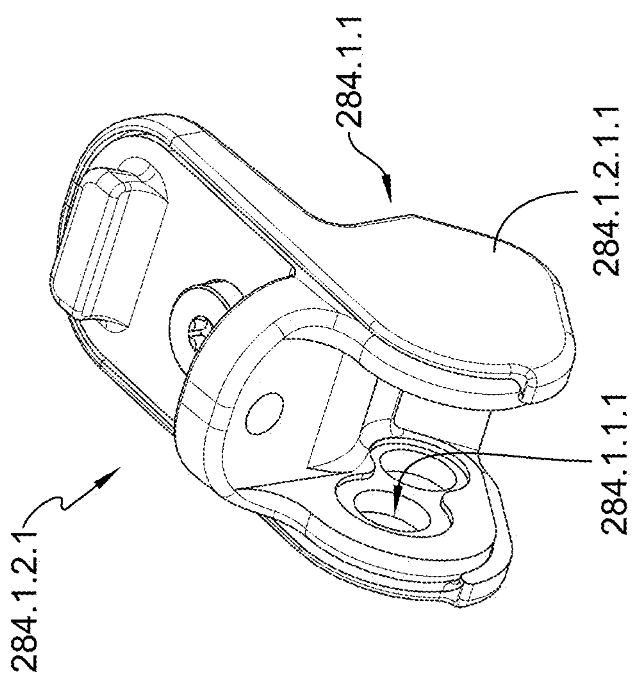


FIG. 54

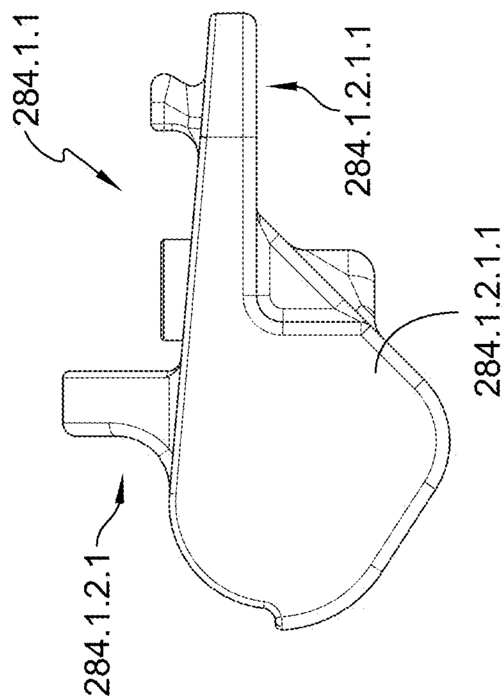
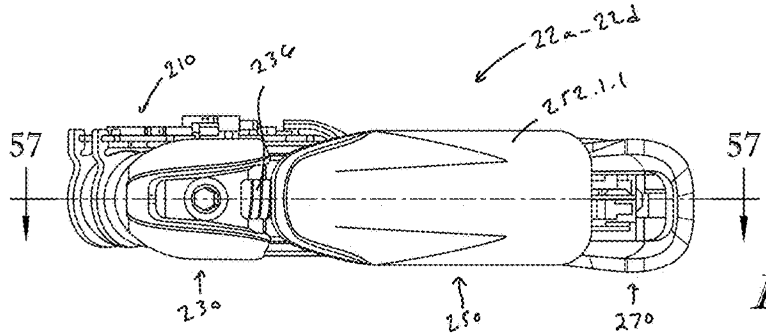
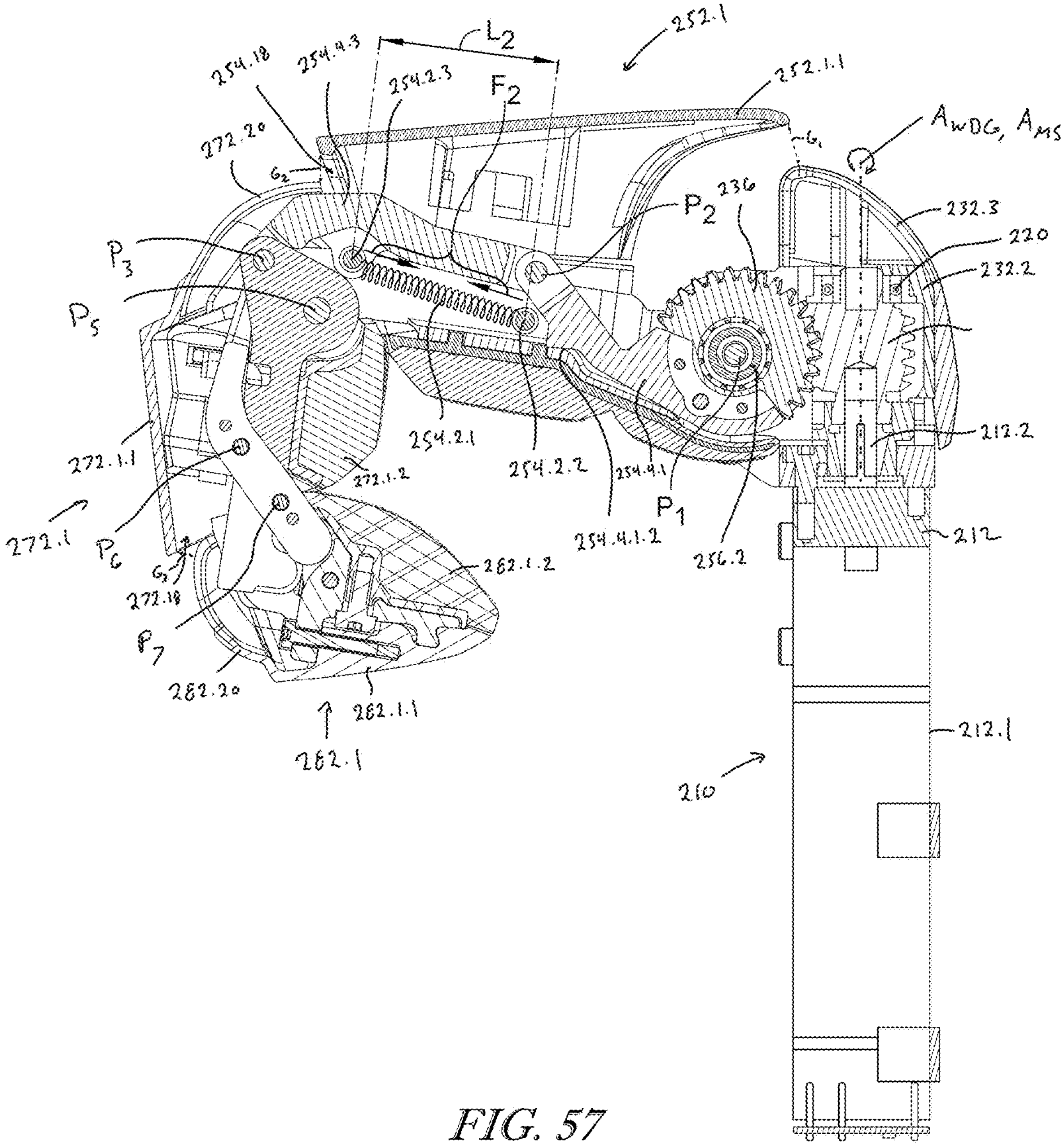


FIG. 55



22a-22d
210
234
252.1.1
57
57
230
250
270

FIG. 56



252.1
L_2
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254.4.3
254.2.3
F_2
252.1.1
A_{WDG}, A_{MS}
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G_2
G_1
P_2
236
232.3
220
232.2
P_3
P_5
254.2.1
254.2.2
254.4.1
212.2
272.1.1
272.1.2
P_1
272.1
P_6
254.4.1.2
256.2
212
G_3
272.18
282.1.2
P_7
282.20
282.1.1
282.1
212.1
210

FIG. 57

MECHANICAL END EFFECTOR

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application claims benefit under 35 U.S.C. § 119 of U.S. Provisional Patent Applications Nos. 63/614,499, 63/617,762, 63/561,315, 63/573,226, 63/615,766, 63/620,633 all of which are incorporated herein by reference for any purpose. U.S. patent application Ser. Nos. 18/919,263 and 18/919,274, and U.S. Provisional Patent Application Nos. 63/557,874, 63/626,040, 63/626,105, 63/625,362, 63/625,370, 63/625,381, 63/625,384, 63/625,389, 63/625,405, 63/625,423, 63/625,431, 63/685,856, 63/696,507, 63/696,533, 63/706,768, 63/722,057, and 63/700,749 are all incorporated herein by reference for any purpose.

TECHNICAL FIELD

[0002] This disclosure relates to a mechanical end effector for a robot, specifically a general-purpose humanoid robot. The mechanical end effector includes various assemblies, components contained in the various assemblies, and connections between said components that provide the mechanical end effector with the ability to substantially mimic the movements, capabilities, and configuration of a human hand.

BACKGROUND

[0003] The current workplace landscape is marked by an unparalleled labor shortage, evident in over 10 million unsafe or undesirable jobs within the United States. These positions often encompass tasks in high-risk sectors—such as manufacturing, construction, and materials handling—where human labor faces safety challenges or heightened physical strain. To mitigate this widening labor gap, there is a pronounced need for high-performance robotic systems that can assume responsibility for a variety of demanding, repetitive, or potentially dangerous operations. Consequently, ongoing advancements in robotics research have concentrated on the development of sophisticated, general-purpose humanoid robots, which are specifically engineered to function within environments originally designed for human workers. These general-purpose humanoid robots are equipped with hardware and software architectures optimized for performing diverse tasks with efficiency, accuracy, and reliability in human-centric environments.

[0004] In order to fulfill the functional and ergonomic requirements of human-centric environments, general-purpose humanoid robots are commonly outfitted with anthropomorphic features, including two legs, two arms, a torso, and a head or face-like interface that may provide user feedback or display information. Central to this anthropomorphic design philosophy is the mechanical end effector of the robot, which must be able to approximate most of the capability of the human hand in terms of dexterity, strength, and overall versatility. By being able to approximate most of the capability of the human hand, the end effector can more effectively interact with complex, real-world objects, thereby performing functions such as grasping, rotating, and manipulating items with minimal risk of slippage or damage. In addition to providing a high level of dexterity, the design must satisfy operational constraints related to energy consumption, cost efficiency, and mechanical durability. As such, there is a need for a mechanical end effector that can provide humanoid robots with the ability to execute tasks with human-equivalent precision, robustness, and adaptability in dynamic and unpredictable work environments.

SUMMARY

[0005] The present invention is directed at an end effector for a humanoid robot, the end effector comprising a frame, and a finger assembly removably connected to the frame. The finger assembly is comprised of: (i) a worm drive link, (ii) a proximal drive link pivotably coupled to the worm drive link, (iii) a proximal link defining a proximal link recess configured to selectively receive at least a portion of the worm drive link and at least a portion of the main proximal drive link therein, (iv) a medial link pivotably connected to both the proximal link and the proximal drive link and including a medial link recess configured to receive an extent of the medial drive link, and (v) a medial drive link pivotably connected to the medial link by at least one first pivotable coupling located on a first side of a sagittal plane extending through the finger assembly and at least one second pivotable coupling located on a second side of the sagittal plane.

[0006] The present invention is also directed at an end effector for a humanoid robot, the end effector comprising a frame, and four finger assemblies, wherein each finger assembly of the four finger assemblies are substantially identical to every other finger assembly of the four finger assemblies, and wherein each finger assembly of the four finger assemblies is removably connected to the frame at a respective point. All of the finger assemblies of the four finger assemblies are located substantially in a single plane, but each finger assembly of the four finger assemblies is angularly offset within the single plane with respect to every other finger assembly of the four finger assemblies. Additionally, the respective points of connection of the four fingers assemblies to the frame are not co-linear, and each finger assembly of the four finger assemblies lacks a mechanical cable configured to actuate any component of the finger assembly.

[0007] It should also be understood that the present invention is directed at an end effector for a humanoid robot. The end effector includes a frame, and a plurality of finger assemblies removably connected to the frame. Each finger assembly of the plurality of finger assemblies includes a motor assembly including: (i) a motor having a motor housing, and (ii) a motor shaft having a motor shaft axis, and wherein the motor shaft is configured to rotate about said motor shaft axis. Each of said finger assemblies also includes a worm drive gear coupled to the motor shaft and configured for rotation about: (i) the motor shaft axis, and (ii) a worm drive gear axis, and wherein the motor shaft axis and the worm drive gear axis are coaxial. The finger assemblies further include a worm wheel in geared engagement with the worm drive gear and configured for rotation about a worm wheel axis in response to rotation of the worm drive gear, and wherein the worm wheel axis is perpendicular to the worm drive gear axis. The finger assemblies additionally include a worm drive link having a first end and a second end, and wherein the first end of the worm drive link fixedly connected to the worm wheel so that the worm drive link is configured for rotation about the worm wheel axis in response to rotation of the worm wheel about the worm wheel axis. The finger assemblies also include a proximal drive link having a first end and a second end, and wherein the first end of the proximal drive link pivotably connected to the second end of the worm drive link. Finally, the finger assemblies have a biasing member configured to bias an extent of the proximal drive link toward a first location, and wherein the extent of the proximal drive link is in the first location when the finger assembly is in an uncurled position.

BRIEF DESCRIPTION OF THE DRAWINGS

[0008] The drawing figures depict one or more implementations in accord with the present teachings, by way of example only, not by way of limitation. In the figures, like reference numerals refer to the same or similar elements.

[0009] FIG. **1** is a perspective view of a wrist coupler and a mechanical end effector that is designed to emulate a human left hand, wherein the mechanical end effector includes a plurality of finger assemblies, a thumb assembly, a housing, and electronics for controlling the finger assemblies and the thumb assembly;

[0010] FIG. **2** is a perspective view of the wrist coupler and the mechanical end effector of FIG. **1**, wherein said wrist coupler is removably secured to a lower extent of a robot arm;

[0011] FIG. **3** is a 6 view of the mechanical end effector of FIGS. **1-2**;

[0012] FIG. **4** is a top or back view of the mechanical end effector of FIGS. **1-2**;

[0013] FIG. **5** is a right side or thumb view of the mechanical end effector of FIGS. **1-2**;

[0014] FIG. **6** is a left side or finger view of the mechanical end effector of FIGS. **1-2**;

[0015] FIG. **7** is a rear view of the mechanical end effector of FIGS. **1-2**;

[0016] FIG. **8** is a front view of the mechanical end effector of FIGS. **1-2**;

[0017] FIG. **9** is a cross-sectional view of the mechanical end effector taken along line **9-9** of FIG. **10**;

[0018] FIG. **10** is a top view of the mechanical end effector of FIGS. **1-2**;

[0019] FIG. **11** is a perspective view of the mechanical end effector of FIGS. **1-2**, wherein an extent of the housing has been removed to show a portion of the components contained within said housing;

[0020] FIG. **12** is a bottom view of the mechanical end effector of FIG. **11**;

[0021] FIG. **13** is a left side view of the mechanical end effector of FIG. **11**;

[0022] FIG. **14** is a bottom view of the mechanical end effector of FIG. **11**, wherein the thumb has been removed to better isolate the finger assemblies and a frame of the mechanical end effector;

[0023] FIG. **15** is an upper right perspective view of a figure assembly of the plurality of figure assemblies contained in the mechanical end effector of FIGS. **1-2**, wherein said finger assembly is in an open, uncurled, or neutral position;

[0024] FIG. **16** is a bottom left perspective view of the figure assembly of FIG. **15**;

[0025] FIG. **17** is a left side view of the figure assembly of FIG. **15**;

[0026] FIG. **18** is a front view of the figure assembly of FIG. **15**;

[0027] FIG. **19** is a rear view of the figure assembly of FIG. **15**;

[0028] FIG. **20** is a left side view of a portion of the figure assembly of FIG. **15**;

[0029] FIG. **21** is a top view of the finger assembly of FIG. **15**;

[0030] FIG. **22** is a bottom view of the finger assembly of FIG. **15**;

[0031] FIG. **23**A is a cross-sectional view of the finger assembly taken along line **23**A-**23**A of FIG. **21**;

[0032] FIG. **23**B is a cross-sectional view of the finger assembly taken along line **23**B-**23**B of FIG. **21**;

[0033] FIG. **23**C is a cross-sectional view of the finger assembly taken along line **23**C-**23**C of FIG. **21**;

[0034] FIG. **24**A is a cross-sectional view of the finger assembly taken along line **24**A-**24**A of FIG. **20**;

[0035] FIG. **24**B is a cross-sectional view of the finger assembly taken along line **24**B-**24**B of FIG. **20**;

[0036] FIG. **25** is a diagram showing layers of materials contained in the housing of the finger assembly of FIG. **1**;

[0037] FIG. **26** is an exploded view of the finger assembly of FIG. **15**;

[0038] FIG. **27** is a perspective view of the finger assembly of FIG. **15**, wherein the housing and motor assembly have been removed to show an internal link assembly;

[0039] FIG. **28** is a side view of the internal link assembly of FIG. **27**;

[0040] FIG. **29** is a top view of the internal link assembly of FIG. **27**;

[0041] FIG. **30** is a front view of the internal link assembly of FIG. **27**;

[0042] FIG. **31** is a cross-sectional view of the internal link assembly taken along line **31-31** of FIG. **29**;

[0043] FIG. **32** is a perspective view of a proximal assembly of the finger assembly of FIG. **15**, wherein said proximal assembly includes: (i) a proximal housing assembly, (ii) a proximal link assembly, (iii) a worm wheel assembly, and (iv) a printed circuit board;

[0044] FIG. **33** is a bottom view of the proximal assembly of FIG. **32**;

[0045] FIG. **34** is a side view of the proximal assembly of FIG. **32**;

[0046] FIG. **35** is a perspective view of the proximal link assembly, the worm wheel assembly, and the printed circuit board of FIG. **32**;

[0047] FIG. **36** is a top view of the proximal link assembly, the worm wheel assembly, and the printed circuit board of FIG. **32**;

[0048] FIG. **37** is a cross-sectional view of the proximal link assembly, the worm wheel assembly, and the printed circuit board taken along line **37-37** of FIG. **36**;

[0049] FIG. **38** is a perspective view of a proximal link of the proximal link assembly of FIG. **32**;

[0050] FIG. **39** is a top view of the proximal link of FIG. **38**;

[0051] FIG. **40** is a side view of the proximal link of FIG. **38**;

[0052] FIG. **41** is a perspective view of a proximal drive link assembly of the proximal link assembly of FIG. **32**;

[0053] FIG. **42** is a side view of the proximal drive link assembly of FIG. **41**;

[0054] FIG. **43** is a perspective view of a medial assembly of the finger assembly of FIG. **15**, wherein said medial assembly includes: (i) a medial housing assembly, and (ii) a medial link assembly;

[0055] FIG. **44** is an end view of the medial assembly of FIG. **43**;

[0056] FIG. **45** is a side view of the medial assembly of FIG. **43**;

[0057] FIG. **46** is a perspective view of the medial link assembly of FIG. **43**;

[0058] FIG. **47** is a side view of the medial link assembly of FIG. **46**;

[0059] FIG. **48** is a top view of a medial link of the medial link assembly of FIG. **46**;

[0060] FIG. **49** is side view of the medial link of FIG. **48**;

[0061] FIG. **50** is a perspective view of the medial link of FIG. **48**;

[0062] FIG. **51** is a perspective view of a medial drive link of the medial link assembly of FIG. **46**;

[0063] FIG. **52** is a top view of the medial drive link of FIG. **51**;

[0064] FIG. **53** is a side view of the medial drive link of FIG. **51**;

[0065] FIG. **54** is a distal link assembly of the finger assembly of FIG. **15**;

[0066] FIG. **55** is a side view of the distal link assembly of FIG. **54**;

[0067] FIG. **56** is a top view of a figure assembly of the plurality of figure assemblies contained in the mechanical end effector of FIGS. **1-2**, wherein said finger assembly is in closed, curled, or inwardly rotated position; and

[0068] FIG. **57** is a cross-sectional view of the figure assembly taken along line **57-57** of FIG. **56**.

DETAILED DESCRIPTION

[0069] In the following detailed description, numerous specific details are set forth by way of examples in order to provide a thorough understanding of the relevant teachings. However, it should be apparent to those skilled in the art that the present teachings may be practiced without such details. In other instances, well-known methods, procedures, components, and/or circuitry have been described at a relatively high-level, without detail, in order to avoid unnecessarily obscuring aspects of the present disclosure.

[0070] While this disclosure includes several embodiments in many different forms, there is shown in the drawings and will herein be described in detail embodiments with the understanding that the present disclosure is to be considered as an exemplification of the principles of the disclosed methods and systems, and is not intended to limit the broad aspects of the disclosed concepts to the embodiments illustrated. As will be realized, the disclosed methods and systems are capable of other and different configurations and several details are capable of being modified all without departing from the scope of the disclosed methods and systems. For example, one or more of the following embodiments, in part or whole, may be combined consistent with the disclosed methods and systems. As such, one or more steps from the flow charts or components in the Figures may be selectively omitted and/or combined consistent with the disclosed methods and systems. Additionally, one or more steps from the flow charts may be performed in a different order. Accordingly, the drawings, flow charts and detailed description are to be regarded as illustrative in nature, not restrictive or limiting.

A. Introduction

[0071] The mechanical end effector **10** disclosed herein may be used as a component of a robot, for example, a versatile humanoid robot. Enabling such a robot to execute general human tasks poses a challenge due to the vast array of potential positions, locations, and states the robot could occupy at any given time in a challenging environment. The multitude of these permutations can be minimized by training the robot system through various methods such as: (i) imitation learning or teleoperation, (ii) supervised learning, (iii) unsupervised learning, (iv) reinforcement learning, (v) inverse reinforcement learning, (vi) regression techniques, or (vii) other established methodologies. To further streamline the vast array of possible positions, locations, and states, reduce manufacturing steps, complexities and costs, minimize components within the robot system, enhance component modularity, and achieve several other advantages that would be apparent to those skilled in the field, two or more components of the end effector can be either: (i) linked, or (ii) fixed to one another. When two or more components are linked or fixed to one another, movement of one of the components results in movement in another one of the components. In contrast to conventional end effectors that fix the medial and distal assemblies to one another, the disclosed finger assembly movably links the medial and distal assemblies to one another. Such linking provides benefits over fixing because it allows for some independent movement of the medial assembly in relation to the distal assembly while still allowing for the movement of the medial assembly to result in movement of the distal assembly. Such linking allows the finger assembly to become underactuated, that is, to retain its ability to flex, curl, or rotate around an object while eliminating the necessity for multiple actuators, motors, or effectors for each finger assembly. Indeed, the disclosed finger assembly includes only one motor that drives linkages that provide three degrees of freedom DoF per finger assembly. Thus, the end effector has a total of 16 DoF.

[0072] Unlike conventional end effectors, the end effector **10** disclosed herein may utilize four identical finger assemblies that are aligned in a single plane (Y-Z), while being offset in two other orthogonal planes (X-Y, and X-Z). The use of identical finger assemblies is beneficial because it reduces the number of distinct components, increases modularity, and reduces the cost of the end effector and the overall robot system. In an alternative embodiment, the end effector **10** may utilize two sets of identical finger assemblies (i.e., two finger assemblies in a first set of assemblies and two finger assemblies in a second set of finger assemblies, wherein each finger contained in the first and second sets of finger assemblies are identical).

[0073] While the structural configuration of each finger assembly will be discussed in greater detail below, it should be understood that each finger assembly is configured to be a separate component of the end effector that is modular and removably coupled to a frame of the end effector. As such, said finger assembly is swappable (and in certain embodiments hot-swappable) with another finger assembly. The separate, modular, and swappable nature of the finger assemblies means that: (i) pulleys, articulation cables, pneumatic or hydraulic mechanisms may be omitted from the end effector, and (ii) components of the end effector are not located in the wrist, lower arm, or generally outside of each finger assembly. In other words, the motor, PCBs, encoders, and other electronic components needed to actuate each finger assembly may be fully contained within each finger assembly and are not distributed throughout the arm and/or robot. This full containment aspect is desirable because it increases serviceability and thus decreases the cost of ownership and operation of the robot.

[0074] While the disclosed finger assemblies in the end effector **10** utilize a single biasing member (e.g., spring), said finger assemblies utilize a direct drive linkage system in order to eliminate the need to use more than one (e.g., multiple) biasing members (e.g., springs) to force the finger assembly to remain in a predefined position (e.g., open, uncurled, or neutral). Eliminating the use of multiple biasing members for this purpose provides a significant benefit over conventional end effectors because it: (i) removes the need for the motor assembly to overcome a significant biasing force applied by multiple biasing members to move the finger assembly, and (ii) increases durability, robustness, and life of the end effector due to the fact that multiple biasing members can rapidly degrade over time.

[0075] Additionally, the disclosed direct drive linkages include components that nest within one another. The use of nesting components is beneficial over conventional finger assemblies of end effectors because each link is supported by at least one coupling point on either side of a plane (e.g., sagittal plane) extending through the finger assembly. In other words, each link in the disclosed finger assembly is coupled on multiple sides, not simply coupled on a single side, which increases the durability of the assembly.

[0076] The disclosed finger assemblies in the end effector **10** have a proximal assembly that includes: (i) one component that is directly tied to the movement of the motor, and (ii) one component that is not directly tied to the movement of the motor. For example, the movement of the proximal drive link assembly is directly tied to the movement of the motor, while the proximal housing is not directly tied to the movement of the motor. In fact, the proximal assembly utilizes a bearing to allow slippage between the motor and at least the proximal housing when an extent of the proximal assembly has come into contact with a resistance point/surface. This configuration is beneficial over conventional end effectors because it allows a single motor to fully actuate the finger assembly, by allowing specific components within the proximal assembly to stop moving while the motor continues to drive other components.

[0077] Finally, the end effector **10** disclosed herein may lack several components typically found in conventional end effectors. For example, the disclosed end effector **10** lacks pulleys, articulation cables, components configured to allow the fingers to abduct or spread from one another, more than one motor per finger assembly, force sensors, and other components typically found in conventional end effectors. Eliminating these components reduces cost and complexity, while increasing modularity, serviceability, and durability. Other benefits of the disclosed end effector **10** and its various assemblies and components should be apparent to one of skill in the art based on this disclosure and the accompanying figures.

B. End Effector 10

[0078] With reference, for example, to FIGS. **1-14**, the end effector **10** includes: (i) a set of finger assemblies **20** with at least one finger assembly **22*n*** (as shown, the set of finger assemblies **20** includes four finger assemblies **22*a***, **22*b***, **22*c***, **22*d***), (ii) a thumb assembly **40**, (iii) a housing assembly **60**, and (iv) electronics **80** that are configured to control each finger assembly **22*n*** of the set of finger assemblies **20** and the thumb assembly **40**. As shown in the figures, the housing assembly **60** is configured to: (i) encase and protect the electronics **80**, and (ii) securely locate each of the finger assemblies **22*a*-22*d*** and the thumb assembly **40** in a particular position relative to each other and the housing assembly **60**. The housing assembly **60** may have: (i) a palm **62**, (ii) a back **64**, (iii) left and right sides **66**, **68**, and (iv) a front **70**. It should be understood in alternative embodiments, the end effector **10** may include a single finger, two fingers, three fingers, or five fingers. In a further alternative, the end effector **10** may not include a single finger assembly, but instead may include a plurality of thumb assemblies.

[0079] As shown in FIGS. **23**A-**25**, said housing assembly **60** may include multiple components that are made from different materials, may include multiple layers that are made from different materials, and/or may be made from materials that have different rigidities, densities, C/D ratios, durabilities, fabrication methods, and the alike. For example, the frame **61.2** may be made from a first material with a first rigidity, the exterior top housing **61.8** may be made from a second material with a second rigidity, the interior bottom housing **61.10** may be made from a third material with a third rigidity, and wherein said first rigidity is greater than the second rigidity, and the second rigidity is greater than the third rigidity. For example, the frame **61.2** may be made from rigid metal, the exterior top housing **61.8** may be made from rigid plastic, and the interior bottom housing **61.10** may be made from deformable silicon or soft plastic. It should be understood that these are examples of possible materials and configurations and are not intended to be limiting in any manner. In other embodiments, the exterior or skin of the end effector **10** may be as rigid as the internal link assemblies of the housing assembly **60**, wherein the housing and the internal link assemblies are both made from a durable and hard plastic. In further embodiments, the exterior or skin of the end effector **10** may be more rigid than the internal link assemblies of the housing assembly **60**.

[0080] As described above in an alternative embodiment, the interior bottom housing **61.10** may include a plurality of layers **61.20**, wherein a first interior layer **61.20.2** that is made from a first material having a first rigidity and a second exterior layer **61.20.4** that is made from a second material having a second rigidity. In this example, the first material may be rigid plastic or metal, while the second material is deformable silicon, soft plastic, or deformable textile or fabric. It should be understood that the second material may be replaceable (i.e., removably coupled) or may not be permanently affixed to the end effector **10**. This design may allow for a softer material to be used on the palm surface of the end effector **10** that is designed to be less durable, and thus needs to be replaced when damaged or at pre-defined intervals (e.g., 1 week, 1 month, 6 months, 1 year, 5 years, or any interval between 1 day and 10 years). In other examples, the plurality of layers **61.20** may have three layers, wherein the first layer **61.20.2** is rigid to provide protection for the internal components, a second layer **61.20.4** is less rigid than the first layer **61.20.2** to enable the end effector **10** to pick up delicate items, and a third layer **61.20.6** that is designed to protect the second layer **61.20.4**. In this example, the first layer **61.20.2** may be made from durable plastic or metal, the second layer **61.20.4** may be made from deformable thermoplastic, and the third layer **61.20.6** may be made from textile, cloth, or fabric (e.g., glove). Said third layer **61.20.6** may be replaceable at pre-determined intervals and may be coupled to the end effector using snaps, buttons, removable fasteners, push-pins, or any other type of mechanical coupling mechanism. In a final example, the plurality of layers **61.20** may have any number of layers, wherein layer **61.20.8** represents layer number four through the nth layer.

[0081] Examples of materials that may be used in the end effector **10** include, but are not limited to, metal (e.g., aluminum, stainless steel, titanium alloys, magnesium alloys, copper alloys, nickel-based alloys), carbon fiber composites, glass fiber composites, basalt fiber composites, Kevlar® composites, polycarbonate, acrylic (PMMA), acrylonitrile butadiene styrene (ABS), nylon, polyoxymethylene (POM), polyether ether ketone (PEEK), polyetherimide (PEI), polyphenylene sulfide (PPS), polytetrafluoroethylene (PTFE), polypropylene (PP), polyethylene (PE), high-density polyethylene (HDPE), thermoplastic polyurethane (TPU), polyamide-imide (PAI), other plastic (e.g., may include a polymer composition), rubber (e.g., nitrile rubber, EPDM), silicone, polyurethane elastomers, ceramic materials (e.g., alumina, zirconia), a combination of these materials, and/or any other suitable material. Additionally, the housing assembly **60** and other components of the end effector **10** may be injection molded, **3**D printed, subtractive manufactured, or created using any other known method of manufacturing.

[0082] FIG. **6** shows a finger side view of the end effector **10**, wherein a surface plane P_{SU} has been added to illustrate the contact points between the palm side of the housing assembly **60** and a flat or planar surface. For example, the surface plane P_{SU} may represent the outermost surface formed by a tote designed to carry parts or components of a car. As shown in this Figure, two main contact points are formed between said surface and the end effector **10**, wherein a first contact point P_{C1} is formed near the tip of the middle finger **22***b* and a second contact point P_{C1} is formed near the base of the palm. The greatest distance D_{SU} between said surface plane P_{SU} and the housing **60** formed near the knuckle assembly is less than 10 mm, preferably less than 5 mm, and most preferably less than 1 mm. As shown in this Figure, it is beneficial to have the palm or inner surface of the end effector **10** flat or nearly flat to help maximize the contact surface area between the end effector **10** and the surface plane P_{SU}, as this design simplifies approach angles, and reduces the need to perform complex grasping movers with the wrist.

[0083] As best shown in FIGS. **3-4**, the housing **60** includes a substantially smooth top or back surface SB and a rough or non-smooth bottom or palm surface Sp. The rough or non-smooth palm surface Sp is created by adding a plurality of contact areas **61.4**. In other words, the entire palm surface Sp is not rough or non-smooth. Said plurality of contact areas **61.4** is designed to increase the end effector's **10** to grasp and hold an object. Specifically, the plurality of contact areas **61.4** are comprised of distinct regions **61.4.2-61.4.10** that include multiple bumps or projections **61.6**. Said regions **61.4.2-61.4.10** are formed on the palm, and each assembly (i.e., proximal, medial, and distal) contained within each finger assembly **22***a*-**22***d*. For example, the palm **62** may have one large contact region **61.4.2**, the proximal assemblies of the fingers **22***a*-**22***d* may include two contact regions **61.4.4**, **61.4.6**, the medial assemblies of the fingers **22***a*-**22***d* may include one contact region **61.4.8**, and the distal assemblies of the fingers **22***a*-**22***d* may also include one contact region **61.4.10**. The height of the bumps or projections **61.6** may be 0.01 mm to 2 mm, and preferably between 0.25 mm and 0.75 mm. It should be understood that in other embodiments, the plurality of contact areas **61.4** may be omitted, the number of regions contained in the plurality of contact areas **61.4** may be increased (e.g., between 18 and 100) or decreased (e.g., between 1 and 16), the number of bumps or projections **64** within each region may be increased or decreased, and/or the height of the bumps or projections **61.6** may be increased or decreased.

[0084] As best shown in FIGS. **24**A-**24**B, the housing **60** of each finger assembly **22***a*-**22***d* and specifically the outer surfaces **61.8.2**, **61.10.2** of the exterior top housing **61.8** and the interior bottom housing **61.10** have a cross-sectional shape that is similar to an obround or a discorectangle. This cross-sectional shape is desirable because it provides a narrow width, rounded edges that help the finger assemblies avoid contact with one another, and substantially flat surfaces that help the finger assemblies maximize contact with the object it is grasping. In an exemplary embodiment, the width of the finger housing is between 40% to 80%, and preferably between 55% and 70% of the height of the finger housing. It should be understood that in other embodiments, the width-to-height ratio may be altered or changed in a manner that causes the height to be less than the width. However, this design or configuration may not be desirable because it limits the space within the housing for components while limiting the dexterously of the end effector **10**.

[0085] With reference, for example, to FIGS. **1-13**, the end effector **10** comprises a thumb assembly **40**. The thumb assembly **40** is coupled to the palm surface **61.2.2** of the frame **61.2** and is replaceable (and in some embodiments, it may be hot-swapping with a replacement thumb assembly **40**). The replaceable aspect of the thumb assembly **40** eliminates the need for various structural elements, such as synthetic tendons or articulation cables, pulleys, pneumatic or hydraulic cables, and other components that extend from the lower arm or wrist to the medial or distal sections of the thumb assembly **40**. This configuration ensures that components such as linkages, motors, PCBs, encoders, and other elements required to actuate each thumb assembly **40** are self-contained within the palm and/or the thumb assembly **40** and are not spread throughout the robot system. This setup is advantageous as it enhances serviceability, consequently reducing the overall cost of ownership and usage. As shown in FIG. **13**, the thumb motor plane P_{TM} is offset by an angle gamma γ from line L_1, wherein: (i) line L_1 is perpendicular to the sagittal plane P_S or the middle finger plane P_{22b} and intersects with the center point of the knuckle assembly of the middle finger **22***b*, and (ii) the an angle gamma γ is usually at least 1 degree, preferably between 2 degrees and 12 degrees, and most preferably between 4 degrees and 6 degrees, and likely less than 16 degrees.

[0086] With reference, for example, to FIGS. **15-25**, the end effector **10** comprises four identical finger assemblies **22***a*-**22***d* that are coupled to the back surface **61.2.4** of the frame **61.2** and are configured to operate independent of one another. In embodiments, the end effector **10** may include more or fewer than four finger assemblies. Configuring the finger assemblies **22***a*-**22***d* identically allows for reducing the number of distinct components required to manufacture the finger assemblies **22**a-**22**d, and enhances modularity, thus reducing expense. The modular nature of the finger assemblies **22**a-**22**d enables them to be easily replaceable and may enable hot-swapping of the finger assemblies. The modular and replaceable aspect of the finger assemblies **22**a-**22**d eliminates the need for various structural elements, such as synthetic tendons or articulation cables, pulleys, pneumatic or hydraulic cables, and other components that extend from the lower arm or wrist to the medial or distal sections of the finger assemblies **20**. This configuration ensures that components such as linkages, motors, PCBs, encoders, and other elements required to actuate each finger assembly **22**a-**22**d are self-contained within the palm and/or within each finger assembly **22**a-**22**d and are not spread throughout the robot system. This setup is advantageous as it enhances serviceability, consequently reducing the overall cost of ownership and usage.

[0087] In other embodiments, it should be understood that finger assemblies **22**a-**22**d may not be identical. Instead, there may be two pairs of finger assemblies, wherein the finger assemblies contained in said pairs of finger assemblies are identical. In other words, there may be two unique types of finger assemblies contained in said end effector **10**, wherein there are two finger assemblies of a first type and two finger assemblies of a second type. For example, the pointer finger **22**a and the small finger **22**d may be the first type, while the middle finger **22**b and the ring finger **22**c may be the second type (while the middle and ring **22**b, **22**c are different from the pointer and small **22**a, **22**d). In another example, the pointer finger **22**a and the middle finger **22**b may be the first type, while the ring finger **22**c and the small finger **22**d may be the second type (while the ring and small **22**c, **22**d are different from the pointer and middle **22**a, **22**b). In an additional embodiment, there may be two unique types of finger assemblies contained in said end effector **10**, wherein there are three finger assemblies of a first type and one finger assembly of a second type. For example, the pointer, middle, and ring fingers **22**a-**22**c may be of the first type and the small finger **22**d may be of the second type. In another embodiment, there may be three unique types of finger assemblies contained in said end effector **10**, wherein there are two finger assemblies of a first type, one finger assembly of a second type, and one finger assembly of a third type. For example, the middle and ring fingers **22**b, **22**c may be the first type, the pointer finger **22**a may be of the second type to allow for abduction, and the small finger may be of the third type **22**d due to its size. In a further embodiment, all finger assemblies **22**a-**22**d may be unique. Finally, it should be understood that other combinations of finger assembly types are contemplated by this application, and the above examples are not intended to be limiting.

[0088] With reference, for example, to FIGS. **11-14**, each finger assembly **22**a-**22**d may be connected to the back surface **61.2.4** of the frame **61.2**. Thus, the overall location of the figure assembly **22**a-**22**d cannot move in the Y-Z plane. Also, the finger assemblies **22**a-**22**d may be connected to the frame **61.2** in a manner that ensures that the tips are not aligned with one another. In other words, each finger assembly **22**a-**22**d is: (i) angularly offset and horizontally offset to at least one other finger assembly **22**a-**22**d in the X-Y plane, and (ii) vertically offset to at least one other finger assembly in the X-Z plane. This configuration of finger assembly **22**a-**22**d enables each finger assembly **22**a-**22**d of the four finger assemblies **22**a-**22**d to be angularly offset along the X-Y plane and within the Y-Z plane with respect to every other finger assembly **22**a-**22**d of the four finger assemblies **22**a-**22**d. The fixed position of the finger assemblies **22**a-**22**d may reduce the complexities of building, using, maintaining, and repairing the end effector **10**.

[0089] As shown, the middle or third finger assembly **22**b is positioned such that its sagittal plane is orientated substantially vertically on the page. Based on the position of the middle or third finger assembly **22**b, it can be seen that the center (i.e., C_{22a}, C_{22c}, C_{22d}) of a knuckle assembly **230** of each of the pointer, ring, and small fingers **22**a, **22**c, and **22**d are positioned: (i) slightly rearward from the line L_1 and the center C_{22b} of the knuckle assembly of the middle finger **22**b (see FIG. **12**), and (ii) are angled relative to the center of the knuckle assembly **230** of the middle finger **22**b (see FIG. **14**). This configuration also causes the fasteners **61.30**a-**61.30**b that removably connected the finger assemblies **22**a-**22**d at a respective point **61.40**a-**61.40**d to the frame **61.2** to be not co-linear. At best, two of the respective point **61.40**a-**61.40**d may be co-linear, but all four points are not co-linear. However, all four respective point **61.40**a-**61.40**d are aligned in the same Y-Z plane.

[0090] FIGS. **11-14** also show that the pointer finger plane P_{22a} that bisects the pointer finger **22**a along its length is offset from the sagittal plane P_S or the middle finger plane P_{22b} by an angle alpha α, wherein the angle alpha α is usually at least 0.25 degree, preferably between 0.5 degrees and 5 degrees, and most preferably between 2 degrees and 3 degrees, and likely less than 7 degrees. Likewise, the ring finger plane P_{22c} that bisects the ring finger **22**c along its length is offset from the sagittal plane P_S or the middle finger plane P_{22b} by an angle beta β, wherein the angle beta β is usually at least 0.25 degree, preferably between 0.5 degrees and 5 degrees, and most preferably between 2 degrees and 3 degrees, and likely less than 7 degrees. Finally, the small finger plane P_{22d} that bisects the small finger **22**c along its length is offset from the ring finger plane P_{22c} by an angle theta θ, wherein the angle theta θ is usually at least 0.25 degree, preferably between 0.5 degrees and 5 degrees, and most preferably between 2 degrees and 3 degrees, and likely less than 7 degrees.

[0091] Exemplary positional relationship between components of a finger assembly **22**a-**22**d is shown in FIG. **20** are listed in Table 1. It should be understood that the dimensions, angles, ratios, and other values that can be derived therefrom that are disclosed in the figures and Tables 1-3 are important to ensure that the end effector **10** can move, grasp objects, and be used in the desired robot system. As such, the structures, features, dimensions, angles, ratios, and other values that can be derived therefrom of non-end effectors for robots and non-linkage based end effectors cannot be simply adopted or implemented into an end effector without careful analysis and verification of the complex realities of designing, testing, manufacturing, training, and using the robot system with an end effector. Theoretical designs that attempt to implement such modifications from non-end effectors for robots and non-linkage based end effectors are insufficient (and in some instances, woefully insufficient) because they amount to mere design exercises that are not tethered to the complex realities of successfully designing, testing, manufacturing, training, and using the robot system with an end effector.

TABLE 1

Angle	Lower Bound	Upper Bound	Preferred Lower Bound	Preferred Upper Bound
λ1	6.4°	10.6°	7.6°	9.3°
λ2	104.5°	174.2°	125.4°	153.3°
λ3	98.2°	163.6°	117.8°	144°
λ4	81.1°	135.2°	97.4°	119°
λ5	103.1°	171.8°	123.7°	151.1°
λ6	96.7°	161.2°	116°	141.8°
λ7	84.6°	140.9°	101.5°	124°
λ8	4.1°	6.9°	5°	6.1°
λ9	10.5°	17.5°	12.6°	15.4°

TABLE 2

P_{22a}	Pointer Finger Plane
P_S, P_{22b}	Sagittal Plane or Middle Finger Plane
P_{22c}	Ring Finger Plane
P_{22d}	Small Finger Plane
P_{FM}	Finger Motor Plane
P_{TM}	Thumb Motor Plane
P_{FC}	Finger Coronal Plane
P_{SU}	Surface Plane

TABLE 3

P_1	First Pivot Point - Fixed
P_2	Second Pivot Point - Not Fixed
P_3	Third Pivot Point - Not Fixed
P_4	Fourth Pivot Point - Semi-Fixed
P_5	Fifth Pivot Point - Semi-Fixed
P_6	Sixth Pivot Point - Semi-Fixed
P_7	Seventh Pivot Point - Not Fixed

C. Finger Assembly

[0092] With reference, for example, to FIGS. **15-25**, each finger assembly **22***a*-**22***d* of the end effector **10** is comprised of a motor assembly **210**, a knuckle assembly **230**, a proximal assembly **250**, a medial assembly **270**, and a distal assembly **280**. Each of the knuckle assembly **230**, proximal assembly **250**, medial assembly **270**, and distal assembly **280** include internal linkages (in combination, internal linkage assembly) that can operate together to move the finger assembly **22***a*-**22***d*. Each of these assemblies will be discussed in great detail below; however, additional information about said assemblies may be contained within U.S. Provisional Patent Applications Nos. 63/614,499, 63/617,762, 63/561,315, 63/573,226, 63/615,766, 63/620,633, all of which are incorporated herein by reference for any purpose.

a. Motor Assembly

[0093] The motor assembly **210** is configured to be releasably coupled to the top surface **61**.**2**.**4** of the housing frame **61**.**2**, and includes: (i) a motor **212**, (ii) controller **214**, (iii) a worm drive gear **216** that is coupled to an extent of the motor **212**, and (v) a worm drive gear bearing **220**. Motor **212** may be a slotless BLDC motor, a brushed DC motor, a stepper motor, a switched reluctance motor, a permanent magnet synchronous motor, a servo motor, or any other suitable motor. As shown in the Figures, the motor assembly **210** for each finger assembly **22***a*-**22***d* only includes a single motor **212**; thus, said finger assembly **22***a*-**22***d* does not include more than one motor **212**. By limiting the number of motors **212** to the number of finger assemblies **22***a*-**22***d*, the end effector **10** becomes underactuated. Stated a different way, each finger assembly **22***a*-**22***d* includes three joints or 3 degrees of freedom (DoF), wherein each of the three joints or DoFs are controlled by a single motor **212**. This not only simplifies manufacturing, increases durability, enables the figure assemblies **22***a*-**22***d* to be modular, but also reduces cost and complexity of control.

[0094] As best shown in FIG. **23**C, the motor **212** includes: (i) internal components (not shown), (ii) a motor housing **212**.**1**, and (iii) a motor shaft **212**.**2**. The internal components of the motor **212** are designed to rotate the motor shaft **212**.**2** about a motor shaft axis A_{MS}. To help ensure that the motor shaft **212**.**2** rotates about the motor shaft axis A_{MS} at the desired speed, the internal components of the motor **212** may include a transmission, gear reduction, or other component. In addition to altering the speed of the motor shaft **212**.**2**, it should be understood that the transmission, gear reduction, or other component may prevent the motor shaft **212**.**2** from making full revolutions (i.e., 365 degrees) around the motor shaft axis A_{MS}. In fact, it may be beneficial to physically limit the rotational movement of the motor shaft **212**.**2** (as opposed to electronically limiting said rotation using programming or control methodologies) because it helps ensure that the finger assembly **22***a*-**22***d* cannot be over-rotated. However, in other embodiments, the transmission, gear reduction, or other component may not prevent the motor shaft **212**.**2** from making full revolutions (i.e., 365 degrees) around the motor shaft axis A_{MS}. In this embodiment, electronically limiting said rotation using programming or control methodologies may be used to help ensure that the finger assembly **22***a*-**22***d* is not over-rotated. Alternatively, it may be desirable to allow the motor shaft **212**.**2** to full revolutions (i.e., 365 degrees) based on the gearing ratio.

[0095] As shown in the Figure, the worm drive gear **216** extends past a frontal portion of the motor housing **212**.**1** and: (i) includes an extent that is designed to receive the motor shaft **212**.**2** to enable said worm drive gear **216** to be coupled to the motor shaft **212**.**2**, and (ii) has helical or screw-like threads. Coupling said worm drive gear **216** to the motor shaft **212**.**2** enables the internal components of the motor **212** to rotate the motor shaft **212**.**2** around the motor shaft axis A_{MS}, wherein said rotation of the motor shaft **212**.**2** around the motor shaft axis A_{MS} causes the worm drive gear **216** to rotate about a worm drive gear axis A_{WDG}. Due to the configuration of the motor assembly **210** and the worm drive gear **216**, the motor shaft axis A_{MS} and the worm drive gear axis A_{WDG} are parallel, aligned, and coaxial. Additionally, this configuration also causes the motor shaft axis A_{MS} and the worm drive gear axis A_{WDG} to be parallel with (and potentially, coaxial with) the finger motor plane PFM. It should be understood that in other embodiments, the motor shaft axis A_{MS}, the worm drive gear axis A_{WDG}, and finger motor plane PFM may not be parallel, aligned, and coaxial. Instead, the motor shaft axis A_{MS} and the worm drive gear axis A_{WDG} may be perpendicular to one another, while the finger motor plane PFM may be parallel with the motor shaft axis A_{MS}.

[0096] As described above, the motor assembly **210** also includes a worm drive gear bearing **220** that is positioned within an extent of the knuckle assembly **230** and is designed to support the distal, rotating end of the worm drive gear **216**. In alternative embodiments, the worm drive gear bearing **220** may be omitted or integrally formed with the worm drive gear **216**. It should also be understood that in alternative embodiments, the motor shaft and the worm drive gear may be integrally formed and/or sealed.

[0097] As best shown in FIGS. **23**A-**23**C and discussed below, the worm drive gear **216** is designed to be in geared engagement with an extent of the knuckle assembly **230**, wherein said geared engagement enables the rotation of the worm drive gear **216**, via the motor shaft **212.2**, to cause the finger assembly **22***a*-**22***d* to move. As shown in the Figures, the motor assembly **210** is a part of the finger assembly **22***a*-**22***d* and is not located in a remote portion of the robot system. While this limits the dimensions of the hand (i.e., how small), it reduces linkages, increases modularity, reduces parts, increases accessibility into the working environment and increases the reliability of the finger assembly **22***a*-**22***d*.

b. Knuckle Assembly

[0098] The knuckle assembly **230** is positioned forward of a majority of the motor assembly **210** and is configured to allow the finger assembly **22***a*-**22***d* to move from the open, uncurled, or neutral position to the closed, curled, or inwardly rotated position. In said closed, curled, or inwardly rotated position, an acute interior angle is formed between the palm **62** and an interior surface of the finger assembly **22***a*-**22***d*. With reference, for example, to FIGS. **15** and **23**A-**23**C, the knuckle assembly **230** includes: (i) a housing assembly **232**, (ii) a knuckle PCB **234**, and (iii) a worm wheel **236** that is in contact with and configured to interact with the worm drive gear **216**.

[0099] The housing assembly **232** includes a frame **232.1**, a knuckle cover **232.2**, and an external skin **232.3**. The frame **232.1** includes: (i) sidewalls **232.1.10**, (ii) a headwall **232.1.12**, and (iii) a rearward extending mounting projection **232.1.14**. The mounting projection **232.1.14** is designed to be coupled with the motor housing **212.1**, while the headwall **232.1.12** is designed to be positioned adjacent to a frontal extent of the motor housing **212.1**. Thus, the frame **232.1** is positioned adjacent to both the lateral surface and the frontal surface of the motor housing **212.1**. This helps provide sufficient support for the knuckle and the portion of the finger assembly **22***a*-**22***d* that extends therefrom. In other words, the frame **232.1** is made from a material that is sufficiently rigid to withstand the torque/other forces that are associated with the movement of the various assemblies.

[0100] The sidewalls **232.1.10** of the frame **232.1** extend forward from the headwall **232.1.12**. Said sidewalls **232.1.10** also form a proximal link aperture **232.1.2** that is configured to receive an extent of a worm wheel interface **256** (discussed further below) and is configured to: (i) be secured to an extent of the housing frame **61.2**, and (ii) at least partially surround the worm wheel **236**, worm drive gear **216**, and an extent of the motor **212**. This design helps protect the motor shaft **212.2** and the worm drive gear **216** from damage that may be caused by an external force. The sidewalls **232.1.10** also include: (i) coupling points **232.1.4** for the knuckle PCB **234**, which is configured to control an extent of the finger assembly **22***a*-**22***d* and provide positional information back to the robot system, and (ii) bearing apertures **232.1.20** that are designed to receive the bearings that allow the motor assembly **210** to continue driving the worm drive gear **216** after an extent of the proximal assembly **250** has reached a resistance point (e.g., contact with an object).

[0101] The knuckle cover **232.2** is positioned adjacent to the sidewalls **232.1.10**, includes a frontal wall **232.2.2** that has a recess that is designed to receive the worm drive gear bearing **220**, and is designed to overlay an upper extent of the worm drive gear **216**. As such, the knuckle cover **232.2** supports and protects the worm drive gear **216** and an extent of the motor **212**. The support and protection provided by the knuckle cover **232.2** allows the external skin **232.3** to be: (i) less rigid than the knuckle cover **232.2**, (ii) easily replaceable in case of damage, and (iii) focused on minimizing the gap G that is formed between knuckle assembly **232** and the proximal assembly **250**. To minimize the gap G, the external skin **232.3** has: (i) a left to right, arched configuration, (ii) a front to back, curvilinear design, and (iii) varying thicknesses (see FIGS. **23**A-**23**C, **26**). The complex design of the external skin **232.3** enables: (i) a substantial extent of the external skin **232.3** to be positioned within an extent of the proximal assembly **250**, when the finger assembly **22***a*-**22***d* is in the open, uncurled, or neutral position, and (ii) a minor extent of, or none of, the external skin **232.3** to be positioned within an extent of the proximal assembly **250**, when the finger assembly **22***a*-**22***d* is in the closed, curled, or inwardly rotated position. By enabling at least a minimal extent of the external skin **232.3** to be positioned within, or adjacent to, the proximal assembly **250**, the gap G_1 formed between the assemblies **232** and **250** is minimized, and wherein said minimization of said gap G_1 is beneficial because it minimizes the chance or probability that a glove or external covering can be caught or pinched between these assemblies. In light of the above disclosure, the knuckle cover **232.2** may be made from metal or a sufficiently rigid material, while the external skin **232.3** may be made from deformable silicon, thermoset plastic, or any other suitable materials disclosed herein or known in the art.

[0102] The worm wheel **236** is a semi-circular toothed gear that is designed to be in geared engagement with the worm drive gear **216**. In particular, the worm wheel **236** includes: (i) a toothed section **236.2** that includes 18 teeth that encircle 220 degrees of the worm wheel **236**, (ii) a recessed portion **236.4** that is designed to receive an extent of the worm drive link **254.4.1**, and (iii) a central bearing opening **236.6** that are designed to receive a first and second worm bearings **256.2***a*, **256.2***b* (as discussed below). Said worm wheel **236** is designed to rotate about a worm wheel axis Aww, wherein said worm wheel axis Aww is located at the center of the central bearing opening **236.6** and the first pivot point P_1. It should be understood that in other embodiments, the worm wheel **236** may include additional teeth (e.g., between 19 and 50) or fewer teeth (e.g., between 5 and 17). Additionally, the toothed section **236.2** may span more than 220 degrees (e.g., between 221 and 300 degrees) or span less than 220 degrees (e.g., between 100 and 119 degrees).

[0103] As discussed above, the rotation of the motor shaft **212.2** around the motor shaft axis A_{MS} causes the worm drive gear **216** to rotate about a worm drive gear axis A_{WDG}. The rotation of the worm drive gear **216** about a worm drive gear axis A_{WDG} causes the worm wheel **236** to rotate above the worm wheel axis Aww or the first pivot point P_1. Because the toothed section **236.2** of the worm wheel **236** only encircles 220 degrees of the worm wheel **236**, said worm wheel **236** can only rotate approximately 220 degrees above the worm wheel axis Aww or the first pivot point P_1. In other words, the worm wheel **236** cannot fully rotate (i.e., at least 365 degrees or more) around the worm wheel axis Aww or the first pivot point P_1. Due to the configuration of the motor assembly **210**, the worm drive gear **216**, and worm wheel **236**, the worm wheel axis Aww is perpendicular to the motor shaft axis A_{MS}, the worm drive gear axis A_{WDG}, and the finger motor plane P_{FM}. However, as shown in the Figures, both the motor shaft axis A_{MS} and the worm drive gear axis A_{WDG} are positioned above or away from the palm in comparison to the worm wheel axis Aww or the first pivot point P_1. In other words, the worm wheel axis Aww or the first pivot point P_1 underlies an extent of the motor shaft axis A_{MS} and the worm drive gear axis A_{WDG}.

[0104] The knuckle PCB **234** includes a first finger encoder (e.g., magnetic, optical, capacitive, resistive, etc.) that is positioned proximate to the metacarpophalangeal joint MJ and configured to collect proximal data, wherein said proximal data includes information related to the rotation of the metacarpophalangeal joint MJ. Said proximal data may use the robot system to generate a vector representation (e.g., a space embedding) indicating the state of the proximal assembly **250** or the environment around the proximal assembly **250**. The encoder of the knuckle PCB **234** may collect data upon a specific command from the robot system or periodically (e.g., between 500 times per second to every minute). Also, as shown in the Figures, the controller **214** and said knuckle PCB can be co-located on a single PCB. In other embodiments, the controller **214** and the knuckle PCB **234** may be split on different PCBs.

c. Proximal Assembly

[0105] The proximal assembly **250** is positioned between the knuckle assembly **230** and the medial assembly **270** and is the first portion of the finger assembly **22***a*-**22***d* configured to move relative to the housing frame **61.2** and the palm **62** in response to actuation of the motor **210** and worm drive gear **216**. The proximal assembly **250** includes: (i) a proximal housing assembly **252**, (ii) a proximal link assembly **254**, (iii) the worm wheel interface **256**, and (iv) a proximal PCB **258**.

i. Proximal Housing Assembly

[0106] As shown in FIGS. **23**A-**24**B and **32-34**, the proximal housing assembly **252** is designed to substantially surround a majority of the other components of the proximal assembly **250**. To achieve this, the proximal housing assembly **252** forms an internal proximal recess **252.18**. The internal proximal recess **252.18** is designed to not only surround components of the proximal assembly **250**, but is also designed to receive: (i) an extent of the medial assembly **270** (namely, the medial tongue **272.20**), when the finger assembly **22***a*-**22***d* is in the open, uncurled, or neutral position, and (ii) a lesser extent of, or none of, the medial assembly **270** (namely, the medial tongue **272.20**), when the finger assembly **22***a*-**22***d* is in the closed, curled, or inwardly rotated position. In other words, the proximal housing assembly **252** overlies: (i) a substantial extent of the medial tongue **272.20** when the finger assembly **22***a*-**22***d* is in the open, uncurled, or neutral position, and (ii) a minor extent of, or none of, the medial tongue **272.20** when the finger assembly **22***a*-**22***d* is in the closed, curled, or inwardly rotated position. Stated another way, the percentage of the medial assembly **270** (namely, the medial tongue **272.20**) that is positioned within the proximal housing assembly **252** is reduced when the finger assembly **22***a*-**22***d* moves from the open, uncurled, or neutral position to the closed, curled, or inwardly rotated position. By enabling at least a minimal extent of the medial assembly **270** (namely, the medial tongue **272.20**) to be positioned within or adjacent to the proximal assembly **250**, the gap G_2 formed between the assemblies **250** and **270** is minimized, and wherein said minimization of said gap G_2 is beneficial because it minimizes the chance or probability that a glove or external covering can be caught or pinched between these assemblies.

[0107] As shown in FIGS. **17-26** and **32-33**, the proximal housing assembly **252** specifically includes: (i) a proximal jacket assembly **252.1** with a top member **252.1.1** and a bottom member **252.1.2**, and (ii) a proximal bottom casing assembly **252.2**. While the bottom member **252.1.2** is in direct contact with and underlies the proximal bottom casing assembly **252.2**, the finger assembly **22***a*-**22***d* lacks a proximal top casing assembly that is in direct contact with the top member **252.1.1**. This design is advantageous because the proximal bottom casing assembly **252.2** provides the bottom member **252.1.2** with additional rigidity, which enables said bottom member **252.1.2** to be made from a softer, easier-to-form, and potentially less durable material, thereby increasing the gripping capability of the end effector **10**. In contrast, the top member **252.1.1** does not need to include a softer, easier-to-form, and potentially less durable material because said top member **252.1.1** is not designed to come into regular contact with objects. Additionally, even if the materials of the proximal bottom casing assembly **252.2** and the bottom member **252.1.2** are the same, it may be desirable to form these components as two separate components to facilitate replicability without exposing an inner extent of the finger assembly **22***a*-**22***d*. Another way of describing this beneficial configuration includes the fact that the proximal jacket assembly **252.1** is configured to provide the primary external shape of the finger assembly **22***a*-**22***d*, while the proximal casing assembly **252.2** is configured to protect the proximal PCB **258** and provide a spacer between the proximal link assembly **254** and the proximal jacket assembly **252.1**. Nevertheless, it should be understood that in an alternative embodiment, the bottom member **252.1.2** and the proximal bottom casing assembly **252.2** may be integrally formed as a single structure.

[0108] As best shown in FIGS. **23**A-**24**B, the top member **252.1.1** of the proximal jacket assembly **252.1** includes an exterior surface back with a curvilinear extent in a first direction (namely, across the width of the finger assembly **22***a*-**22***d*), and the bottom member **252.1.2** of the proximal jacket assembly **252.1** includes an exterior palm surface with a curvilinear extent in the first direction (namely, across the width of the finger assembly **22***a*-**22***d*) and a second direction (namely, across the length of the finger assembly **22***a*-**22***d*). The curvilinear extent in the first direction helps ensure that the finger assembly **22***a*-**22***d* has rounded edges to help with grasping objects, while the curvilinear extent in the second direction helps ensure that the finger can curl inward. Additionally, the bottom member **252.1.2** of the proximal jacket assembly **252.1** may include a main body portion **252.1.2.1** and a rearward projection **252.1.2.2**, wherein said main body portion is designed to be positioned forward of the first joint or metacarpophalangeal joint MJ, while the rearward projection **252.1.2.2** is designed to underlie and protect the metacarpophalangeal joint MJ. Due to the fact that the bottom member **252.1.2** includes two distinct portions **252.1.2.1**, **252.1.2.2**, said bottom member **252.1.2** also includes two contact regions **61.4.4**, **61.4.6**. It should be understood that in an alternative embodiment, the portions **252.1.2.1**, **252.1.2.2** of the bottom member **252.1.2** may be omitted.

[0109] As discussed above, the proximal housing assembly **252** may be: (i) made from the same materials as the housing assembly **60**, (ii) made from material that differs from the materials used in the housing assembly **60**, and/or (iii) may include silicon, plastic (e.g., may include a polymer composition), carbon composite, or metal, a combination of these materials, any other material disclosed herein, and/or any other suitable material. Alternatively, the proximal housing assembly **252** may include additional components or layers (e.g., between three and an nth).

ii. Proximal Link Assembly

[0110] As shown in FIGS. **27-42**, the proximal link assembly **254** includes: (i) a primary or main proximal link or first bar **254.1**, (ii) a biasing assembly **254.2**, (iii) a medial assembly coupler **254.3**, and (iv) a proximal drive link assembly **254.4**. The proximal link assembly **254** is involved with all movements of the finger assembly **22***a*-**22***d*. In other words, at least one aspect of the proximal link assembly **254** must move in order to cause any portion of the finger assembly **22***a*-**22***d* to move. This feature is beneficial because it reduces complexities, reduces components, cost, weight, increases reliability, and may have other benefits.

[0111] The primary or main proximal link or first bar **254.1** is best shown in FIGS. **27** and **38-40**. The main proximal link **254.1** includes: (i) partially-circular frame members or first proximal link segment **254.1.1**, (ii) second proximal link segment **254.1.2**, (iii) third proximal link segment **254.1.3**, (iv) proximal link bridge **254.1.4**, (v) medial assembly opening **254.1.5**, and (vi) first and second medial link projections **254.1.6***a*, **254.1.6***b*. The partially-circular frame members segment **254.1.1** include left and right extents **254.1.1.1**, **254.1.1.2** that extend from the rearmost extent of the main proximal link **254** to line S_1 shown in FIG. **39**. Like partially-circular frame members segment **254.1.1**, the second proximal link segment **254.1.2** also includes left and right extents **254.1.2.1**, **254.1.2.2** that extend between lines S_1 and S_2 shown in FIG. **39**. As shown in FIG. **39**, the left and right extents **254.1.2.1**, **254.1.2.2** taper inward as they extend from line S_1 to line S_2, which reduces the overall width of the link **254.1**. The reduction in width is beneficial because it allows for a reduction in the width of the finger assembly **22***a*-**22***d* to allow for conformal materials to aid in gripping objects. It should be understood that in other embodiments, the taper may be greater or lesser, or it may be eliminated.

[0112] Also, as shown in FIG. **39**, like the second proximal link segment **254.1.2**, the third proximal link segment **254.1.3** also includes left and right extents **254.1.3.1**, **254.1.3.2** that extend forward from line S_2 toward the forward most extent of main proximal link or first bar **254.1**. These left and right extents **254.1.3.1**, **254.1.3.2** are substantially parallel to the left and right extents **254.1.1.1**, **254.1.1.2**, but are not aligned therewith due to the taper of the left and right extents **254.1.2.1**, **254.1.2.2**. In other embodiments, said left and right extents **254.1.3.1**, **254.1.3.2** need not be substantially parallel and/or may be substantially aligned with other components of the main proximal link **254.1**.

[0113] As shown in FIG. **38**, the partially-circular frame members segment **254.1.1** includes a metacarpophalangeal joint coupler **254.1.1.1** that helps form a first joint or metacarpophalangeal joint MJ and includes an axle aperture **254.1.1.1.1** and stopping projection **254.1.1.1.2**. As such, the first joint or metacarpophalangeal joint MJ is formed between the knuckle assembly **230** and the proximal assembly **250**. The axle aperture **254.1.1.1.1** of the metacarpophalangeal joint coupler **254.1.1.1** is non-circular and is configured to receive an extent of the worm wheel interface **256** (which will be discussed later). The non-circular configuration allows helps ensure that the worm wheel interface **256** does not slip within the aperture **254.1.1.1.1**, when the motor assembly **210** drives the worm drive gear **216**, which turns the worm wheel **236**, and whereby causing the worm drive link **254.4.1** and the proximal drive link **254.4.3** to move the primary or main proximal link or first bar **254.1**. Slipping within said aperture **254.1.1.1.1** would not only cause the finger assembly **22***a*-**22***d* to fail to properly move, but it would also cause the encoders and other sensors to error in knowing the finger assemblies **22***a*-**22***d* location and position in space. It should be understood that other non-circular configurations of the axle aperture **254.1.1.1.1** are contemplated by this disclosure (e.g., tear-drop).

[0114] Referring to FIGS. **27**, **28**, **34**, and **40**, the stopping projection **254.1.1.1.2** is positioned in a lower extent of the partially-circular frame members segment **254.1.1**. When the proximal assembly **250** is closed, curled, or in the inwardly rotated position, the stopping projection **254.1.1.1.2** includes a first limiting interface region **254.1.1.1.2.1** that is configured to interact with an extent of the knuckle frame member **232.1**. It should be understood that the above described interface region **254.1.1.1.2.1** need not make contact with the described adjacent structures, and instead, a gap may be present between these structures regardless of the state of the finger assembly **22***a*-**22***d*.

[0115] As shown in FIGS. **38-40**, the third segment **254.1.3** of the main proximal link **254.1** includes the second limiting interface region **254.1.3.1** and housing mounting projections **254.1.3.2**. The second limiting interface region **254.1.3.1** is best shown in FIGS. **23**A and **38-40** and is configured to prevent the proximal assembly **250** from over-rotating or curling backward. While the second limiting interface region **254.1.3.1** is positioned on the forwardmost extent of the third segment **254.1.3**, the housing mounting projections **254.1.3.2** are positioned on the uppermost point of the third segment **254.1.3** and are configured to couple to both the proximal jacket and proximal casing assemblies **252.1**, **252.2** within the finger assembly **22***a*-**22***d*. Other methods of preventing over-rotation and coupling the housing assembly **252** within the finger assembly **22***a*-**22***d* are contemplated by this disclosure. For example, the housing assembly **252** may be configured to prevent over-rotation, while said assembly **252** may be formed from a single piece of material.

[0116] As shown in FIG. **39**, the proximal bridge **254.1.4** extends between the left and right extents **254.1.3.1** and **254.1.3.2** of the third proximal link segment **254.1.3**. Thus, the combination of the proximal bridge **254.1.4** and the left and right extents **254.1.3.1**, **254.1.3.2** forms a U-shaped member with a proximal link recess **254.1.7**. Said proximal link recess **254.1.7** includes a first portion **254.1.7.1** and a second portion **254.1.7.2**. When the finger assembly **22***a*-**22***d* is closed, curled, or inwardly rotated position: (i) the first portion **254.1.7.1** that extends rearward from line S_3 is configured to receive the worm drive link **254.4.1**, and (ii) the second portion **254.1.7.2** that extends forward from line S_3 is configured to receive the proximal drive link **254.4.3**.

Finally, the medial assembly opening **254.1.5** and first and second medial link projections **254.1.6** are positioned in a forward extent of the proximal link **254.1** (i.e., forward of line S_3) and are configured to interact with the medial assembly **270**.

[0117] As shown in FIG. **52**, the biasing assembly **254.2** includes a biasing member **254.2.1**, a first biasing coupler **254.2.2**, and a second biasing coupler **254.2.3**. The first biasing coupler **254.2.2** is positioned within the first portion **254.1.7.1** of the proximal link recess **254.1.7** of the main proximal link **254.1** and extends between the left and right extents **254.1.3.1**, **254.1.3.2** of the third proximal link segment **254.1.3**. Meanwhile, the second biasing coupler **254.2.3** is coupled to a projection that depends from the proximal drive link **254.4.3** (discussed further below). As such, one end of the biasing member **254.2.1** is coupled to the first biasing coupler **254.2.2**, while a second opposed end of the biasing member **254.2.1** is coupled to the second biasing coupler **254.2.3**. The biasing member **254.2.1** may be a spring (e.g., coil spring) or any other member (e.g., magnet) that can provide a biasing force on an extent of the finger assembly ***22a-22d*** in order to control the order of closure/collapse of the components contained in said finger assembly ***22a-22d***.

[0118] As shown in FIGS. **31** and **57**, when the finger assembly ***22a-22d*** moves from the open, uncurled, or neutral position to the closed, curled, or inwardly rotated position, the biasing member **254.2.1** moves from a first or collapsed position with a length of L_1 to a second or extended position with a length L_2. In the first or collapsed position, the biasing member **254.2.1** exerts a first biasing force F_1 that is less than a second biasing force F_2 that is exerted in the second or extended position. The biasing member **254.2.1** is designed to prevent the medial or distal assemblies **270**, **280** before the proximal housing **252** has come into contact with a resistance point (e.g., an object). Once said proximal housing **252** has come into contact with a resistance point (e.g., an object), the main proximal link **254.1** and the proximal housing **252** stops moving. However, the motor assembly **210** can continue driving the worm drive gear **216** in a first direction, which turns the worm wheel **236**, whereby causing the worm drive link **254.4.1** and the proximal drive link **254.4.3** to move into the proximal link recess **254.1.7** and rotation about the worm wheel axis Aww, thus forcing the biasing member **254.2.1** to expand for its original state, and therefore forces the medial and distal assemblies **270**, **280** to curl inwards. The finger assembly ***22a-22d*** can uncurl or return to its original position, if the motor assembly **210** drove driving the worm drive gear **216** in a second direction, which turns the worm wheel **236**, whereby causing the worm drive link **254.4.1** and the proximal drive link **254.4.3** to move out of the proximal link recess **254.1.7**, thus forcing the medial and distal assemblies **270**, **280** to uncurl, therefore allowing the biasing member **254.2.1** to return to its original state, and consequently allowing the main proximal link **254.1** and the proximal housing **252** to return to their original position. In should be understood that other biasing members, structures, assemblies, or components may be used instead of the coil spring shown in the figures and in certain embodiments, that biasing assembly **254.2** may be eliminated.

[0119] As shown in in FIGS. **37** and **41-42**, the drive link assembly **254.4** includes: (i) worm drive link or second bar **254.4.1**, (ii) worm wheel coupler **254.4.2**, (iii) proximal drive link, angled link, third bar **254.4.3**, (iv) drive link coupler **254.4.4**. The worm drive link **254.4.1** includes: (i) a worm wheel interface region **254.4.1.3** at a first end of the worm drive link **254.4.1**, and wherein said worm wheel interface region **254.4.1.3** is configured to be positioned adjacent to and fixedly connected with the worm wheel **236**, and (ii) a worm wheel coupler recess **254.4.1.4** that is positioned adjacent to the worm wheel interface region **254.4.1.3** and configured to: (a) increase the interactive surface area between the worm drive link **254.4.1** and worm wheel **236**, (b) align the worm drive link **254.4.1** with the worm wheel **236**, and (c) is designed to ensure that the worm wheel coupler **254.4.2** does not interfere with the movement of the worm wheel **236**. It should be understood that the worm wheel coupler recess **254.4.1.4** may be omitted in other embodiments and an alternative version of the worm wheel coupler **254.4.2** may be used that lacks the clearance requirements necessitating the worm wheel coupler recess **254.4.1.4**.

[0120] The worm drive link **254.4.1** includes two interface regions, namely a third limiting interface region **254.4.1.1**, and a fourth limiting interface region **254.4.1.2**. The third limiting interface region **254.4.1.1** extends along a rear extent of the worm drive link **254.4.1** and is configured to be positioned adjacent to an extent of the knuckle cover **232.2** of the knuckle housing assembly **232** when the finger assembly ***22a-22d*** is in the open, uncurled, or neutral position. Meanwhile, the fourth limiting interface region **254.4.1.2** is positioned along a forward extent of the worm drive link **254.4.1** and is configured to be positioned adjacent to an extent of the main proximal link **254.1** when the finger assembly ***22a-22d*** is in the closed, curled, or inwardly rotated position. It should be understood that the above described interface regions **254.4.1.1**, **254.4.1.2** need not make contact with the described adjacent structure. Instead, a gap may be present between these structures regardless of the state of the finger assembly ***22a-22d***.

[0121] The proximal drive link, angled link, third bar **254.4.3** includes a worm drive link opening **254.4.3.1** at a first end and a medial link opening **254.4.3.2** at a second end. Said proximal drive link **254.4.3** is configured to be coupled between: (i) the worm drive link **254.4.1** using a drive link coupler **254.4.4** that is inserted through the worm drive link opening **254.4.3.1** and an extent of the worm drive link **254.4.1**, and (ii) a main medial link **274.1** (discussed further below) using a main medial link coupler **254.4.5** that is inserted through the medial link opening **254.4.3.2** and an extent of the main medial link **274.1**. The drive link coupler **254.4.4** enables the worm drive link **254.4.1** to be pivotably connected to the proximal drive link **254.4.3** in order to form a second pivot point P_2, and wherein the second pivot point P_2 is designed to move from a first location when the finger assembly ***22a-22d*** is in open, uncurled, or neutral position (FIG. **23**C) to a second location the finger assembly ***22a-22d*** is in the closed, curled, or inwardly rotated position (FIG. **57**). In comparing FIG. **23**C with FIG. **57**, it can be seen that the first location in further away from the palm **62** and is positioned closer to the motor assembly **210** in comparison to the second location. Said movement of the second pivot point P_2 enables the finger assembly ***22a-22d*** to transfer the movement of the worm drive link **254.4.1** to the main medial link **274.1**. As shown in FIGS. **23**C and **57**, this transfer of movement or energy, the angle between the worm drive link

254.4.1 and the proximal drive link **254.4.3** changes depending on the position of the finger assembly **22***a*-**22***d*.

iii. Worm Wheel Interface and Proximal PCB

[0122] The worm wheel interface **256** includes first and second worm locking members **256.1***a*, **256.1***b*, along with first and second worm bearings **256.2***a*, **256.2***b*. The worm wheel assembly **256** utilizes the configuration of the locking members and bearings **256.1***a*, **256.1***b*, **256.2***a*, **256.2***b* to allow the main proximal link **254.1** to remain in a fixed position once it has come into contact with a resistance point, while the motor assembly **210** continues to drive the proximal drive link assembly **254.4** (causing movement of the medial and distal assemblies **270**, **280**). In other words, the bearings **256.1***a*, **256.1***b* allow the main proximal link **254.1** to stop rotating even when the worm wheel **236** continues to rotate. It should be understood that without this slippage between the main proximal link **254.1** and the worm wheel **236**, the finger assembly **22***a*-**22***d* could not rotate the medial and distal assemblies **270**, **280** once the proximal assembly **250** came into contact with a resistance point.

[0123] The proximal PCB **258** includes a second finger encoder (e.g., magnetic, optical, capacitive, resistive, etc.) that is positioned proximate to the proximal interphalangeal joint PIJ and configured to collect medial data, wherein said medial data includes information related to the rotation of the proximal interphalangeal joint PIJ. Said medial data may use the robot system to generate a vector representation (e.g., a space embedding) indicating the state of the medial assembly **270** or the environment around the medial assembly **270**. The encoder of the proximal PCB **258** may collect data upon a specific command from the robot system or periodically (e.g., between 500 times per second to every minute).

d. Medial Assembly

[0124] The medial assembly **270** is positioned between the proximal assembly **250** and the distal assembly **280** and is the second portion of the finger assembly **22***a*-**22***d* configured to move relative to the palm **610**. The medial assembly **270** includes: (i) a medial housing assembly **272**, and (ii) a medial link assembly **274**.

i. Medial Housing Assembly

[0125] As shown in FIGS. **23**A-**24**B, **43**-**45**, and **57**, the medial housing assembly **272** is designed to substantially surround a majority of the other components of the medial assembly **270**. To achieve this, the medial housing assembly **272** forms an internal medial recess **272.18**. The internal medial recess **272.18** is designed to not only surround components of the medial assembly **270**, but is also designed to receive: (i) an extent of the distal assembly **280** (namely, the distal tongue **282.20**), when the finger assembly **22***a*-**22***d* is in the open, uncurled, or neutral position, and (ii) a lesser extent of, or none of, the distal assembly **280** (namely, the distal tongue **282.20**), when the finger assembly **22***a*-**22***d* is in the closed, curled, or inwardly rotated position. In other words, the medial housing assembly **272** overlies: (i) a substantial extent of the distal tongue **282.20** when the finger assembly **22***a*-**22***d* is in the open, uncurled, or neutral position, and (ii) a minor extent of, or none of, the distal tongue **282.20** when the finger assembly **22***a*-**22***d* is in the closed, curled, or inwardly rotated position. Stated another way, the percentage of the distal assembly **280** (namely, the distal tongue **282.20**) that is positioned within the medial housing assembly **272** is reduced when the finger assembly **22***a*-**22***d* moves from the open, uncurled, or neutral position to the closed, curled, or inwardly rotated position. By enabling at least a minimal extent of the distal assembly **280** (namely, the distal tongue **282.20**) to be positioned within or adjacent to the medial assembly **270**, the gap G_3 formed between the assemblies **270** and **280** is minimized, and wherein said minimization of said gap G_3 is beneficial because it minimizes the chance or probability that a glove or external covering can be caught or pinched between these assemblies.

[0126] As shown in FIGS. **17**-**26** and **43**-**45**, the medial housing assembly **272** specifically includes: (i) a medial jacket assembly **272.1** with a top member **272.1.1** and a bottom member **272.1.2**, and (ii) a medial bottom casing assembly **272.2**. While the bottom member **272.1.2** is in direct contact with and underlies the medial bottom casing assembly **272.2**, the finger assembly **22***a*-**22***d* lacks a medial top casing assembly that is in direct contact with the top member **272.1.1**. This design is advantageous because the medial bottom casing assembly **272.2** provides the bottom member **272.1.2** with additional rigidity, which enables said bottom member **272.1.2** to be made from a softer, easier-to-form, and potentially less durable material, thereby increasing the gripping capability of the end effector **10**. In contrast, the top member **272.1.1** does not need to include a softer, easier-to-form, and potentially less durable material because said top member **272.1.1** is not designed to come into regular contact with objects. Additionally, even if the materials of the medial bottom casing assembly **272.2** and the bottom member **272.1.2** are the same, it may be desirable to form these components as two separate components to facilitate replicability without exposing an inner extent of the finger assembly **22***a*-**22***d*. Another way of describing this beneficial configuration includes the fact that the medial jacket assembly **272.1** is configured to provide the primary external shape of the finger assembly **22***a*-**22***d*, while the medial casing assembly **272.2** is configured to protect the proximal PCB **258** and provide a spacer between the medial link assembly **274** and the medial jacket assembly **272.1**. Nevertheless, it should be understood that in an alternative embodiment, the bottom member **272.1.2** and the medial bottom casing assembly **272.2** may be integrally formed as a single structure.

[0127] As best shown in FIGS. **23**A-**24**B, the top member **272.1.1** of the medial jacket assembly **272.1** includes an exterior surface back with a curvilinear extent in a first direction (namely, across the width of the finger assembly **22***a*-**22***d*), and the bottom member **272.1.2** of the medial jacket assembly **272.1** includes an exterior palm surface that is curvilinear extent in the first direction (namely, across the width of the finger assembly **22***a*-**22***d*) and a second direction (namely, across the length of the finger assembly **22***a*-**22***d*). The curvilinear extent in the first direction helps ensure that the finger assembly **22***a*-**22***d* has rounded edges to help with grasping objects, while the curvilinear extent in the second direction helps ensure that the finger can curl inward. Additionally and as discussed above, the top member **272.1.1** of the medial jacket assembly **272.1** includes a rearwardly extending medial tongue **272.20**. The medial tongue **272.20** has an arched shape with a curvilinear rear surface **272.20.2**, wherein the width of said medial tongue **272.20** is reduced from a first or front width W_1 to a second or rear width W_2. As such, the medial tongue **272.20** includes curvilinear extents in at least two directions. As discussed above, the medial tongue **272.20** is designed to be positioned within or adjacent to proximal housing assembly **252** and configured to minimize the gap G_2 that is formed between assemblies **250** and **270**. It should be understood that in an alternative embodiment, the medial tongue **272.20** may be omitted.

[0128] As discussed above, the medial housing assembly **272** may be: (i) made from the same materials as the housing assembly **60**, (ii) made from materials that differ from the materials used in the housing assembly **60**, and/or (iii) may include silicon, plastic (e.g., may include a polymer composition), carbon composite, or metal, a combination of these materials, and/or any other know material used in robot systems. Alternatively, the medial housing assembly **272** may include additional components or layers (e.g., between three and an nth). It should be also be understood in alternative embodiments that the medial jacket assembly **272.1** and the medial casing assembly **272.2** may be combined into a single component and/or additional exterior members may be added to the end effector **10**/finger assembly **22***a*-**22***d*.

ii. Medial Link Assembly **274**

[0129] As shown in FIG. **40**, the medial link assembly **274** includes: (i) a primary or main medial link or fourth bar **274.1**, (ii) a medial drive link or fifth bar **274.2**, and (iii) a main/drive link couplers or sixth bar **274.3***a*, **274.3***b*. The medial link assembly **274** is involved with a majority of the movements of the finger assembly **22***a*-**22***d*. While the proximal assembly **250** could move without causing a positional change between said proximal assembly **250** and the medial assembly **270**, the distal assembly **280** cannot move without causing a positional change between said distal assembly **280** and the medial assembly **270**. Because most movements of the end effector **10** involve movement of the medial assembly **270** relative to the proximal assembly **250** and/or distal assembly **280**, said medial assembly **270** is involved with a majority of the movements of the finger assembly **22***a*-**22***d*. As discussed above, this is contrast to conventional end effectors and/or conventional fingers and is beneficial because it reduces complexities, reduces components, increases reliability, and may afford other benefits.

[0130] The primary or main medial link or fourth bar **274.1** is best shown in FIGS. **46-53**. The main medial link **274.1** helps form a second or proximal interphalangeal joint PIJ that is positioned between the proximal assembly **250** and the medial assembly **270**. The main medial link **274.1** is designed to be pivotably connected to both the proximal link **254.1** and the proximal drive link **254.4.3** and includes three integrally formed components, wherein said components include: (i) proximal interphalangeal joint coupler **274.1.1** that extends rearward from line M_1, (ii) medial link neck or biasing neck **274.1.2** that extends between lines M_1 and M_2, and (iii) medial link extension **274.1.3** that extends forward from M_2. The first component of the main medial link **274.1** is the proximal interphalangeal joint coupler **274.1.1** and is comprised of: (i) a first and second partially-triangular frame members **274.1.1.1***a*, **274.1.1.1***b*, (ii) a first medial link or interphalangeal joint recesses **274.1.1.2**, and (iii) medial link bridge **274.1.1.3** that couples the first and second partially-triangular frame members **274.1.1.1***a*, **274.1.1.1***b* to one another. The first and second partially-triangular frame members **274.1.1.1***a*, **274.1.1.1***b* are the rearmost extent of the main medial link **274.1** and have: (i) a proximal drive link aperture **274.1.1.1.1**, (ii) a drive link assembly recesses **274.1.1.2**, (iii) first and second limiting projections **274.1.1.1.3***a*, **274.1.1.1.3***b*, and (vi) a proximal main link aperture **274.1.1.1.4**.

[0131] As discussed above, the first and second partially-triangular frame members **274.1.1.1***a*, **274.1.1.1***b* of the proximal interphalangeal joint coupler **274.1.1** of the main medial link **274.1** include the proximal drive link aperture **274.1.1.1.1**. In particular, the proximal drive link aperture **274.1.1.1.1** is formed in the drive link assembly recesses **274.1.1.1.5***a*, **274.1.1.1.5***b* and is configured to receive an extent of a securement member **274.1.1.1.10** that pivotally connects the proximal drive link assembly **254.4** to the main medial link **274.1**. Pivotally connecting the proximal drive link assembly **254.4** to the main medial link **274.1** forms a third pivot point P_3, which further enables the transfer of energy from the motor assembly **210** to the distal assembly **280**. Like a majority of the pivot points, the third pivot point P_3 is configured to move from a first location to a second location when the finger assembly **22***a*-**22***d* moves from the open, uncurled, or neutral position to the closed, curled, or inwardly rotated position. When comparing FIG. **31** to FIG. **57**, the first location is positioned rearward and above or towards the back of the end effector **10** in comparison to the second location.

[0132] The proximal link opening **274.1.1.1.4** that is formed in the first and second partially-triangular frame members **274.1.1.1***a*, **274.1.1.1***b* and is positioned forward and below the proximal drive link aperture **274.1.1.1.1**. In particular, the proximal link opening **274.1.1.1.4** pivotally couples the main proximal link **254.1** to the main medial link **274.1** using the medial assembly coupler **254.3**, and whereby creating a fifth pivot point P_5. Unlike a majority of the other pivot points, the fifth pivot point P_5 is semi-fixed because: (i) unlike the first pivot point P_1, it moves when the proximal assembly **250** moves, and (ii) unlike the second pivot point P_2 or the third pivot point P_3, it cannot move relative to the proximal assembly **250**. Thus, the movement of the fifth pivot point P_5 is between the movement capabilities of the fixed and non-fixed pivot points and therefore is semi-fixed. Said fifth pivot point P_5 needs to be fixed relative to the proximal assembly **250** to enable the proximal drive link assembly **254.4** to force the medial assembly **270** around a pivot point P_5 or medial axis AM. Said medial axis AM is parallel with the worm wheel axis Aww, but is perpendicular (in one direction) to both the motor shaft axis A_{MS} and the worm drive gear axis A_{WDG}.

[0133] The first and second limiting projections **274.1.1.1.3***a*, **274.1.1.3***b* of the proximal interphalangeal joint coupler **274.1.1** have a wedge configuration that forms the sixth limiting interface regions **274.1.1.1.1.1***a*, **274.1.1.1.1.1***b*. Said sixth limiting interface regions **274.1.1.1.1.1***a* and **274.1.1.1.1.1***b* are positioned adjacent to the medial drive link **274.2** and help ensure that the medial assembly **274** does not over-rotate or curl backward. Finally, the combination of the first and second partially-triangular frame members **274.1.1.1***a*, **274.1.1.1***b* and the medial link bridge **274.1.1.3** form a U-shaped extent, which said first medial link or interphalangeal joint recess **274.1.1.2** is formed therebetween. Said interphalangeal joint recess **274.1.1.2** is designed to receive an extent of the proximal link assembly **254**, and specifically an second end of the proximal drive link **254.4.3**. The interlocking, stacking, and/or overlying nature of these connections will be discussed in greater detail below.

[0134] The medial link neck or biasing neck **274.1.2** extends forward from the first and second partially-triangular frame members **274.1.1.1***a*, **274.1.1.1***b* and couples the first and second partially-triangular frame members **274.1.1.1***a*, **274.1.1.1***b* to a medial link extension **274.1.3**. The medial link extension **274.1.3** is configured to be coupled to the medial housing assembly **272** and provides a majority of the structural body of said main medial link **274.1**. The medial link extension **274.1.3** includes: (i) a medial link frame member **274.1.3.1**, (ii) a medial link sloped member **274.1.3.2**, (iii) a housing mounting projections **274.1.3.4**, and (iv) medial drive link projections **274.1.3.5***a*, **274.1.3.5***b*. The combination of the frame members **274.1.3.1**, sloped member **274.1.3.2**, and frontal member **274.1.3.3** form a medial link recess or truncated rectangular-shaped recess **274.1.3.6** in the middle of the medial link extension **274.1.3**. This medial link recess or truncated rectangular-shaped recess **274.1.3.6** is configured to receive an extent of the medial drive link **274.2** and allow sufficient clearance for the movement of the medial drive link **274.2** relative to the medial link extension **274.1.3**. Meanwhile, the housing mounting projections **274.1.3.4** are positioned on the uppermost point of the medial link frame member **274.1.3.1** and are configured to couple both the medial jacket and medial casing assemblies **272.1**, **272.2** to the main medial link **274.1**.

[0135] The medial drive link projections **274.1.3.5***a*, **274.1.3.5***b* extend from the sides of the medial link extension **274.1.3** and are configured to be positioned within the distal housing assembly **282**. Like the fifth pivot point P_5, the sixth pivot point P_6 is semi-fixed because: (i) unlike the first pivot point P_1, it moves when the medial assembly **270** moves, and (ii) unlike the second pivot point P_2 or the third pivot point P_3, it cannot move relative to the medial assembly **270**. Thus, the movement of the sixth pivot point P_6 is between the movement capabilities of the fixed and non-fixed pivot points and therefore is semi-fixed. Said sixth pivot point P_6 needs to be fixed relative to the medial assembly **270** to enable the movement of the medial drive link **274.2** to force the distal assembly **280** around a pivot point P_6 or distal axis Ap. Said distal axis A_D is parallel with the medical axis AM and the worm wheel axis Aww, but is perpendicular (in one direction) to both the motor shaft axis A_{MS} and the worm drive gear axis A_{WDG}.

[0136] The medial drive link, or fifth bar **274.2** is best shown in FIGS. **26-31** and **46-53**. The medial drive link **274.2** includes: (i) an angled segment **274.2.2** forward from a rearmost point of the medial drive link **274.2** to line M_3, (iii) lateral segment **274.2.3** extending from line M_3 to M_4, and (iv) the elongated segment **274.2.4** extending forward from line M_4. This complex geometry can be best seen in FIG. **53**. The angled segment **274.2.2** of the medial drive link **274.2** includes main proximal link opening **274.2.2.1** that are configured to receive first and second medial link projections **254.1.6***a*, **254.1.6***b* to form the fourth pivot point P_4. In other words, the medial drive link **274.2** is pivotably connected to the medial link **274.1**: (i) on a first side of a sagittal plane extending through the finger assembly via opening **274.2.2.1** and a projection **254.1.6***a*, and (ii) on a second side of a sagittal plane extending through the finger assembly via opening **274.2.2.1** and a projection **254.1.6***b*. Like the fifth pivot point P_5 and the sixth pivot point P_6, the fourth pivot point P_4 is semi-fixed because: (i) unlike the first pivot point P_1, it moves when the proximal assembly **250** moves, and (ii) unlike the second pivot point P_2 or the third pivot point P_3, it cannot move relative to the proximal assembly **250**. Thus, the movement of the fourth pivot point P_4 is between the movement capabilities of the fixed and non-fixed pivot points and therefore is semi-fixed. Said fourth pivot point P_4 needs to be fixed relative to the proximal assembly **250** to enable the medial drive link **274.2** to rotate around the fourth pivot point P_4.

[0137] The main/drive link couplers or sixth bar **274.3***a*, **274.3***b* is secured within an extent of the distal housing assembly **282** and is configured to couple the main medial link **274.1** and the medial drive link **274.2** to one another, while being positioned within an extent of the distal assembly **280**. The main/drive link couplers **274.3***a*, **274.3***b***.3** includes: (i) a main body **274.3.1** with a first aperture or upper coupler aperture **274.3.1.1**, and a second aperture or lower coupler aperture **274.3.1.2**, and (ii) first and second flanges **274.3.2***a*, **274.3.2***b*. While the flanges **274.3.2***a*, **274.3.2***b* surround the apertures **274.3.1.1**, **274.3.1.2**: (i) the apertures **274.3.1.1** are configured to receive the medial drive link projections **274.1.3.5***a*, **274.1.3.5***b*, and (ii) the apertures **274.3.1.2** are configured to receive the left and right portion couplers **274.2.5***a*, **274.2.5***b*. It should be understood that the main/drive link couplers **274.3***a*, **274.3***b* may be eliminated in certain embodiments, and instead, the main medial link **274.1** and the medial drive link **274.2** may be coupled to one another differently.

[0138] As shown in the Figures, the link assemblies **254**, **274**, and **284** have interlocking, overlapping, underlying, and/or stacking configuration. This complex configuration helps increase the durability of the finger assembly **22***a*-**22***d*. In particular, the worm drive link **254.4.1** includes a forked second end that is designed to receive an extent of the first end of the proximal drive link **254.4.3**. Likewise, the main medial link **274.1** also includes a forked rear end that is formed by the first and second partially-triangular frame members **274.1.1.1***a*, **274.1.1.1***b* that is designed to receive a second end of the proximal drive link **254.4.3**. As such, both ends of the proximal drive link **254.4.3** is centered within a fork-like recess formed in the adjacent links. The links also are designed to position the primary proximal link **254.1** outside of the worm wheel **236** and an extent of the medial primary **274.1**. This not only provides the finger assembly **22***a*-**22***d* with rigidity, but it also allows the finger assembly **22***a*-**22***d* to narrow as it extends from the base of the finger assembly **22***a*-**22***d* to the tip of the said finger assembly **22***a*-**22***d*. This configuration also allows for the second end of the proximal drive link **254.4.3** to be positioned within the main medial link **274.1**, which is also positioned within the primary proximal link **254.1**. The medial drive link **274.2** not only includes an extent that is positioned outside of the main medial link **274.1**, but it also includes an extent that is positioned within the main medial link **274.1**. And finally, an extent of the distal assembly **280** is positioned outside of the main medial link **274.1**. In sum, each of the links is supported on two sides, and therefore, said links are not solely supported on a single side. Nevertheless, in an alternative embodiment, the links could be supported on a single side.

[0139] Based on the above disclosure, as best shown in FIG. **57**, and when the finger assembly **22***a*-**22***d* is in the closed, curled, or in the inwardly rotated position, the proximal link recess **254.1.7** is designed to receive a substantial extent of the proximal link assembly **254**. Additionally, the medial link recess or truncated rectangular-shaped recess **274.1.3.6** is designed to receive differing extents of the medial drive link **274.2** based on the position of the finger assembly **22***a*-**22***d*. Further, the interphalangeal joint recesses **274.1.1.2** is designed to receive the second end of the proximal link assembly **254**. Based on this disclosure, it should be understood that the

e. Distal Assembly **280**

[0140] The distal assembly **280** is positioned forward of the medial assembly **270** and is the third portion of the finger assembly **22***a*-**22***d* configured to move relative to the palm **610**. The distal assembly **280** includes: (i) a distal housing assembly **282**, and (ii) a distal link assembly **284**.

i. Distal Housing Assembly **282**

[0141] As shown in FIGS. **23**A-**24**B, **43**-**45**, and **57**, the distal housing assembly **282** is designed to substantially surround a majority of the other components of the distal assembly **280**. To achieve this, the distal housing assembly **282** forms an internal distal recess **282.18** and specifically includes: (i) a distal jacket assembly **282.1** with a top member **282.1.1** and a bottom member **282.1.2**, and (ii) a distal bottom casing assembly **282.2**. While the bottom member **282.1.2** is in direct contact with and underlies the distal bottom casing assembly **282.2**, the finger assembly **22***a*-**22***d* lacks a distal top casing assembly that is in direct contact with the top member **282.1.1**. This design is advantageous because the distal bottom casing assembly **282.2** provides the bottom member **282.1.2** with additional rigidity, which enables said bottom member **282.1.2** to be made from a softer, easier-to-form, and potentially less durable material, thereby increasing the gripping capability of the end effector **10**. In contrast, the top member **282.1.1** does not need to include a softer, easier-to-form, and potentially less durable material because said top member **282.1.1** is not designed to come into regular contact with objects. Additionally, even if the materials of the distal bottom casing assembly **282.2** and the bottom member **282.1.2** are the same, it may be desirable to form these components as two separate components to facilitate replicability without exposing an inner extent of the finger assembly **22***a*-**22***d*. Another way of describing this beneficial configuration includes the fact that the distal jacket assembly **282.1** is configured to provide the primary external shape of the finger assembly **22***a*-**22***d*, while the distal casing assembly **282.2** is configured to protect the distal link assembly **284**. Nevertheless, it should be understood that in an alternative embodiment, the bottom member **282.1.2** and the distal bottom casing assembly **282.2** may be integrally formed as a single structure.

[0142] As best shown in FIGS. **23**A-**24**B, the top member **282.1.1** of the distal jacket assembly **282.1** includes an exterior surface back with a curvilinear extent in a first direction (namely, across the width of the finger assembly **22***a*-**22***d*), and the bottom member **282.1.2** of the distal jacket assembly **282.1** includes an exterior palm surface that is curvilinear extent in the first direction (namely, across the width of the finger assembly **22***a*-**22***d*) and a second direction (namely, across the length of the finger assembly **22***a*-**22***d*). The curvilinear extent in the first direction helps ensure that the finger assembly **22***a*-**22***d* has rounded edges to help with grasping objects, while the curvilinear extent in the second direction helps ensure that the finger can curl inward. Additionally and as discussed above, the top member **282.1.1** of the distal jacket assembly **282.1** includes a rearwardly extending distal tongue **282.20**. The distal tongue **282.20** has an arched shape with a curvilinear rear surface **282.20.2**, wherein the width of said distal tongue **282.20** is reduced from a first or front width to a second or rear width. As such, the distal tongue **282.20** includes curvilinear extents in at least two directions. As discussed above, the distal tongue **282.20** is designed to be positioned within or adjacent to medial housing assembly **272** and configured to minimize the gap G_3 that is formed between assemblies **270** and **280**. It should be understood that in an alternative embodiment, the distal tongue **282.20** may be omitted.

[0143] As discussed above, the distal housing assembly **282** may be: (i) made from the same materials as the housing assembly **60**, (ii) made from materials that differ from the materials used in the housing assembly **60**, and/or (iii) may include silicon, plastic (e.g., may include a polymer composition), carbon composite, or metal, a combination of these materials, and/or any other know material used in robot systems. Alternatively, the distal housing assembly **282** may include additional components or layers (e.g., between three and an nth). It should be also be understood in alternative embodiments that the distal jacket assembly **282.1** and the distal casing assembly **282.2** may be combined into a single component and/or additional exterior members may be added to the end effector **10**/finger assembly **22***a*-**22***d*.

ii. Distal Link Assembly **284**

[0144] As shown in FIGS. **54**-**55**, the distal link assembly **284** includes primary or main distal link or seventh bar **284.1** that helps form a third joint or distal interphalangeal joint **284.1.1**, and includes a tip assembly **284.1.2**. Said third joint or distal interphalangeal joint **284.1.1** is formed between the medial assembly **270** and the distal assembly **280**. The distal link assembly **284** is involved in the least number of movements of the finger assembly **22***a*-**22***d* compared to the number of movements involving the proximal and medial assemblies **250**, **270**. As best shown in FIGS. **54**-**55**, the third joint **284.1.1** includes first and second coupler recesses **284.1.1.1***a*, **284.1.1.1***b*, while the tip assembly **284.1.2** has: (i) a tip body **284.1.2.1** with first and second portions **284.1.2.1.1***a*, **284.1.2.1.1***b*, and internal projections **284.1.2.1.2**, and (ii) tip coupler **284.1.2.2** for coupling the first and second portions **284.1.2.1.1***a*, **284.1.2.1.1***b* of the tip body **284.1.2.1** to one another.

D. Industrial Application

[0145] While the disclosure shows illustrative embodiments of a robot (in particular, a humanoid robot), it should be understood that embodiments are designed to be examples of the principles of the disclosed assemblies, methods and systems, and are not intended to limit the broad aspects of the disclosed concepts to the embodiments illustrated. As will be realized, the disclosed robot, and its functionality and methods of operation, are capable of other and different configurations and several details are capable of being modified all without departing from the scope of the disclosed methods and systems. For example, one or more of the disclosed embodiments, in part or whole, may be combined with a disclosed assembly, method and system. As such, one or more steps from the diagrams or components in the Figures may be selectively omitted and/or combined consistent with the disclosed assemblies, methods and systems. Additionally, one or more steps from the arrangement of components may be omitted or performed in a different order. Accordingly, the drawings, diagrams, and detailed description are to be regarded as illustrative in nature, not restrictive or limiting, of the said humanoid robot.

[0146] While the above-described robot is designed as a head for use with a general-purpose humanoid robot, it should be understood that its assemblies, components, learning capabilities, and/or kinematic capabilities may be used with other robots. Examples of other robots include: articulated robot (e.g., an arm having two, six, or ten degrees of freedom, etc.), a cartesian robot (e.g., rectilinear or gantry robots, robots having three prismatic joints, etc.), Selective Compliance Assembly Robot Arm (SCARA) robots (e.g., with a donut shaped work envelope, with two parallel joints that provide compliance in one selected plane, with rotary shafts positioned vertically, with an end effector attached to an arm, etc.), delta robots (e.g., parallel link robots with parallel joint linkages connected with a common base, having direct control of each joint over the end effector, which may be used for pick-and-place or product transfer applications, etc.), polar robots (e.g., with a twisting joint connecting the arm with the base and a combination of two rotary joints and one linear joint connecting the links, having a centrally pivoting shaft and an extendable rotating arm, spherical robots, etc.), cylindrical robots (e.g., with at least one rotary joint at the base and at least one prismatic joint connecting the links, with a pivoting shaft and extendable arm that moves vertically and by sliding, with a cylindrical configuration that offers vertical and horizontal linear movement along with rotary movement about the vertical axis, etc.), self-driving car, a kitchen appliance, construction equipment, or a variety of other types of robot systems. The robot system may include one or more sensors (e.g., cameras, temperature, pressure, force, inductive or capacitive touch), motors (e.g., servo motors and stepper motors), actuators, biasing members, encoders, housing, or any other component known in the art that is used in connection with robot systems. Likewise, the robot system may omit one or more sensors (e.g., cameras, temperature, pressure, force, inductive or capacitive touch), motors (e.g., servo motors and stepper motors), actuators, biasing members, encoders, housing, or any other component known in the art that is used in connection with robot systems.

[0147] In other embodiments, other configurations and/or components may be utilized. As is known in the data processing and communications arts, a general-purpose computer typically comprises a central processor or other processing device, an internal communication bus, various types of memory or storage media (RAM, ROM, EEPROM, cache memory, disk drives etc.) for code and data storage, and one or more network interface cards or ports for communication purposes. The software functionalities involve programming, including executable code as well as associated stored data. The software code is executable by the general-purpose computer. In operation, the code is stored within the general-purpose computer platform. At other times, however, the software may be stored at other locations and/or transported for loading into the appropriate general-purpose computer system.

[0148] A server, for example, includes a data communication interface for packet data communication. The server also includes a central processing unit (CPU), in the form of one or more processors, for executing program instructions. The server platform typically includes an internal communication bus, program storage and data storage for various data files to be processed and/or communicated by the server, although the server often receives programming and data via network communications. The hardware elements, operating systems and programming languages of such servers are conventional in nature, and it is presumed that those skilled in the art are adequately familiar therewith. The server functions may be implemented in a distributed fashion on a number of similar platforms, to distribute the processing load.

[0149] Hence, aspects of the disclosed methods and systems outlined above may be embodied in programming. Program aspects of the technology may be thought of as "products" or "articles of manufacture" typically in the form of executable code and/or associated data that is carried on or embodied in a type of machine-readable medium. "Storage" type media includes any or all of the tangible memory of the computers, processors or the like, or associated modules thereof, such as various semiconductor memories, tape drives, disk drives and the like, which may provide non-transitory storage at any time for the software programming. All or portions of the software may at times be communicated through the Internet or various other telecommunication networks. Thus, another type of media that may bear the software elements includes optical, electrical and electromagnetic waves, such as used across physical interfaces between local devices, through wired and optical landline networks and over various air-links. The physical elements that carry such waves, such as wired or wireless links, optical links or the like, also may be considered as media bearing the software. As used herein, unless restricted to non-transitory, tangible "storage" media, terms such as computer or machine "readable medium" refer to any medium that participates in providing instructions to a processor for execution.

[0150] A machine-readable medium may take many forms, including but not limited to, a tangible storage medium, a carrier wave medium or physical transmission medium. Non-volatile storage media include, for example, optical or magnetic disks, such as any of the storage devices in any computer(s) or the like, such as may be used to implement the disclosed methods and systems. Volatile storage media include dynamic memory, such as the main memory of such a computer platform. Tangible transmission media include coaxial cables, copper wire and fiber optics, including the wires that comprise a bus within a computer system. Carrier-wave transmission media can take the form of electric or electromagnetic signals, or acoustic or light waves such as those generated during radio frequency (RF) and infrared (IR) data communications. Common forms of computer-readable media therefore include for example: a floppy disk, a flexible disk, hard disk, magnetic tape, any other magnetic medium, a CD-ROM, DVD or DVD-ROM, any other optical medium, punch cards, paper tape, any other physical storage medium with patterns of holes, a RAM, a PROM and EPROM, a FLASH-EPROM, any other memory chip or cartridge, a carrier wave transporting data or instructions, cables or links transporting such a carrier wave, or any other medium from which a computer can read programming code and/or data. Many of these forms of computer readable media may be involved in carrying one or more sequences of one or more instructions to a processor for execution.

[0151] It is to be understood that the invention is not limited to the exact details of construction, operation, exact materials or embodiments shown and described, as obvious modifications and equivalents will be apparent to one skilled in the art. While the specific embodiments have been illustrated and described, numerous modifications come to mind without significantly departing from the spirit of the invention, and the scope of protection is only limited by the scope of the accompanying Claims. It should also be understood that substantially utilized herein means a deviation less than 15% and preferably less than 5%. It should also be understood that other configuration or arrangements of the above-described components is contemplated by this Application. Moreover, the description provided in the background section should not be assumed to be prior art merely because it is mentioned in or associated with the background section. The background section may include information that describes one or more aspects of the subject of the technology. Finally, the mere fact that something is described as conventional does not mean that the Applicant admits it is prior art.

[0152] In this Application, to the extent any U.S. patents, U.S. patent applications, or other materials (e.g., articles) have been incorporated by reference, the text of such materials is only incorporated by reference to the extent that they do not conflict with materials, statements and drawings set forth herein. In the event of such conflict, the text of the present document controls, and terms in this document should not be given a narrower reading in virtue of the way in which those terms are used in other materials incorporated by reference. It should also be understood that structures and/or features not directly associated with a robot cannot be adopted or implemented into the disclosed humanoid robot without careful analysis and verification of the complex realities of designing, testing, manufacturing, and certifying a robot for completion of usable work nearby and/or around humans. Theoretical designs that attempt to implement such modifications from non-robotic structures and/or features are insufficient (and in some instances, woefully insufficient) because they amount to mere design exercises that are not tethered to the complex realities of successfully designing, manufacturing and testing a robot.

1. An end effector for a humanoid robot, the end effector comprising:
- a frame;
- a finger assembly removably connected to the frame, the finger assembly comprising:
  - a worm drive link;
  - a proximal drive link pivotably coupled to the worm drive link;
  - a proximal link defining a proximal link recess configured to selectively receive at least a portion of the worm drive link and at least a portion of the main proximal drive link therein;
  - a medial link pivotably connected to both the proximal link and the proximal drive link and including a medial link recess configured to receive an extent of the medial drive link; and
  - a medial drive link pivotably connected to the medial link by at least one first pivotable coupling located on a first side of a sagittal plane extending through the finger assembly and at least one second pivotable coupling located on a second side of the sagittal plane.

2. The end effector of claim **1**, wherein the finger assembly lacks a mechanical cable configured to actuate any component of the finger assembly.

3. The end effector of claim **1**, wherein the finger assembly further comprises:
- a motor including a motor shaft;
- a worm drive gear coupled to the motor shaft;
- a worm wheel in geared engagement with the worm drive gear and fixedly connected to the worm drive link; and
- a proximal drive link pivotably connected to the worm drive link and configured to move in response to rotation of the worm drive link.

4. The end effector of claim **1**, the finger assembly further comprising:
- a medial housing assembly having an internal cavity;
- a distal housing assembly including: (i) a rear external surface with a first end positioned adjacent the medial housing assembly when the finger assembly is in an open position, and (ii) a tongue that extends towards the proximal link assembly and has an upper surface that is offset inwardly from the rear external surface;
- wherein, when the finger assembly is in the open position, a substantial majority of the tongue is positioned within the internal cavity of the medial housing assembly.

5. The end effector of claim **1**, wherein the finger assembly lacks both a pressure sensor and a force sensor, but includes a textile covering.

6. The end effector of claim **1**, wherein the finger assembly further comprises a single electric motor, a worm drive, and a worm wheel configured to actuate the worm drive link.

7. The end effector of claim **1**, wherein the finger assembly further comprises a biasing member having a first extent connected to the proximal link and a second extent connected to the proximal drive link, and wherein the single biasing member is configured to bias the proximal drive link toward an uncurled position.

8. The end effector of claim **1**, wherein the finger assembly further includes:
- a knuckle positioned adjacent to the proximal assembly;
- a proximal assembly that includes the worm drive link, proximal drive link, and the proximal link;
- a medial assembly that includes the medial drive link and medial link;
- a distal assembly positioned adjacent to the medial assembly;
- a metacarpophalangeal joint formed between the knuckle and the proximal assembly;
- a proximal finger interphalangeal joint formed between the proximal assembly and the medial assembly; and
- a distal finger interphalangeal joint formed between the medial assembly and the distal assembly.

9. The end effector of claim **8**, further comprising:
- a first finger encoder positioned proximate to the metacarpophalangeal joint and configured to collect data related to rotation of the metacarpophalangeal joint; and
- a second finger encoder positioned proximate to the proximal finger interphalangeal joint and configured to collect data related to rotation of the proximal finger interphalangeal joint.

10. An end effector for a humanoid robot, the end effector comprising:

a frame;

four finger assemblies, wherein each finger assembly of the four finger assemblies are substantially identical to every other finger assembly of the four finger assemblies, and wherein each finger assembly of the four finger assemblies is removably connected to the frame at a respective point;

wherein all of the finger assemblies of the four finger assemblies are located substantially in a single plane;

wherein each finger assembly of the four finger assemblies is angularly offset within the single plane with respect to every other finger assembly of the four finger assemblies;

wherein the respective points of connection of the four fingers assemblies to the frame are not co-linear; and

wherein each finger assembly of the four finger assemblies lacks a mechanical cable configured to actuate any component of the finger assembly.

11. The end effector of claim **10**, wherein each finger assembly of the four finger assemblies comprises:

a worm drive link;

a proximal drive link pivotably coupled to the worm drive link;

a proximal link defining a proximal link recess configured to selectively receive at least a portion of the worm drive link and at least a portion of the main proximal drive link therein;

a medial drive link pivotably connected to a medial link by at least one first pivotable coupling located on a first side of a sagittal plane extending through the finger assembly and at least one second pivotable coupling located on a second side of the sagittal plane; and

a medial link pivotably connected to both the proximal link and the proximal drive link and including a medial link recess configured to receive an extent of the medial drive link.

14. The end effector of claim **10**, wherein each finger assembly of the four finger assemblies only have a single electric motor and include a textile covering.

15. The end effector of claim **10**, wherein each finger assembly of the four finger assemblies is configured to operable independently of every other finger assembly of the four finger assemblies and does not include a force sensor.

16. The end effector of claim **10**, wherein at least one of the four finger assemblies includes: (i) a proximal housing assembly with an internal proximal recess, and (ii) a medial housing assembly includes a tongue that is positioned within the internal proximal recess of the proximal housing assembly, when the at least one finger assembly is in an uncurled position.

17. The end effector of claim **10**, wherein at least one of the four finger assemblies includes a proximal housing assembly having: (i) an exterior surface with a curvilinear extent in a first direction, and (ii) an interior surface that is curvilinear extent in the first direction and a second direction, and wherein the interior surface includes a plurality of projections.

18. The end effector of claim **10**, wherein at least one of the four finger assemblies include a textile that covers that surrounds an extent of said finger assembly.

19. An end effector for a humanoid robot, the end effector comprising:

a frame;

a plurality of finger assemblies removably connected to the frame, each finger assembly of the plurality of finger assemblies comprising:

a motor assembly including: (i) a motor having a motor housing, and (ii) a motor shaft having a motor shaft axis, and wherein the motor shaft is configured to rotate about said motor shaft axis;

a worm drive gear coupled to the motor shaft and configured for rotation about: (i) the motor shaft axis, and (ii) a worm drive gear axis, and wherein the motor shaft axis and the worm drive gear axis are coaxial;

a worm wheel in geared engagement with the worm drive gear and configured for rotation about a worm wheel axis in response to rotation of the worm drive gear, and wherein the worm wheel axis is perpendicular to the worm drive gear axis;

a worm drive link having a first end and a second end, and wherein the first end of the worm drive link fixedly connected to the worm wheel so that the worm drive link is configured for rotation about the worm wheel axis in response to rotation of the worm wheel about the worm wheel axis;

a proximal drive link having a first end and a second end, and wherein the first end of the proximal drive link pivotably connected to the second end of the worm drive link; and

a biasing member configured to bias an extent of the proximal drive link toward a first location, and wherein the extent of the proximal drive link is in the first location when the finger assembly is in an uncurled position.

20. The end effector of claim **19**, wherein each finger assembly of the plurality of finger assemblies lacks a mechanical cable configured to actuate any component of the finger assembly, and includes a textile covering.

21. The end effector of claim **20**, wherein each finger assembly of the plurality of finger assemblies is configured to be swappable with every other finger assembly of the plurality of finger assemblies.

22. The end effector of claim **19**, wherein a finger assembly of the plurality of finger assemblies includes: (i) a proximal housing assembly with an internal proximal recess, and (ii) a medial housing assembly includes a tongue;

wherein said tongue is positioned within the internal proximal recess of the proximal housing assembly, when the finger assembly is in the uncurled position; and

wherein said tongue is not positioned within the internal proximal recess of the proximal housing assembly, when the finger assembly is in a curled position.

23. The end effector of claim **19**, wherein a finger assembly of the plurality of finger assemblies includes further includes:

a knuckle positioned adjacent to the proximal assembly;

a proximal assembly that includes the worm drive link, proximal drive link and the proximal link;

a metacarpophalangeal joint formed between the knuckle and the proximal assembly; and

a first finger encoder configured to collect data related to rotation of the metacarpophalangeal joint.

24. The end effector of claim **19**, further comprising a medial link pivotably connected to both the proximal link and the proximal drive link and including a medial link recess configured to receive an extent of the medial drive link; and

a medial drive link pivotably connected to a medial link by at least one first pivotable coupling located on a first side of a sagittal plane extending through the finger assembly and at least one second pivotable coupling located on a second side of the sagittal plane.

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