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ROBOTICDEVICESWITHONBOARD CONTROL AND RELATED SYSTEMS AND DEVICES

Shane Michael Farritor

Erik Mumm

Philip Chu

Nishant Kumar

Jason Dumpert

See next page for additional authors

Authors
Shane Michael Farritor, Erik Mumm, Philip Chu, Nishant Kumar, Jason Dumpert, and Yutaka Tsutano

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(54) **ROBOTIC DEVICES WITH ON BOARD CONTROL AND RELATED SYSTEMS AND DEVICES**

(71) Applicant: **Board of Regents of the University of Nebraska**, Lincoln, NE (US)

(72) Inventors: **Shane Farritor**, Lincoln, NE (US); **Erik Mumm**, Longmont, CO (US); **Philip Chu**, Friendswood, TX (US); **Nishant Kumar**, Bergenfield, NJ (US); **Jason Dumpert**, Omaha, NE (US); **Yutaka Tsutano**, Lincoln, NE (US)

(73) Assignee: **Board of Regents of the University of Nebraska**, Lincoln, NE (US)

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(56) **References Cited**

U.S. PATENT DOCUMENTS

3,870,264 A 3/1975 Robinson
3,989,952 A 11/1976 Timberlake et al.
(Continued)

FOREIGN PATENT DOCUMENTS

CN 102821918 12/2012
DE 102010040405 3/2012
(Continued)

OTHER PUBLICATIONS

Franzino, "The Laprotek Surgical System and the Next Generation of Robotics," Surg Clin North Am, 2003 83(6): 1317-1320.
(Continued)

Primary Examiner — David Luo
(74) *Attorney, Agent, or Firm* — Davis, Brown, Koehn, Shors & Roberts, P.C.; Sean D. Solberg

(57) **ABSTRACT**

The embodiments disclosed herein relate to various medical device components, including components that can be incorporated into robotic and/or in vivo medical devices. Certain embodiments include various modular medical devices for in vivo medical procedures.

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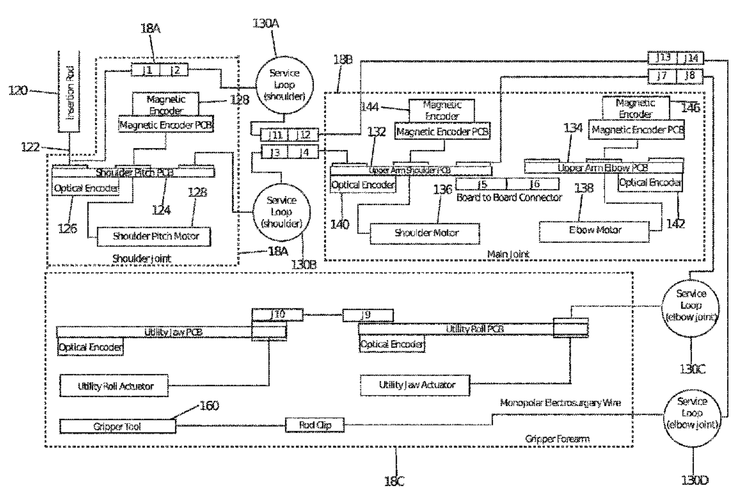

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(56) **References Cited**

U.S. PATENT DOCUMENTS

4,258,716 A 3/1981 Sutherland
4,278,077 A 7/1981 Mizumoto
4,538,594 A 9/1985 Boebel et al.
4,568,311 A 2/1986 Miyake
4,736,645 A 4/1988 Zimmer
4,771,652 A 9/1988 Zimmer
4,852,391 A 8/1989 Ruch et al.
4,896,015 A 1/1990 Taboada et al.
4,922,755 A 5/1990 Oshiro et al.
4,922,782 A 5/1990 Kawai
4,990,050 A 2/1991 Tsuge et al.
5,019,968 A 5/1991 Wang et al.
5,172,639 A 12/1992 Wiesman et al.
5,195,388 A 3/1993 Zona et al.
5,201,325 A 4/1993 McEwen et al.
5,271,384 A 12/1993 McEwen et al.
5,284,096 A 2/1994 Pelrine et al.
5,297,443 A 3/1994 Wentz
5,297,536 A 3/1994 Wilk
5,304,899 A 4/1994 Sasaki et al.
5,307,447 A 4/1994 Asano et al.
5,353,807 A 10/1994 DeMarco
5,363,935 A 11/1994 Schempf et al.
5,382,885 A 1/1995 Salcudean et al.
5,388,528 A 2/1995 Pelrine et al.
5,436,542 A 7/1995 Petelin et al.
5,441,494 A 8/1995 Ortiz
5,458,131 A 10/1995 Wilk
5,458,583 A 10/1995 McNeely et al.
5,458,598 A 10/1995 Feinberg et al.
5,471,515 A 11/1995 Fossum et al.
5,515,478 A 5/1996 Wang
5,524,180 A 6/1996 Wang et al.
5,553,198 A 9/1996 Wang et al.
5,562,448 A 10/1996 Mushabac
5,588,442 A 12/1996 Scovil et al.
5,620,417 A 4/1997 Jang et al.
5,623,582 A 4/1997 Rosenberg
5,624,380 A 4/1997 Takayama et al.
5,624,398 A 4/1997 Smith et al.
5,632,761 A 5/1997 Smith et al.
5,645,520 A 7/1997 Nakamura et al.
5,657,429 A 8/1997 Wang et al.
5,657,584 A 8/1997 Hamlin
5,672,168 A 9/1997 de la Torre et al.
5,674,030 A 10/1997 Sigel
5,728,599 A 3/1998 Rosteker et al.
5,736,821 A 4/1998 Suyaman et al.
5,754,741 A 5/1998 Wang et al.
5,762,458 A 6/1998 Wang et al.
5,769,640 A 6/1998 Jacobus et al.
5,791,231 A 8/1998 Cohn et al.
5,792,135 A 8/1998 Madhani et al.
5,797,538 A 8/1998 Heaton et al.
5,797,900 A 8/1998 Madhani et al.
5,807,377 A 9/1998 Madhani et al.
5,808,665 A 9/1998 Green
5,815,640 A 9/1998 Wang et al.
5,825,982 A 10/1998 Wright et al.
5,841,950 A 11/1998 Wang et al.
5,845,646 A 12/1998 Lemelson
5,855,583 A 1/1999 Wang et al.
5,876,325 A 3/1999 Mizuno et al.
5,878,193 A 3/1999 Wang et al.
5,878,783 A 3/1999 Smart
5,895,417 A 4/1999 Pomeranz et al.
5,906,591 A 5/1999 Dario et al.
5,907,664 A 5/1999 Wang et al.
5,910,129 A 6/1999 Koblish et al.
5,911,036 A 6/1999 Wright et al.
5,971,976 A 10/1999 Wang et al.
5,993,467 A 11/1999 Yoon
6,001,108 A 12/1999 Wang et al.
6,007,550 A 12/1999 Wang et al.
6,030,365 A 2/2000 Laufer
6,031,371 A 2/2000 Smart
6,058,323 A 5/2000 Lemelson
6,063,095 A 5/2000 Wang et al.
6,066,090 A 5/2000 Yoon
6,102,850 A 8/2000 Wang et al.
6,107,795 A 8/2000 Smart
6,132,368 A 10/2000 Cooper
6,132,441 A 10/2000 Grace
6,139,563 A 10/2000 Cosgrove, III et al.
6,156,006 A 12/2000 Brosens et al.
6,159,146 A 12/2000 El Gazayerli
6,162,171 A 12/2000 Ng et al.
D438,617 S 3/2001 Cooper et al.
6,206,903 B1 3/2001 Ramans
D441,076 S 4/2001 Cooper et al.
6,223,100 B1 4/2001 Green
D441,862 S 5/2001 Cooper et al.
6,238,415 B1 5/2001 Sepetka et al.
6,240,312 B1 5/2001 Alfano et al.
6,241,730 B1 6/2001 Alby
6,244,809 B1 6/2001 Wang et al.
6,246,200 B1 6/2001 Blumenkranz et al.
D444,555 S 7/2001 Cooper et al.
6,286,514 B1 9/2001 Lemelson
6,296,635 B1 10/2001 Smith et al.
6,309,397 B1 10/2001 Julian et al.
6,309,403 B1 10/2001 Minoret et al.
6,312,435 B1 11/2001 Wallace et al.
6,321,106 B1 11/2001 Lemelson
6,327,492 B1 12/2001 Lemelson
6,331,181 B1 12/2001 Tiemey et al.
6,346,072 B1 2/2002 Cooper
6,352,503 B1 3/2002 Matsui et al.
6,364,888 B1 4/2002 Niemeyer et al.
6,371,952 B1 4/2002 Madhani et al.
6,394,998 B1 5/2002 Wallace et al.
6,398,726 B1 6/2002 Ramans et al.
6,400,980 B1 6/2002 Lemelson
6,408,224 B1 6/2002 Lemelson
6,424,885 B1 7/2002 Niemeyer et al.
6,432,112 B2 8/2002 Brock et al.
6,436,107 B1 8/2002 Wang et al.
6,441,577 B2 8/2002 Blumenkranz et al.
6,450,104 B1 9/2002 Grant et al.
6,451,027 B1 9/2002 Cooper et al.
6,454,758 B1 9/2002 Thompson et al.
6,459,926 B1 10/2002 Nowlin et al.
6,463,361 B1 10/2002 Wang et al.
6,468,203 B2 10/2002 Belson
6,468,265 B1 10/2002 Evans et al.
6,470,236 B2 10/2002 Ohtsuki
6,491,691 B1 12/2002 Morley et al.
6,491,701 B2 12/2002 Nemeyer et al.
6,493,608 B1 12/2002 Niemeyer et al.
6,496,099 B2 12/2002 Wang et al.
6,508,413 B2 1/2003 Bauer et al.
6,512,345 B2 1/2003 Borenstein
6,522,906 B1 2/2003 Salisbury, Jr. et al.
6,544,276 B1 4/2003 Azizi
6,548,982 B1 4/2003 Papanikolopoulos et al.
6,554,790 B1 4/2003 Moll
6,565,554 B1 5/2003 Niemeyer
6,574,355 B2 6/2003 Green
6,587,750 B2 7/2003 Gerbi et al.
6,591,239 B1 7/2003 McCall et al.
6,594,552 B1 7/2003 Nowlin et al.
6,610,007 B2 8/2003 Belson et al.
6,620,173 B2 9/2003 Gerbi et al.
6,642,836 B1 11/2003 Wang et al.

(56) **References Cited**

U.S. PATENT DOCUMENTS

6,645,196 B1	11/2003	Nixon et al.	
6,646,541 B1	11/2003	Wang et al.	
6,648,814 B2	11/2003	Kim et al.	
6,659,939 B2	12/2003	Moll et al.	
6,661,571 B1	12/2003	Shioda et al.	
6,671,581 B2	12/2003	Niemeyer et al.	
6,676,684 B1	1/2004	Morley et al.	
6,684,129 B2	1/2004	Salisbury, Jr. et al.	
6,685,648 B2	2/2004	Flaherty et al.	
6,685,698 B2	2/2004	Morley et al.	
6,687,571 B1	2/2004	Byme et al.	
6,692,485 B1	2/2004	Brock et al.	
6,699,177 B1	3/2004	Wang et al.	
6,699,235 B2	3/2004	Wallace et al.	
6,702,734 B2	3/2004	Kim et al.	
6,702,805 B1	3/2004	Stuart	
6,714,839 B2	3/2004	Salisbury, Jr. et al.	
6,714,841 B1	3/2004	Wright et al.	
6,719,684 B2	4/2004	Kim et al.	
6,720,988 B1	4/2004	Gere et al.	
6,726,699 B1	4/2004	Wright et al.	
6,728,599 B2	4/2004	Wright et al.	
6,730,021 B2	5/2004	Vassiliades, Jr. et al.	
6,731,988 B1	5/2004	Green	
6,746,443 B1	6/2004	Morley et al.	
6,764,441 B2	7/2004	Chiel et al.	
6,764,445 B2	7/2004	Ramans et al.	
6,766,204 B2	7/2004	Niemeyer et al.	
6,770,081 B1	8/2004	Cooper et al.	
6,774,597 B1	8/2004	Borenstein	
6,776,165 B2	8/2004	Jin	
6,780,184 B2	8/2004	Tanrisever	
6,783,524 B2	8/2004	Anderson et al.	
6,785,593 B2	8/2004	Wang et al.	
6,788,018 B1	9/2004	Blumenkranz	
6,792,663 B2	9/2004	Krzyzanowski	
6,793,653 B2	9/2004	Sanchez et al.	
6,799,065 B1	9/2004	Niemeyer	
6,799,088 B2	9/2004	Wang et al.	
6,801,325 B2	10/2004	Farr et al.	
6,804,581 B2	10/2004	Wang et al.	
6,810,281 B2	10/2004	Brock et al.	
6,817,972 B2	11/2004	Snow	
6,817,974 B2	11/2004	Cooper et al.	
6,817,975 B1	11/2004	Farr et al.	
6,820,653 B1	11/2004	Schempf et al.	
6,824,508 B2	11/2004	Kim et al.	
6,824,510 B2	11/2004	Kim et al.	
6,832,988 B2	12/2004	Sprout	
6,832,996 B2	12/2004	Woloszko et al.	
6,836,703 B2	12/2004	Wang et al.	
6,837,846 B2	1/2005	Jaffe et al.	
6,837,883 B2	1/2005	Moll et al.	
6,839,612 B2	1/2005	Sanchez et al.	
6,840,938 B1	1/2005	Morley et al.	
6,852,107 B2	2/2005	Wang et al.	
6,858,003 B2	2/2005	Evans et al.	
6,860,346 B2	3/2005	Burt et al.	
6,860,877 B1	3/2005	Sanchez et al.	
6,866,671 B2	3/2005	Tiemey et al.	
6,870,343 B2	3/2005	Borenstein et al.	
6,871,117 B2	3/2005	Wang et al.	
6,871,563 B2	3/2005	Choset et al.	
6,879,880 B2	4/2005	Nowlin et al.	
6,892,112 B2	5/2005	Wang et al.	
6,899,705 B2	5/2005	Niemeyer	
6,902,560 B1	6/2005	Morley et al.	
6,905,460 B2	6/2005	Wang et al.	
6,905,491 B1	6/2005	Wang et al.	
6,911,916 B1	6/2005	Wang et al.	
6,917,176 B2	7/2005	Schempf et al.	
6,933,695 B2	8/2005	Blumenkranz	
6,936,001 B1	8/2005	Snow	
6,936,003 B2	8/2005	Iddan	
6,936,042 B2	8/2005	Wallace et al.	
6,943,663 B2	9/2005	Wang et al.	
6,949,096 B2	9/2005	Davison et al.	
6,951,535 B2	10/2005	Ghodoussi et al.	
6,965,812 B2	11/2005	Wang et al.	
6,974,411 B2	12/2005	Belson	
6,974,449 B2	12/2005	Niemeyer	
6,979,423 B2	12/2005	Moll	
6,984,203 B2	1/2006	Tartaglia et al.	
6,984,205 B2	1/2006	Gazdzinski	
6,991,627 B2	1/2006	Madhani et al.	
6,993,413 B2	1/2006	Sunaoshi	
6,994,703 B2	2/2006	Wang et al.	
6,994,708 B2	2/2006	Manzo	
6,997,908 B2	2/2006	Carrillo, Jr. et al.	
7,025,064 B2	4/2006	Wang et al.	
7,027,892 B2	4/2006	Wang et al.	
7,033,344 B2	4/2006	Imran	
7,039,453 B2	5/2006	Mullick	
7,042,184 B2	5/2006	Oleynikov et al.	
7,048,745 B2	5/2006	Tierney et al.	
7,053,752 B2	5/2006	Wang et al.	
7,063,682 B1	6/2006	Whayne et al.	
7,066,879 B2	6/2006	Fowler et al.	
7,066,926 B2	6/2006	Wallace et al.	
7,074,179 B2	7/2006	Wang et al.	
7,077,446 B2	7/2006	Kameda et al.	
7,083,571 B2	8/2006	Wang et al.	
7,083,615 B2	8/2006	Peterson et al.	
7,087,049 B2	8/2006	Nowlin et al.	
7,090,683 B2	8/2006	Brock et al.	
7,097,640 B2	8/2006	Wang et al.	
7,105,000 B2	9/2006	McBrayer	
7,107,090 B2	9/2006	Salisbury, Jr. et al.	
7,109,678 B2	9/2006	Kraus et al.	
7,118,582 B1	10/2006	Wang et al.	
7,121,781 B2	10/2006	Sanchez et al.	
7,125,403 B2	10/2006	Julian et al.	
7,126,303 B2	10/2006	Farritor et al.	
7,147,650 B2	12/2006	Lee	
7,155,315 B2	12/2006	Niemeyer et al.	
7,155,316 B2 *	12/2006	Sutherland	A61B 90/25 700/248
7,169,141 B2	1/2007	Brock et al.	
7,182,025 B2	2/2007	Ghorbel et al.	
7,182,089 B2	2/2007	Ries	
7,199,545 B2	4/2007	Oleynikov et al.	
7,206,626 B2	4/2007	Quaid, III	
7,206,627 B2	4/2007	Abovitz et al.	
7,210,364 B2	5/2007	Ghorbel et al.	
7,214,230 B2	5/2007	Brock et al.	
7,217,240 B2	5/2007	Snow	
7,239,940 B2	7/2007	Wang et al.	
7,250,028 B2	7/2007	Julian et al.	
7,259,652 B2	8/2007	Wang et al.	
7,273,488 B2	9/2007	Nakamura et al.	
7,311,107 B2	12/2007	Harel et al.	
7,339,341 B2	3/2008	Oleynikov et al.	
7,372,229 B2	5/2008	Farritor et al.	
7,447,537 B1	11/2008	Funda et al.	
7,492,116 B2	2/2009	Oleynikov et al.	
7,566,300 B2	7/2009	Devierre et al.	
7,574,250 B2	8/2009	Niemeyer	
7,637,905 B2	12/2009	Saadat et al.	
7,645,230 B2	1/2010	Mikkaichi et al.	
7,655,004 B2	2/2010	Long	
7,670,329 B2	3/2010	Flaherty et al.	
7,731,727 B2	6/2010	Sauer	
7,762,825 B2	7/2010	Burbank et al.	
7,772,796 B2	8/2010	Farritor et al.	
7,785,251 B2	8/2010	Wilk	
7,785,333 B2	8/2010	Miyamoto et al.	
7,789,825 B2	9/2010	Nobis et al.	
7,794,494 B2	9/2010	Sahatjian et al.	
7,865,266 B2	1/2011	Moll et al.	
7,960,935 B2	6/2011	Farritor et al.	
8,021,358 B2	9/2011	Doyle et al.	
8,353,897 B2	1/2013	Doyle et al.	
9,089,353 B2	7/2015	Farritor et al.	
2001/0018591 A1	8/2001	Brook et al.	

(56) **References Cited**

U.S. PATENT DOCUMENTS

2001/0049497 A1 12/2001 Kalloo et al.
2002/0003173 A1 1/2002 Bauer et al.
2002/0013601 A1 1/2002 Nobles et al.
2002/0026186 A1 2/2002 Woloszko et al.
2002/0038077 A1 3/2002 de la Torre et al.
2002/0065507 A1 5/2002 Zadno-Azizi
2002/0091374 A1 6/2002 Cooper
2002/0103417 A1 8/2002 Gazdzinski
2002/0111535 A1 8/2002 Kim et al.
2002/0120254 A1 8/2002 Julian et al.
2002/0128552 A1 9/2002 Nowlin et al.
2002/0140392 A1 10/2002 Borenstein et al.
2002/0147487 A1 10/2002 Sundquist et al.
2002/0151906 A1 10/2002 Demarais et al.
2002/0156347 A1 10/2002 Kim et al.
2002/0171385 A1 11/2002 Kim et al.
2002/0173700 A1 11/2002 Kim et al.
2002/0190682 A1 12/2002 Schempf et al.
2003/0020810 A1 1/2003 Takizawa et al.
2003/0045888 A1 3/2003 Brock et al.
2003/0065250 A1 4/2003 Chiel et al.
2003/0089267 A1 5/2003 Ghorbel et al.
2003/0092964 A1 5/2003 Kim et al.
2003/0097129 A1 5/2003 Davison et al.
2003/0100817 A1 5/2003 Wang et al.
2003/0114731 A1 6/2003 Cadeddu et al.
2003/0135203 A1 6/2003 Wang et al.
2003/0139742 A1 7/2003 Wampler et al.
2003/0144656 A1 7/2003 Ocel et al.
2003/0167000 A1 9/2003 Mullick
2003/0172871 A1 9/2003 Scherer
2003/0179308 A1 9/2003 Zamorano et al.
2003/0181788 A1 9/2003 Yokoi et al.
2003/0229268 A1 12/2003 Uchiyama et al.
2003/0230372 A1 12/2003 Schmidt
2004/0024311 A1 2/2004 Quaid
2004/0034282 A1 2/2004 Quaid
2004/0034283 A1 2/2004 Quaid
2004/0034302 A1 2/2004 Abovitz et al.
2004/0050394 A1 3/2004 Jin
2004/0070822 A1 4/2004 Shioda et al.
2004/0099175 A1 5/2004 Perrot et al.
2004/0102772 A1 5/2004 Baxter et al.
2004/0106916 A1 6/2004 Quaid et al.
2004/0111113 A1 6/2004 Nakamura et al.
2004/0117032 A1 6/2004 Roth
2004/0138525 A1 7/2004 Saadat et al.
2004/0138552 A1 7/2004 Harel et al.
2004/0140786 A1 7/2004 Borenstein
2004/0153057 A1 8/2004 Davison
2004/0173116 A1 9/2004 Ghorbel et al.
2004/0176664 A1 9/2004 Iddan
2004/0215331 A1 10/2004 Chew et al.
2004/0225229 A1 11/2004 Viola
2004/0254680 A1 12/2004 Sunaoshi
2004/0267326 A1 12/2004 Ocel et al.
2005/0014994 A1 1/2005 Fowler et al.
2005/0021069 A1 1/2005 Feuer et al.
2005/0029978 A1 2/2005 Oleynikov et al.
2005/0043583 A1 2/2005 Killmann et al.
2005/0049462 A1 3/2005 Kanazawa
2005/0054901 A1 3/2005 Yoshino
2005/0054902 A1 3/2005 Konno
2005/0064378 A1 3/2005 Toly
2005/0065400 A1 3/2005 Banik et al.
2005/0083460 A1 4/2005 Hattori et al.
2005/0095650 A1 5/2005 Julius et al.
2005/0096502 A1 5/2005 Khalili
2005/0143644 A1 6/2005 Gilad et al.
2005/0154376 A1 7/2005 Riviere et al.
2005/0165449 A1 7/2005 Cadeddu et al.
2005/0283137 A1 12/2005 Doyle et al.
2005/0288555 A1 12/2005 Binmoeller
2005/0288665 A1 12/2005 Woloszko
2006/0020272 A1 1/2006 Gildenberg
2006/0046226 A1 3/2006 Bergler et al.
2006/0119304 A1 6/2006 Farritor et al.
2006/0149135 A1 7/2006 Paz
2006/0152591 A1 7/2006 Lin
2006/0155263 A1 7/2006 Lipow
2006/0195015 A1 8/2006 Mullick et al.
2006/0196301 A1 9/2006 Oleynikov et al.
2006/0198619 A1 9/2006 Oleynikov et al.
2006/0241570 A1 10/2006 Wilk
2006/0241732 A1 10/2006 Denker
2006/0253109 A1 11/2006 Chu
2006/0258954 A1 11/2006 Timberlake et al.
2007/0032701 A1 2/2007 Fowler et al.
2007/0043397 A1 2/2007 Ocel et al.
2007/0055342 A1 3/2007 Wu et al.
2007/0080658 A1 4/2007 Farritor et al.
2007/0106113 A1 5/2007 Ravo
2007/0123748 A1 5/2007 Meglan
2007/0142725 A1 6/2007 Hardin et al.
2007/0156019 A1 7/2007 Larkin et al.
2007/0156211 A1 7/2007 Ferren et al.
2007/0167955 A1 7/2007 De La Menardiere et al.
2007/0225633 A1 9/2007 Ferren et al.
2007/0225634 A1 9/2007 Ferren et al.
2007/0241714 A1 10/2007 Okeynikov et al.
2007/0244520 A1 10/2007 Ferren et al.
2007/0250064 A1 10/2007 Darois et al.
2007/0255273 A1 11/2007 Fernandez et al.
2008/0004634 A1 1/2008 Farritor et al.
2008/0015565 A1 1/2008 Davison
2008/0015566 A1 1/2008 Livneh
2008/0033569 A1 2/2008 Ferren
2008/0045803 A1 2/2008 Williams et al.
2008/0058835 A1 3/2008 Farritor et al.
2008/0058989 A1 3/2008 Oleynikov et al.
2008/0103440 A1 5/2008 Ferren et al.
2008/0109014 A1 5/2008 de la Pena
2008/0111513 A1 5/2008 Farritor et al.
2008/0119870 A1 5/2008 Williams et al.
2008/0132890 A1 6/2008 Woloszko et al.
2008/0161804 A1 6/2008 Rioux et al.
2008/0164079 A1 7/2008 Ferren et al.
2008/0183033 A1 7/2008 Bern et al.
2008/0221591 A1 9/2008 Farritor et al.
2008/0269557 A1 10/2008 Marescaux et al.
2008/0269562 A1 10/2008 Marescaux et al.
2009/0020724 A1 1/2009 Paffrath
2009/0024142 A1 1/2009 Ruiz Morales
2009/0048612 A1 2/2009 Farritor et al.
2009/0054909 A1 2/2009 Farritor et al.
2009/0069821 A1 3/2009 Farritor et al.
2009/0076536 A1 3/2009 Rentschler et al.
2009/0137952 A1 5/2009 Ramamurthy et al.
2009/0143787 A9 6/2009 De La Pena
2009/0163929 A1 6/2009 Yeung et al.
2009/0171373 A1 7/2009 Farritor et al.
2009/0234369 A1 9/2009 Bax et al.
2009/0236400 A1 9/2009 Cole et al.
2009/0240246 A1 9/2009 Devill et al.
2009/0247821 A1 10/2009 Rogers
2009/0248038 A1 10/2009 Blumenkranz et al.
2009/0281377 A1 11/2009 Newell et al.
2009/0305210 A1 12/2009 Guru et al.
2010/0010294 A1 1/2010 Conlon et al.
2010/0016659 A1 1/2010 Weitzner et al.
2010/0016853 A1 1/2010 Burbank
2010/0042097 A1 2/2010 Newton et al.
2010/0056863 A1 3/2010 Dejima et al.
2010/0069710 A1 3/2010 Yamatani et al.
2010/0069940 A1 3/2010 Miller et al.
2010/0081875 A1 4/2010 Fowler et al.
2010/0139436 A1 6/2010 Kawashima et al.
2010/0198231 A1 8/2010 Manzo et al.
2010/0245549 A1 9/2010 Allen et al.
2010/0262162 A1 10/2010 Omori
2010/0292691 A1 11/2010 Brogna
2010/0318059 A1 12/2010 Farritor et al.
2011/0020779 A1 1/2011 Hannaford et al.
2011/0071347 A1 3/2011 Rogers et al.

(56) **References Cited**

U.S. PATENT DOCUMENTS

2011/0071544	A1	3/2011	Steger et al.
2011/0098529	A1	4/2011	Ostrovsky et al.
2011/0152615	A1	6/2011	Schostek et al.
2011/0224605	A1	9/2011	Farritor et al.
2011/0230894	A1	9/2011	Simaan et al.
2011/0237890	A1	9/2011	Farritor et al.
2011/0238080	A1	9/2011	Ranjit et al.
2011/0264078	A1	10/2011	Lipow et al.
2011/0270443	A1	11/2011	Kamiya et al.
2012/0035582	A1	2/2012	Nelson et al.
2012/0109150	A1	5/2012	Quaid et al.
2012/0116362	A1	5/2012	Kieturakis
2012/0179168	A1	7/2012	Farritor et al.
2012/0253515	A1	10/2012	Coste-Maniere et al.
2013/0131695	A1	5/2013	Scarfogliero et al.
2013/0345717	A1	12/2013	Markvicka et al.
2014/0039515	A1	2/2014	Mondry et al.
2014/0046340	A1	2/2014	Wilson et al.
2014/0058205	A1	2/2014	Frederick et al.
2014/0303434	A1	10/2014	Farritor et al.
2015/0051446	A1	2/2015	Farritor et al.

FOREIGN PATENT DOCUMENTS

EP	1354670	10/2003
EP	2286756	2/2011
EP	2286756 A1	2/2011
EP	2329787	6/2011
EP	2563261	3/2013
JP	05-115425	5/1993
JP	2006508049	9/1994
JP	07-016235	1/1995
JP	07-136173	5/1995
JP	7306155	11/1995
JP	08-224248	9/1996
JP	2001500510	1/2001
JP	2001505810	5/2001
JP	2003220065	8/2003
JP	2004144533	5/2004
JP	2004-180781	7/2004
JP	2004322310	11/2004
JP	2004329292	11/2004
JP	2006507809	3/2006
JP	2010536436	8/2007
JP	2009106606	5/2009
JP	2010533045	10/2010
JP	2010536436	12/2010
JP	2011504794	2/2011
JP	2011045500	3/2011
JP	2011115591	6/2011
WO	199221291	5/1991
WO	2001089405	11/2001
WO	2002082979	10/2002
WO	2002100256	12/2002
WO	2005009211	7/2004
WO	2005044095	5/2005
WO	2006052927	8/2005
WO	2006005075	1/2006
WO	2006079108	1/2006
WO	2006079108	7/2006
WO	2007011654	1/2007
WO	2007111571	10/2007
WO	2007149559	12/2007
WO	2009023851	2/2009
WO	2009144729	12/2009
WO	2010050771	5/2010
WO	2011075693	6/2011
WO	2011118646	9/2011
WO	2011135503	11/2011
WO	2013009887	1/2013
WO	2014011238	1/2014

OTHER PUBLICATIONS

Franklin et al., "Prospective Comparison of Open vs. Laparoscopic Colon Surgery for Carcinoma: Five-Year Results," Dis Colon Rectum, 1996; 39: S35-S46.

Flynn et al., "Tomorrow's surgery: micromotors and microrobots for minimally invasive procedures," Minimally Invasive Surgery & Allied Technologies, 1998; 7(4): 343-352.

Fireman et al., "Diagnosing small bowel Crohn's desease with wireless capsule endoscopy," Gut 2003; 52: 390-392.

Fearing et al., "Wing Transmission for a Micromechanical Flying Insect," Proceedings of the 2000 IEEE International Conference to Robotics & Automation, Apr. 2000; 1509-1516.

Faraz et al., "Engineering Approaches to Mechanical and Robotic Design for Minimaly Invasive Surgery (MIS)," Kluwer Academic Publishers (Boston), 2000, 13pp.

Falcone et al., "Robotic Surgery," Clin. Obstet. Gynecol. 2003, 46(1): 37-43.

Fraulob et al., "Miniature assistance module for robot-assisted heart surgery," Biomed. Tech. 2002, 47 Suppl. 1, Pt. 1: 12-15.

Fukuda et al., "Mechanism and Swimming Experiment of Micro Mobile Robot in Water," Proceedings of the 1994 IEEE International Conference on Robotics and Automation, 1994: 814-819.

Fukuda et al., "Micro Active Catheter System with Multi Degrees of Freedom," Proceedings of the IEEE International Conference on Robotics and Automation, May 1994, pp. 2290-2295.

Fuller et al., "Laparoscopic Trocar Injuries: A Report from a U.S. Food and Drug Administration (FDA) Center for Devices and Radiological Health (CDRH) Systematic Technology Assessment of Medical Products (STAMP) Committe," U.S. Food and Drug Adminstration, available at http://www.fdaJ:?;ov, Finalized: Nov. 7, 2003; Updated: Jun. 24, 2005, 11 pp.

Dumpert et al., "Improving in Vivo Robot Visioin Quality," from the Proceedings of Medicine Meets Virtual Realtiy, Long Beach, CA, Jan. 26-29, 2005. 1 pg.

Dakin et al., "Comparison of laparoscopic skills performance between standard instruments and two surgical robotic systems," Surg Endosc., 2003; 17: 574-579.

Cuschieri, "Technology for Minimal Access Surgery," BMJ, 1999, 319: 1-6.

Grady, "Doctors Try New Surgery for Gallbladder Removal," The New York Times, Apr. 20, 2007, 3 pp.

Choi et al., "Flexure-based Manipulator for Active Handheld Microsurgical Instrument," Proceedings of the 27th Annual International Conference of the IEEE Engineering in Medicine and Biology Society (EMBS), Sep. 2005, 4pp.

Canthasopeephan et al., (2003), "Measuring Forces in Liver Cutting: New Equipment and Experimenal Results," Annals of Biomedical Engineering 31: 1372-1382.

Cavusoglu et al., "Robotics for Telesurgery: Second Generation Berkeley/UCSF Laparoscopic Telesurgical Workstation and Looking Towards the Future Applications," Industrial Robot: An International Journal, 2003; 30(1): 22-29.

Guber et al., "Miniaturized Instrument Systems for Minimally Invasive Diagnosis and Therapy," Biomedizinische Technic. 2002, Band 47, Erganmngsband 1: 198-201.

Abbott et al., "Design of an Endoluminal Notes Robotic System," from the Proceedings of the 2007 IEEE/RSJ Int'l Conf. on Intelligent Robot Systems, San Diego, CA, Oct. 29-Nov. 2, 2007, pp. 410-416.

Allendorf et al., "Postoperative Immune Function Varies Inversely with the Degree of Surgical Trauma in a Murine Model," Surgical Endoscopy 1997; 11:427-430.

Ang, "Active Tremor Compensation in Handheld Instrument for Microsurgery," Doctoral Dissertation, tech report CMU-RI-TR-04-28, Robotics Institute, Carnegie Mellon Unviersity, May 2004, 167pp.

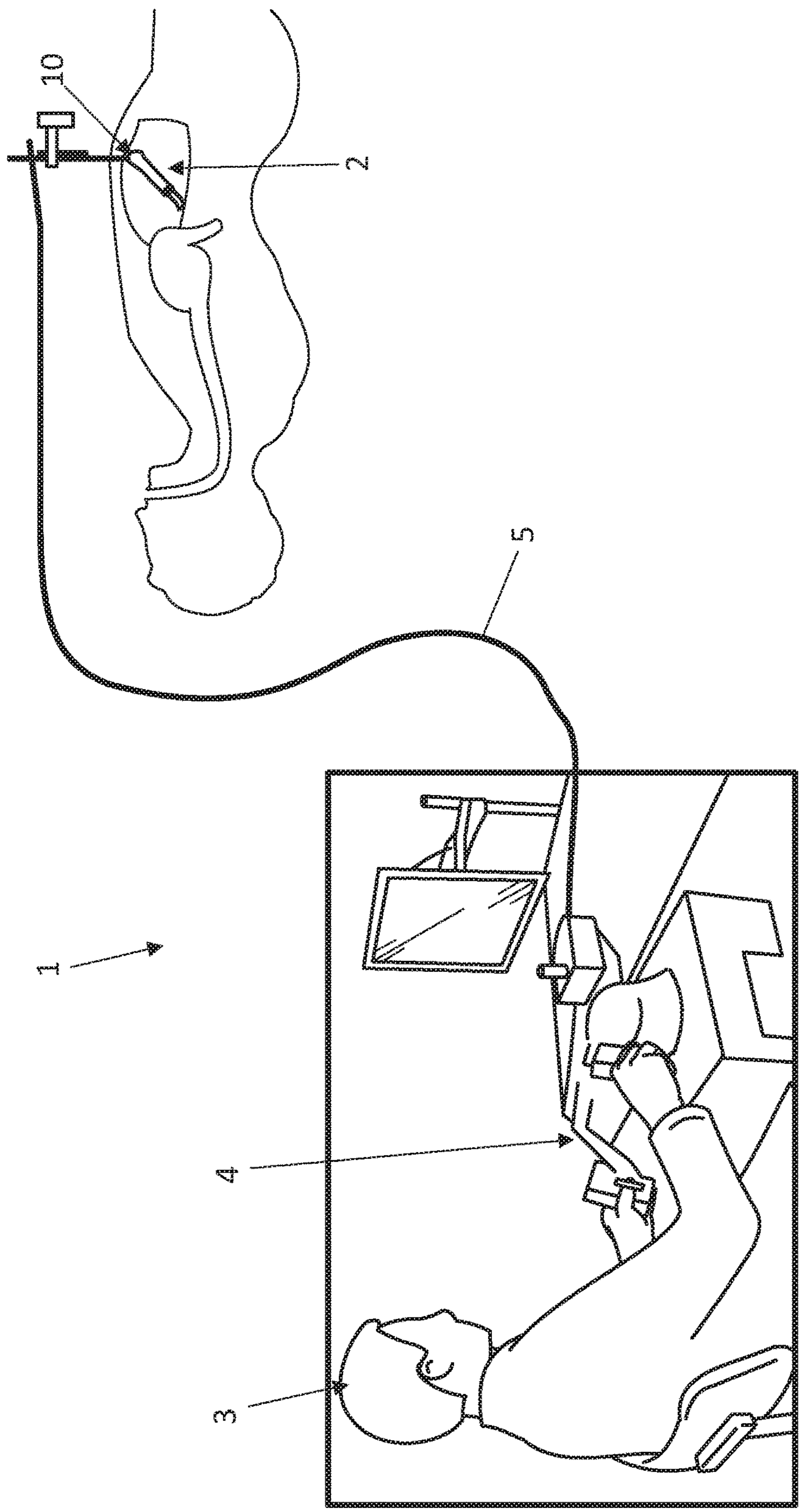
Atmel 8005X2 Core, http://www.atmel.com, 2006, 186pp.

(56) **References Cited**

OTHER PUBLICATIONS

Bailey et al., "Complications of Laparoscopic Surgery," Quality Medical Publishers, Inc., 1995, 25pp.
Ballantyne, "Robotic Surgery, Telerobotic Surgery, Telepresence, and Telementoring," Surgical Endoscopy, 2002; 16: 1389-1402.
Bauer et al., "Case Report: Remote Percutaneous Renal Percutaneous Renal Access Using a New Automated Telesurgical Robotic System," Telemedicine Journal and e-Health 2001; (4): 341-347.
Begos et al., "Laparoscopic Cholecystectomy: From Gimmick to Gold Standard," J Clin Gastroenterol, 1994; 19(4): 325-330.
Berg et al., "Surgery with Cooperative Robots," Medicine Meets Virtual Reality, Feb. 2007, 1 pg.
Breda et al., "Future developments and perspectives in laparoscopy," Eur. Urology 2001; 40(1): 84-91.
Breedveld et al., "Design of Steerable Endoscopes to Improve the Visual Perception of Depth During Laparoscopic Surgery," ASME, Jan. 2004; vol. 126, pp. 1-5.
Breedveld et al., "Locomotion through the Intestine by means of Rolling Stents," Proceedings of the ASME Design Engineering Technical Conferences, 2004, pp. 1-7.
Calafiore et al., Multiple Arterial Conduits Without Cardiopulmonary Bypass: Early Angiographic Results,: Ann Thorac Surg, 1999; 67: 450-456.
Camarillo et al., "Robotic Technology in Surgery: Past, Present and Future," The American Journal of Surgery, 2004; 188: 2S-15.
Cavusoglu et al., "Telesurgery and Surgical Simulation: Haptic Interfaces to Real and Virtual Surgical Environments," In McLaughliin, M.L, Hespanha, J.P., and Sukhatme, G., editors. Touch in virtual environments, IMSC Series in Multimedia 2001, 28pp.
Dumpert et al., "Stereoscopic in Vivo Surgical Robots," IEEE Sensors Special Issue on In Vivo Sensors for Medicine, Jan. 2007, 10 pp.
Green, "Telepresence Surgery", Jan. 1, 1995, Publisher: IEEE Engineering in Medicine and Biology.
Cleary et al., "State of the Art in Surgical Rootics: Clinical Applications and Technology Challenges", "Computer Aided Surgery", Jan. 1, 2002, pp. 312-328, vol. 6.
Stoianovici et al., "Robotic Tools for Minimally Invasive Urologic Surgery", Nov. 1, 2002, pp. 1-17.

* cited by examiner



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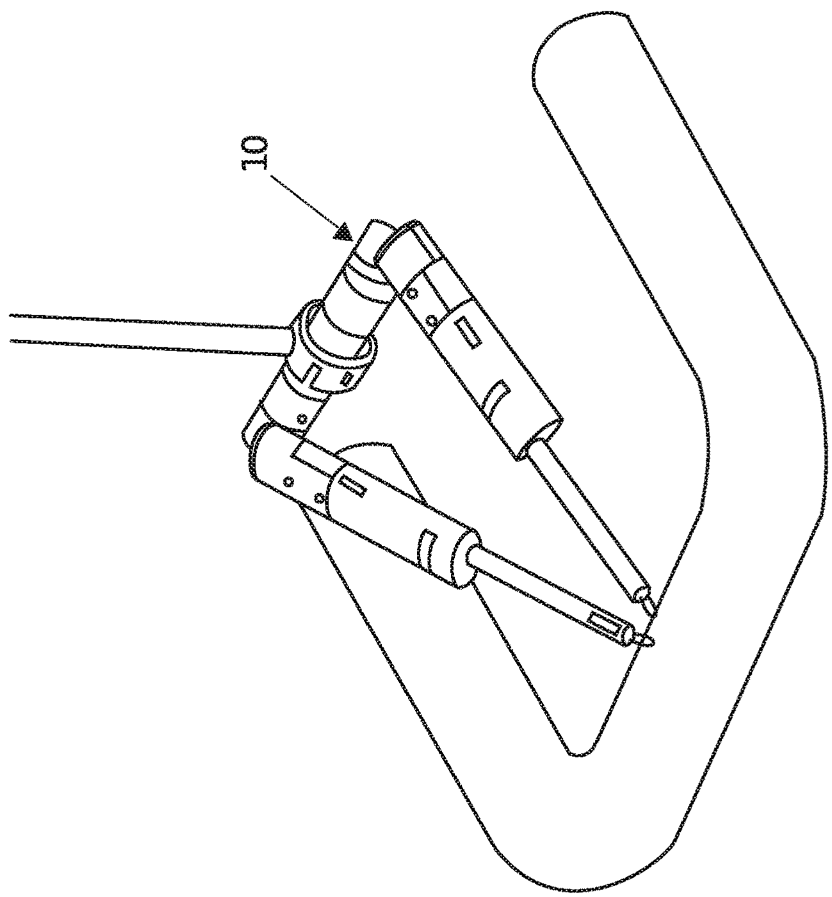

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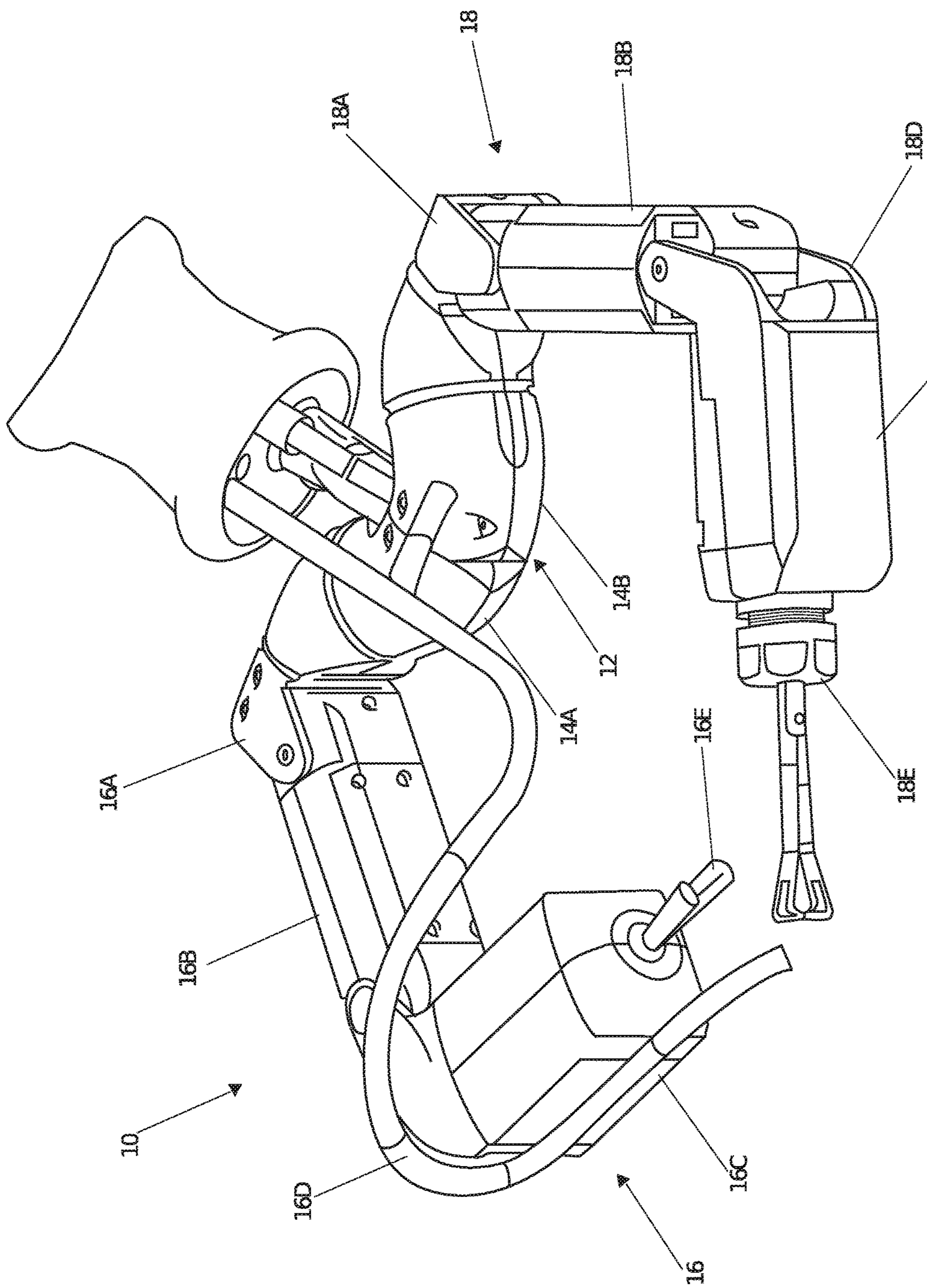

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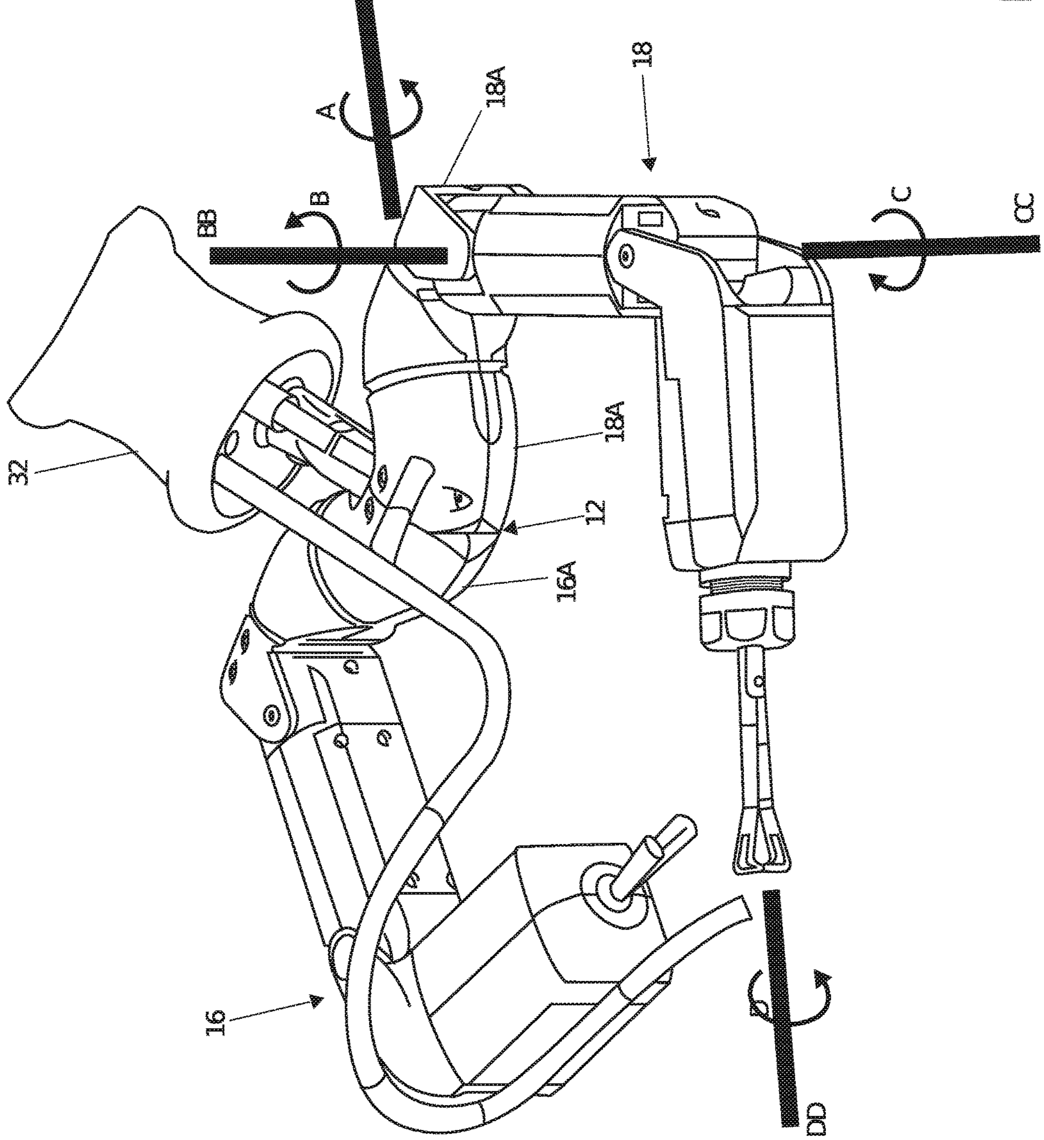

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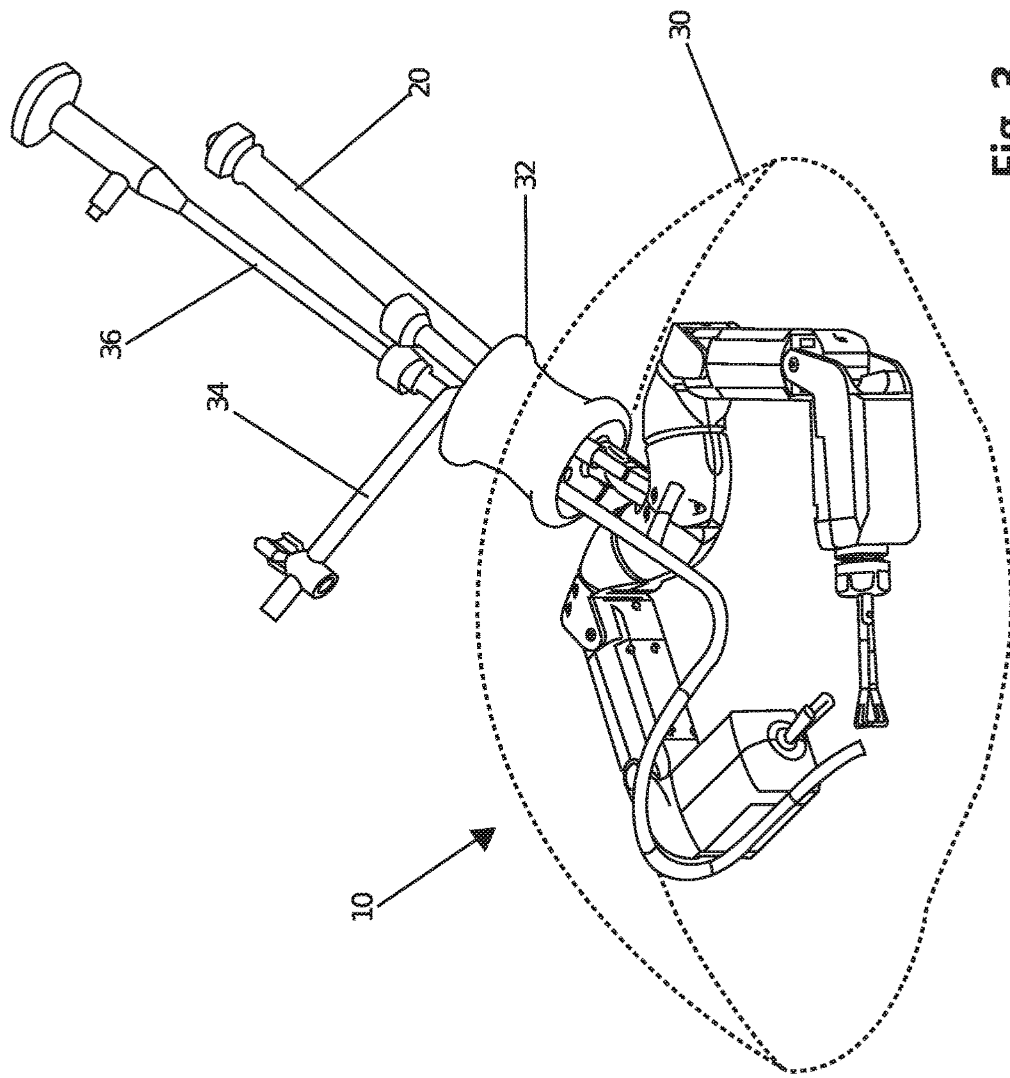

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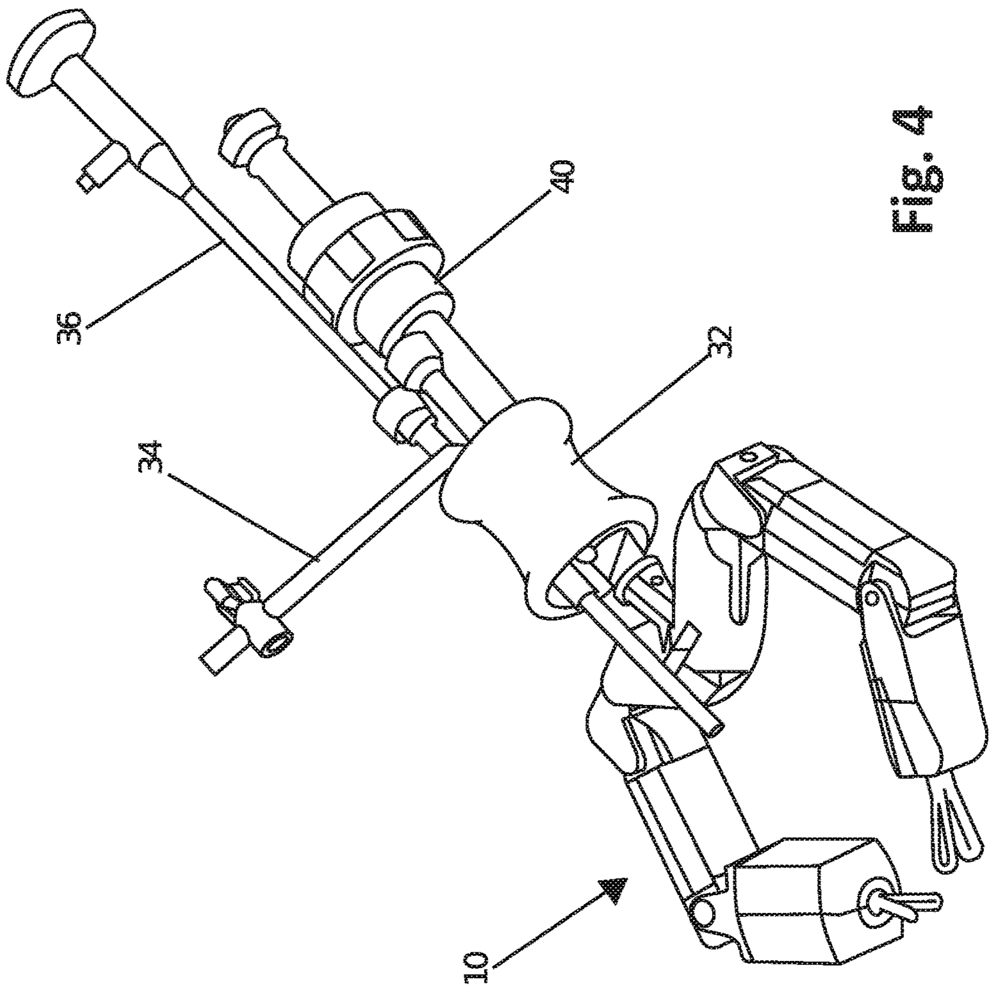

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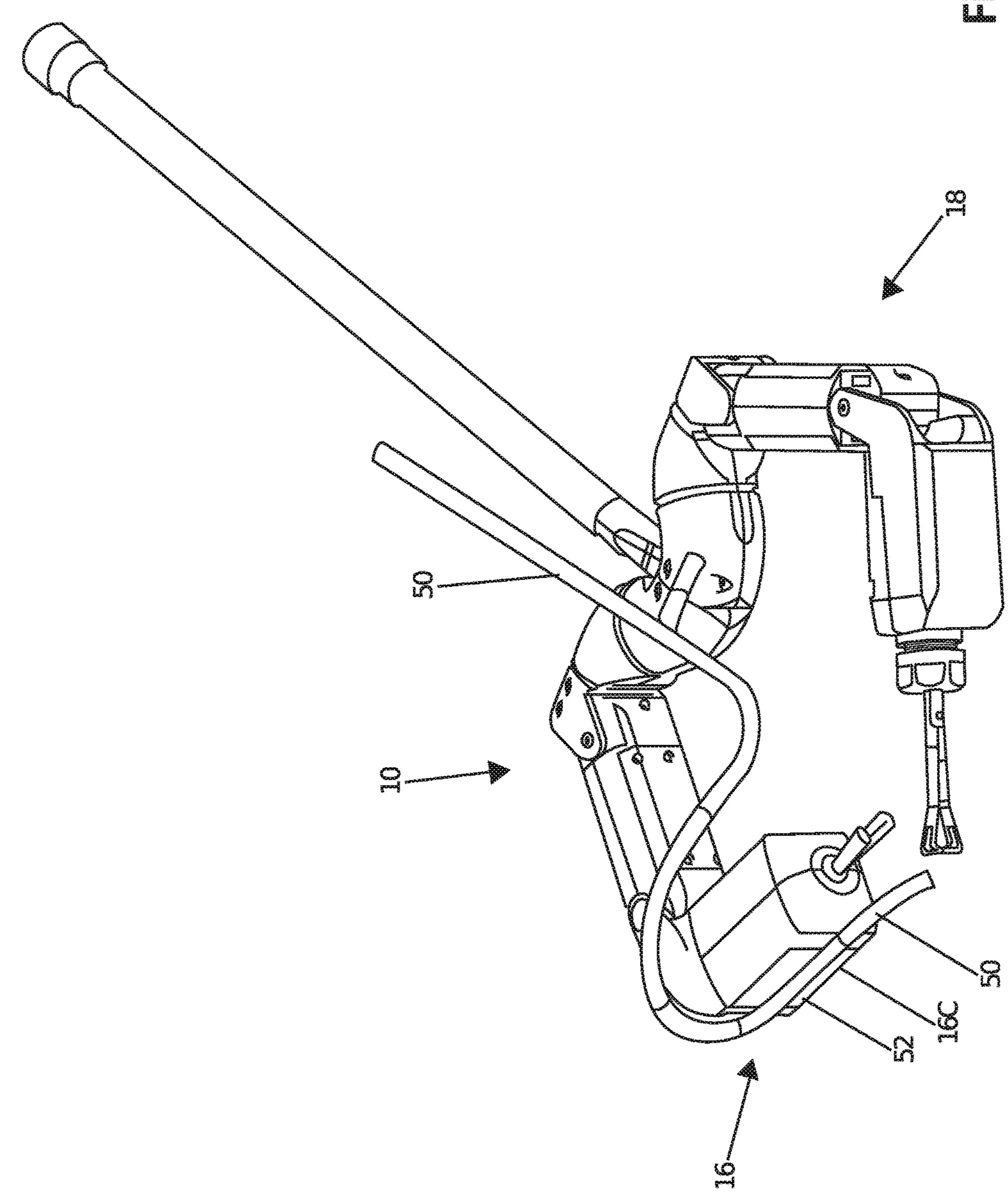

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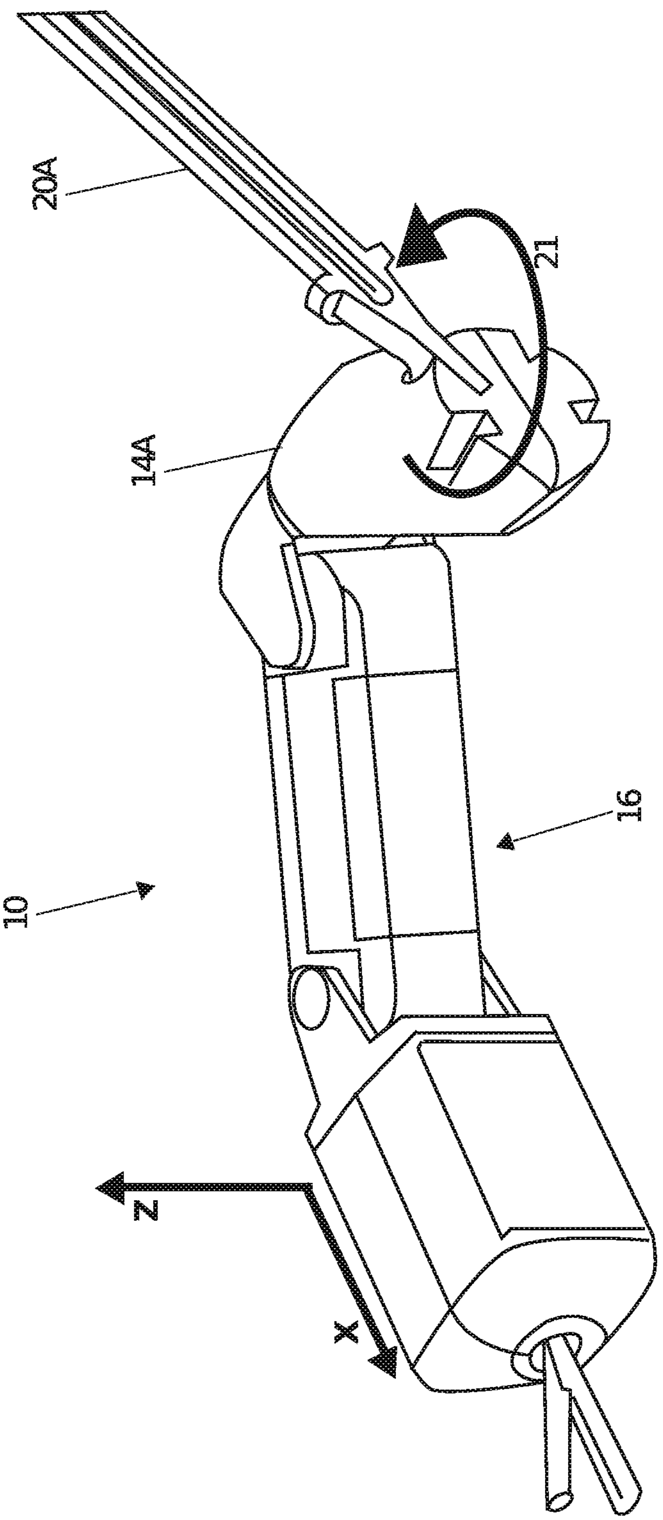

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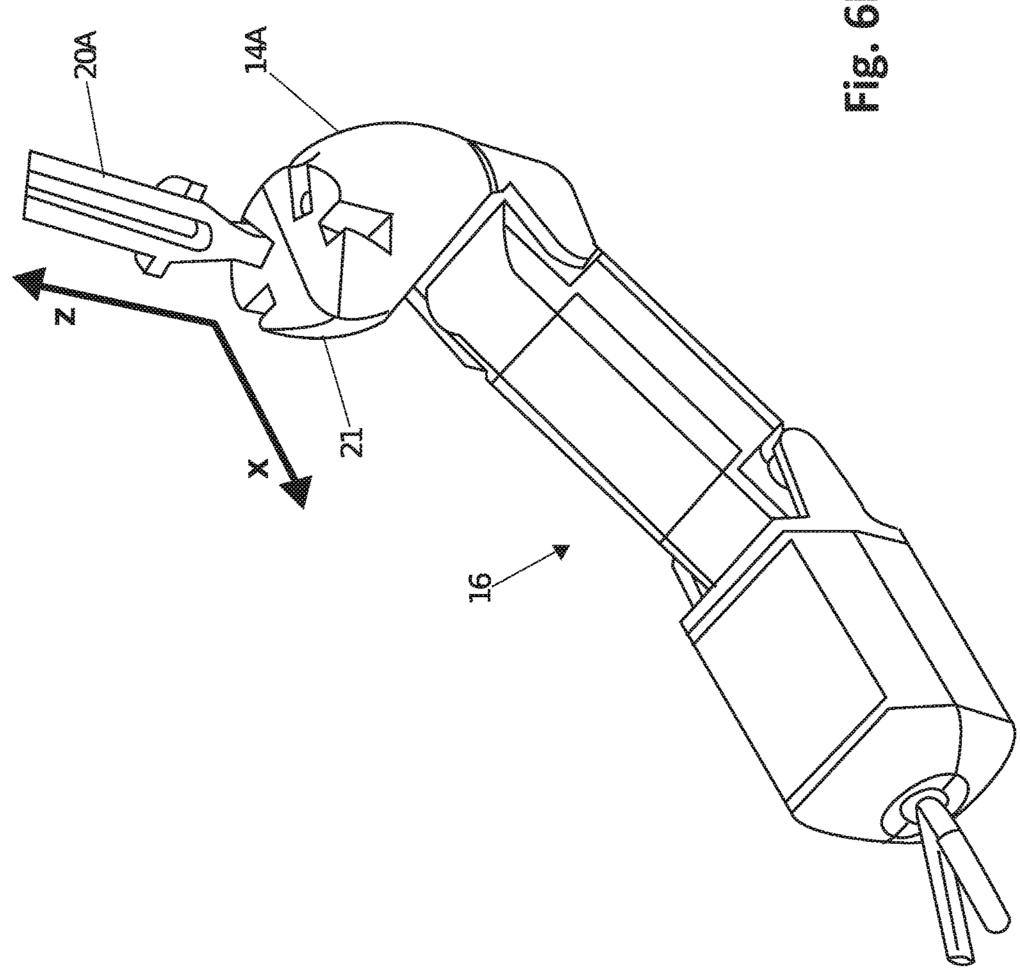

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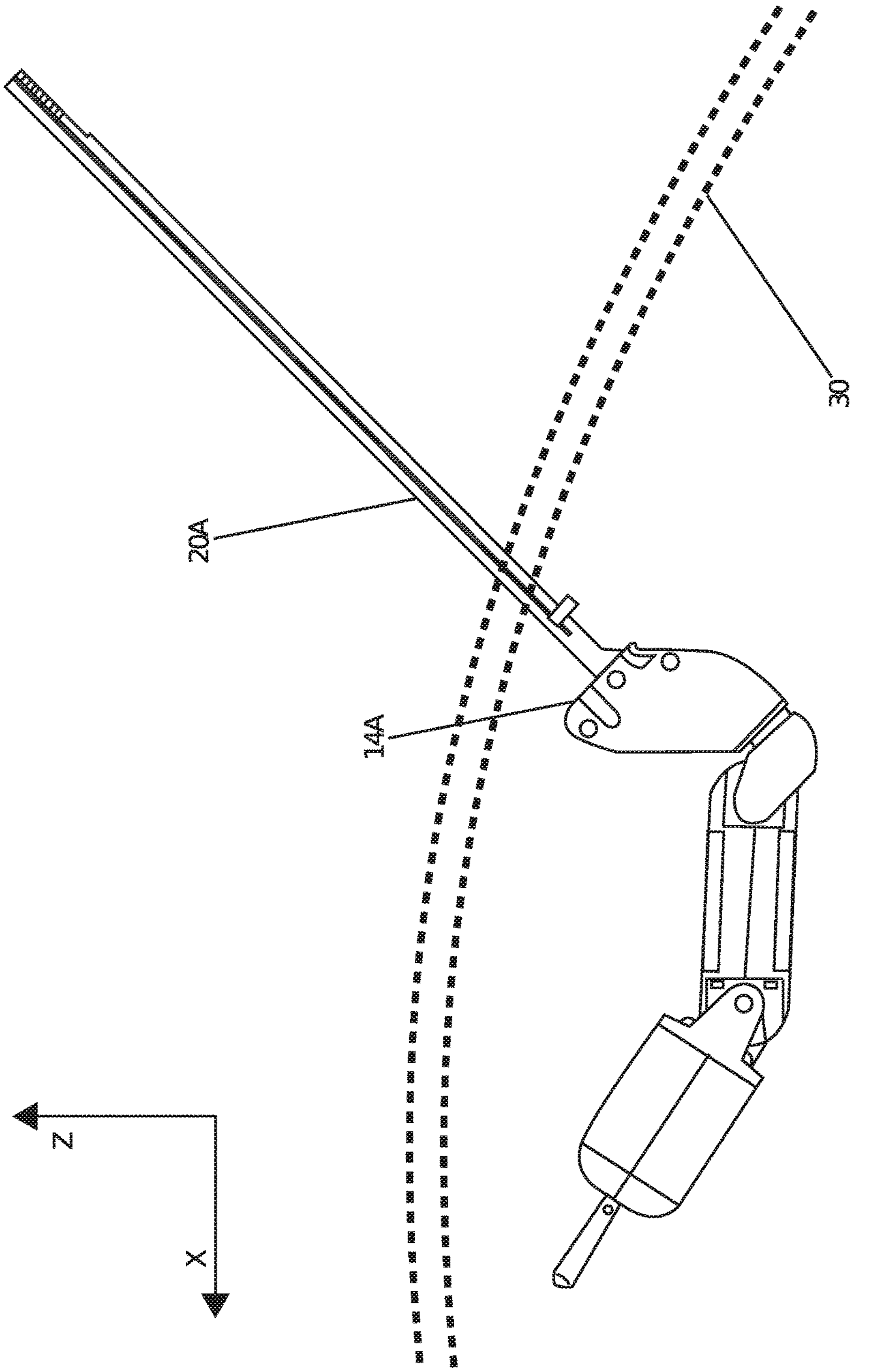
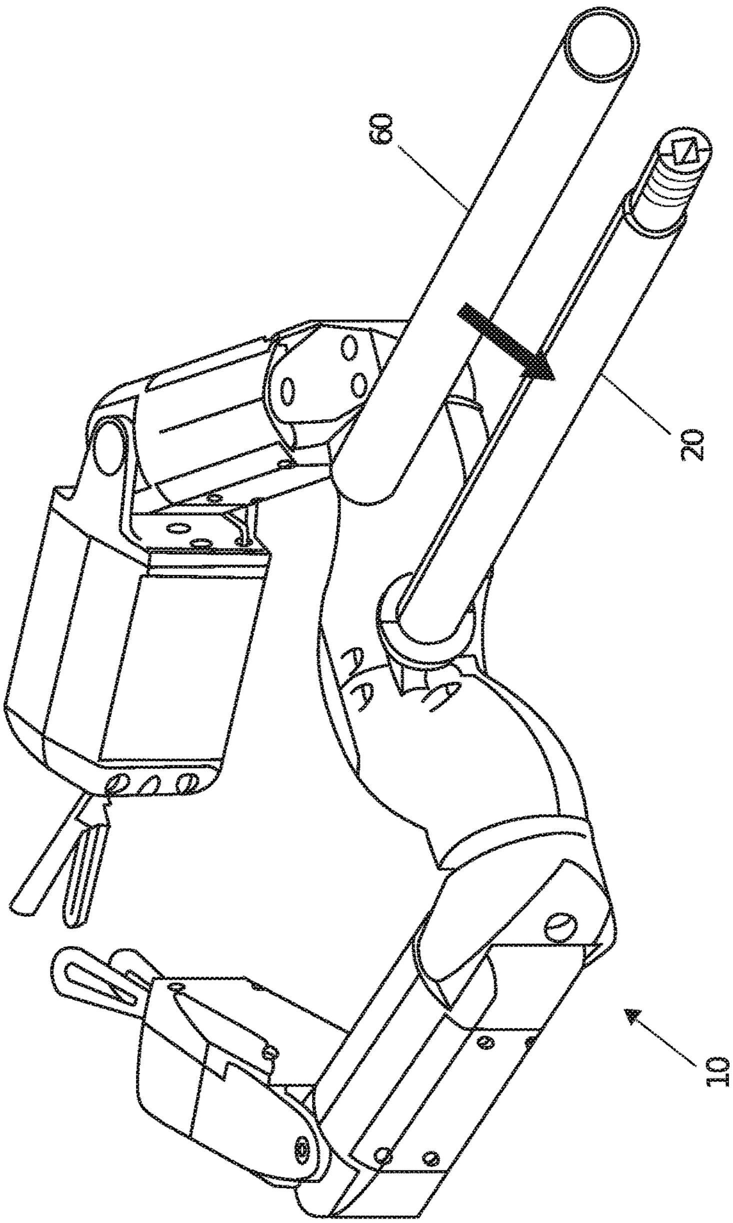
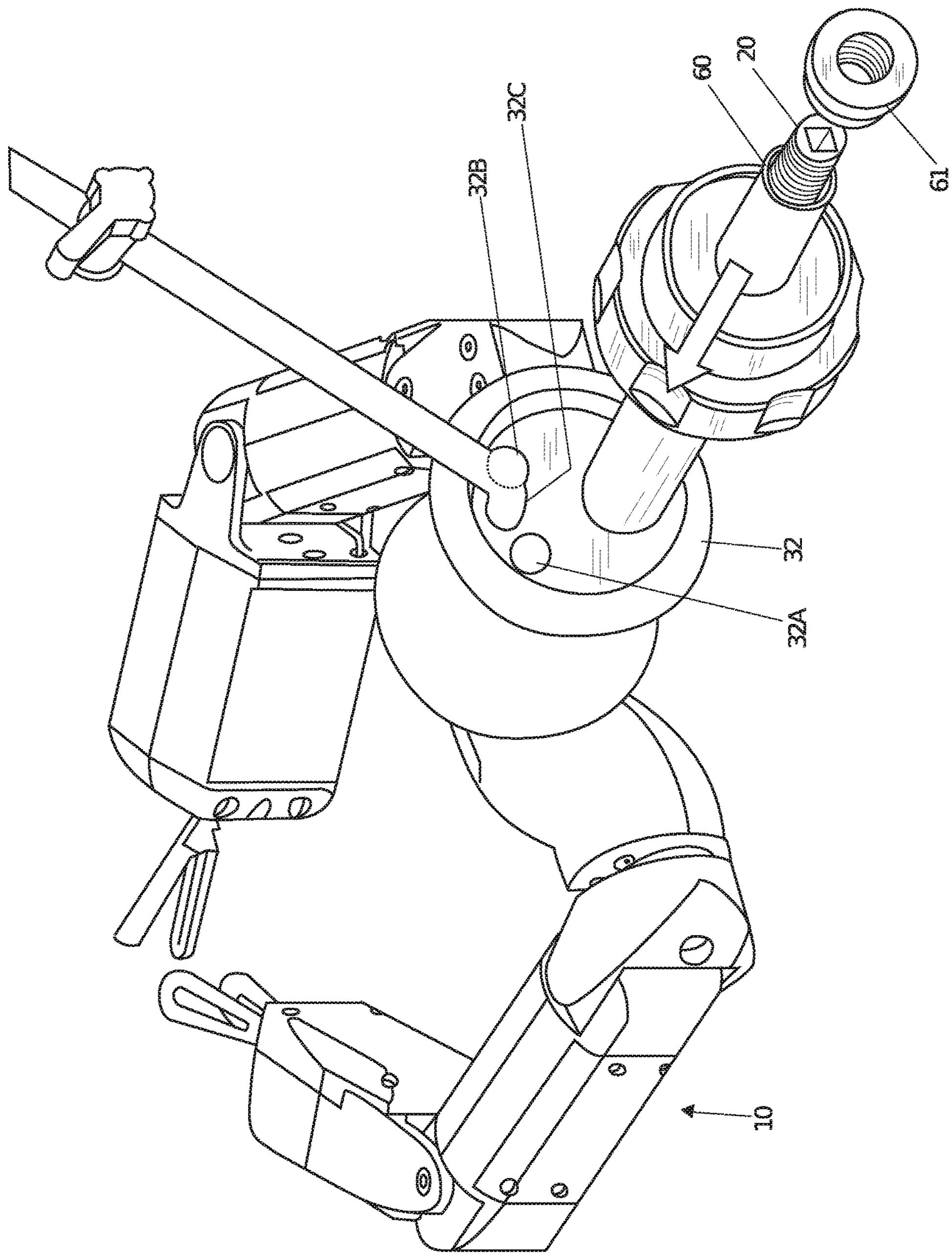


Fig. 7

Fig. 8





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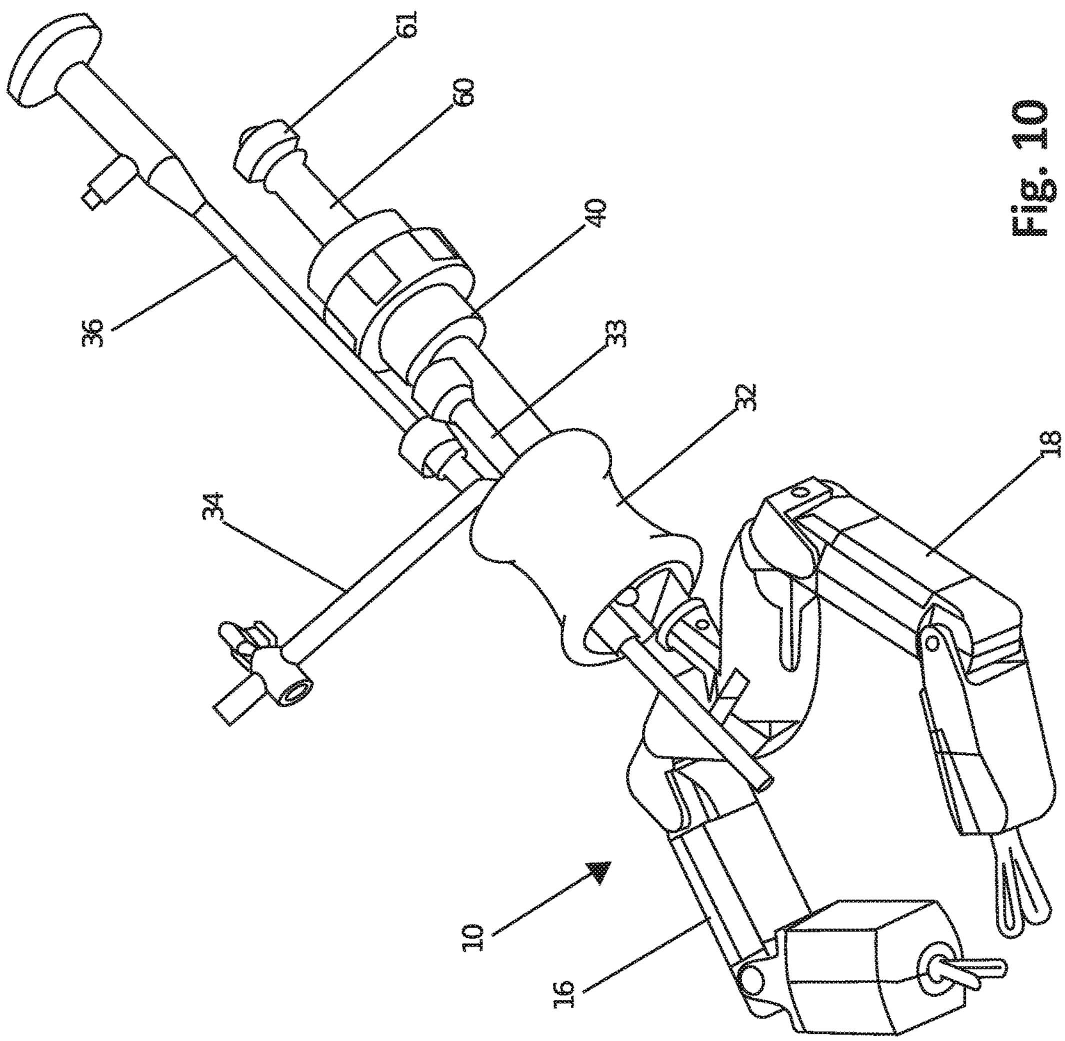

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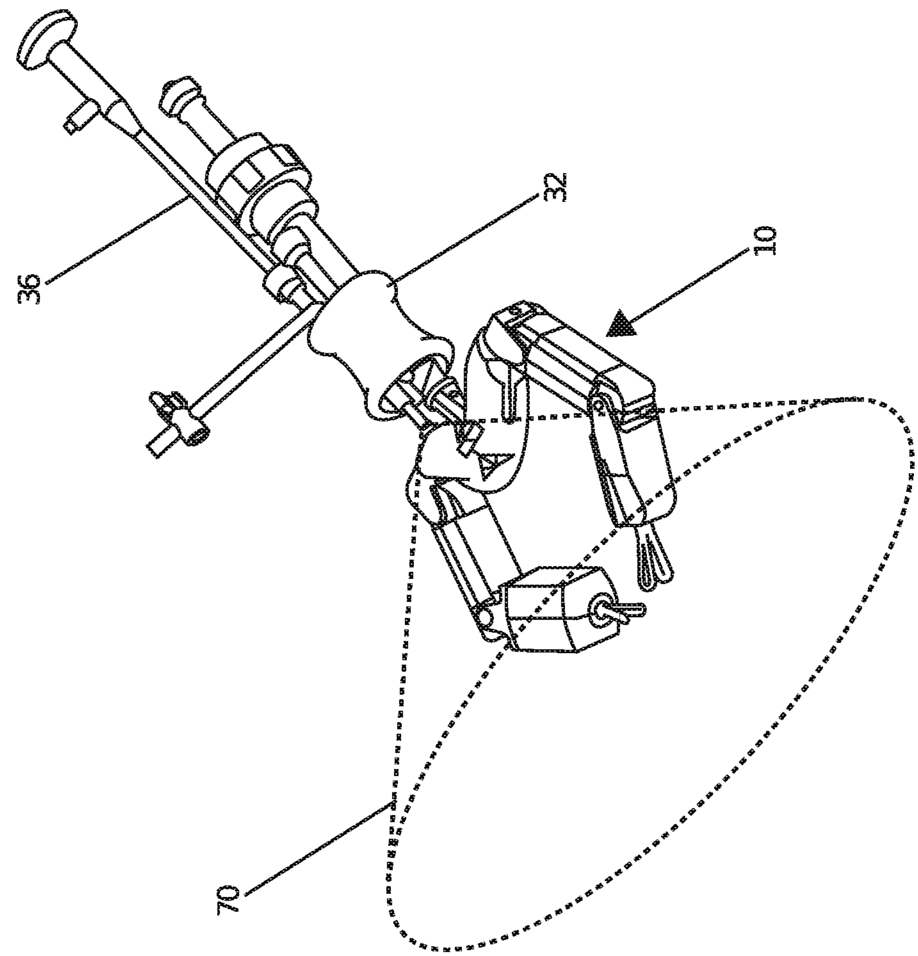

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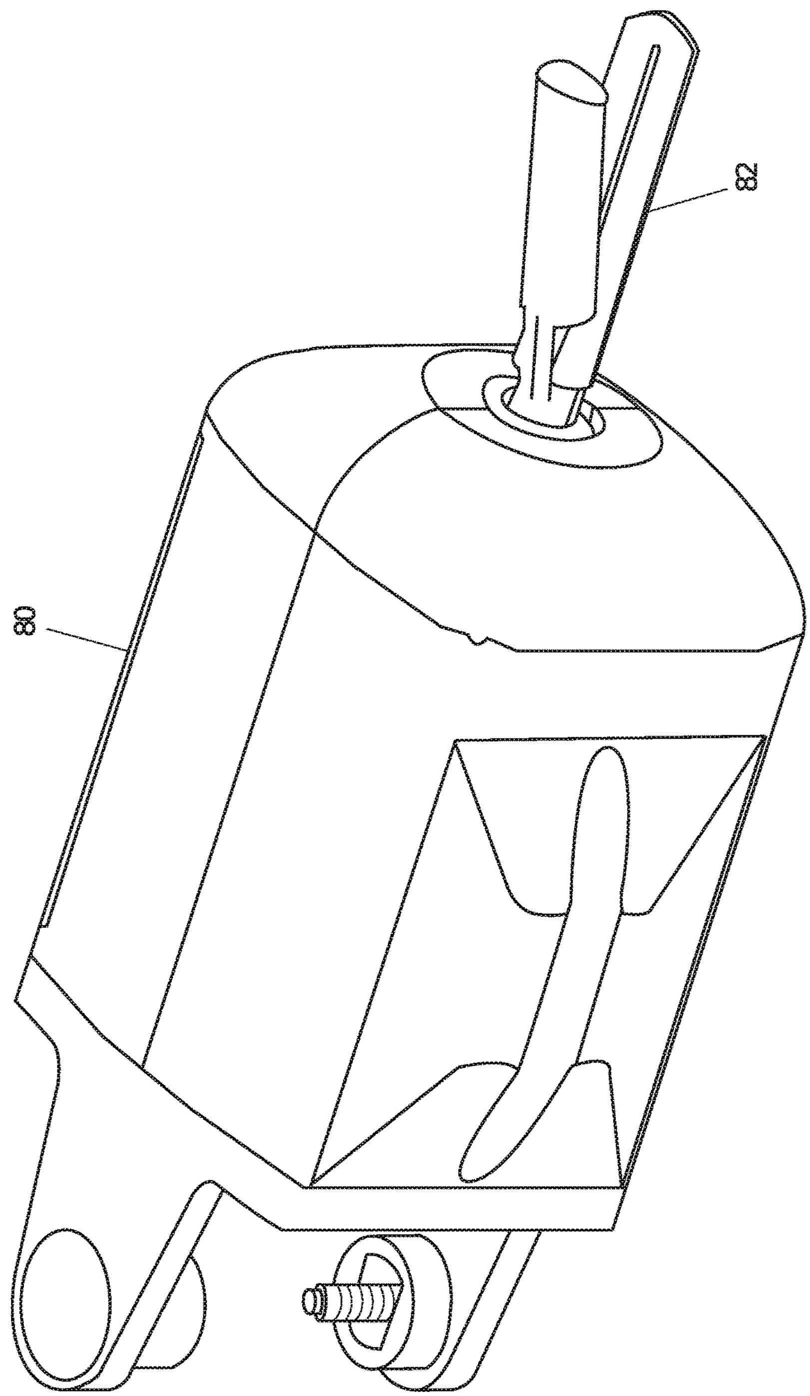

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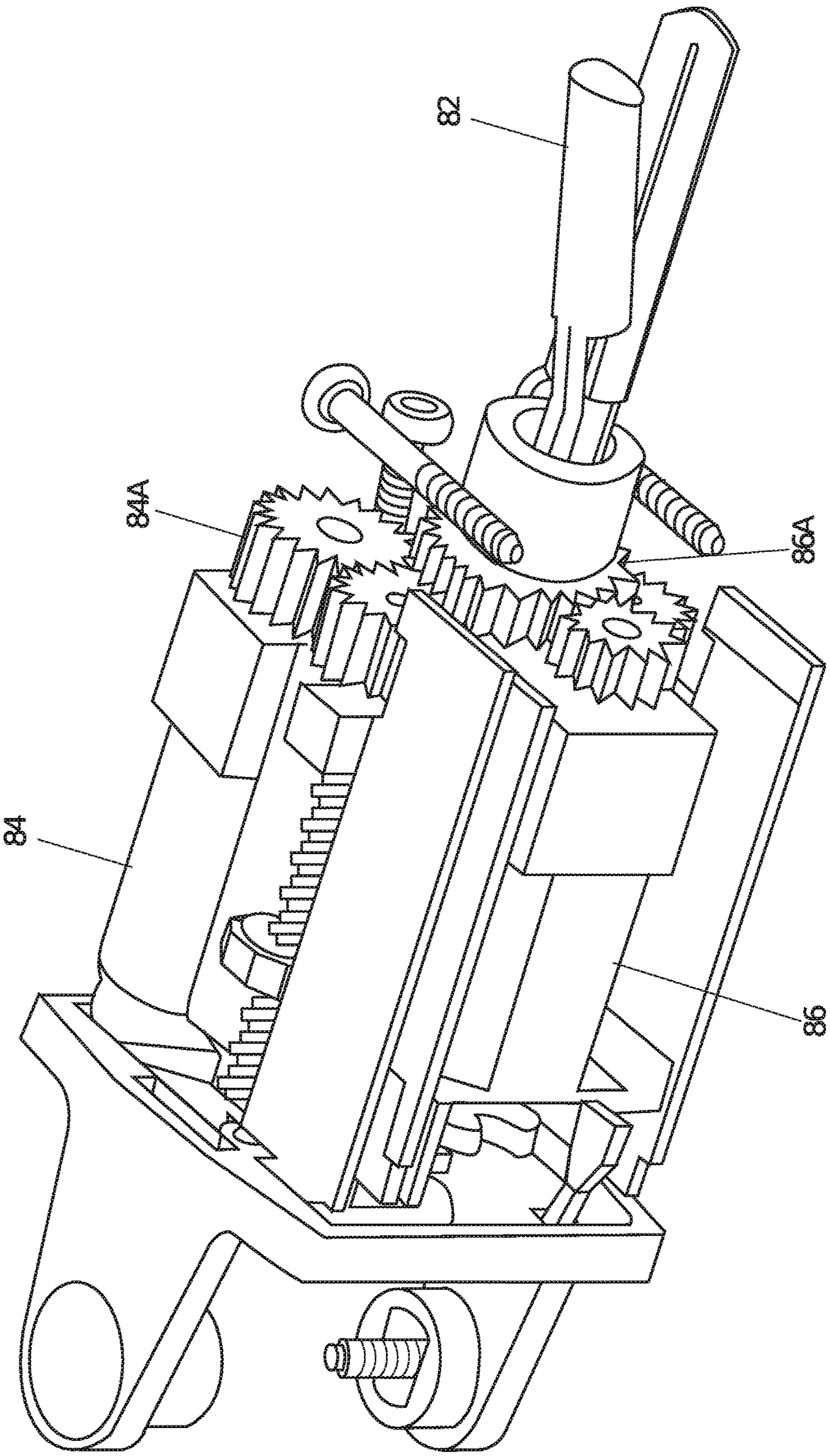

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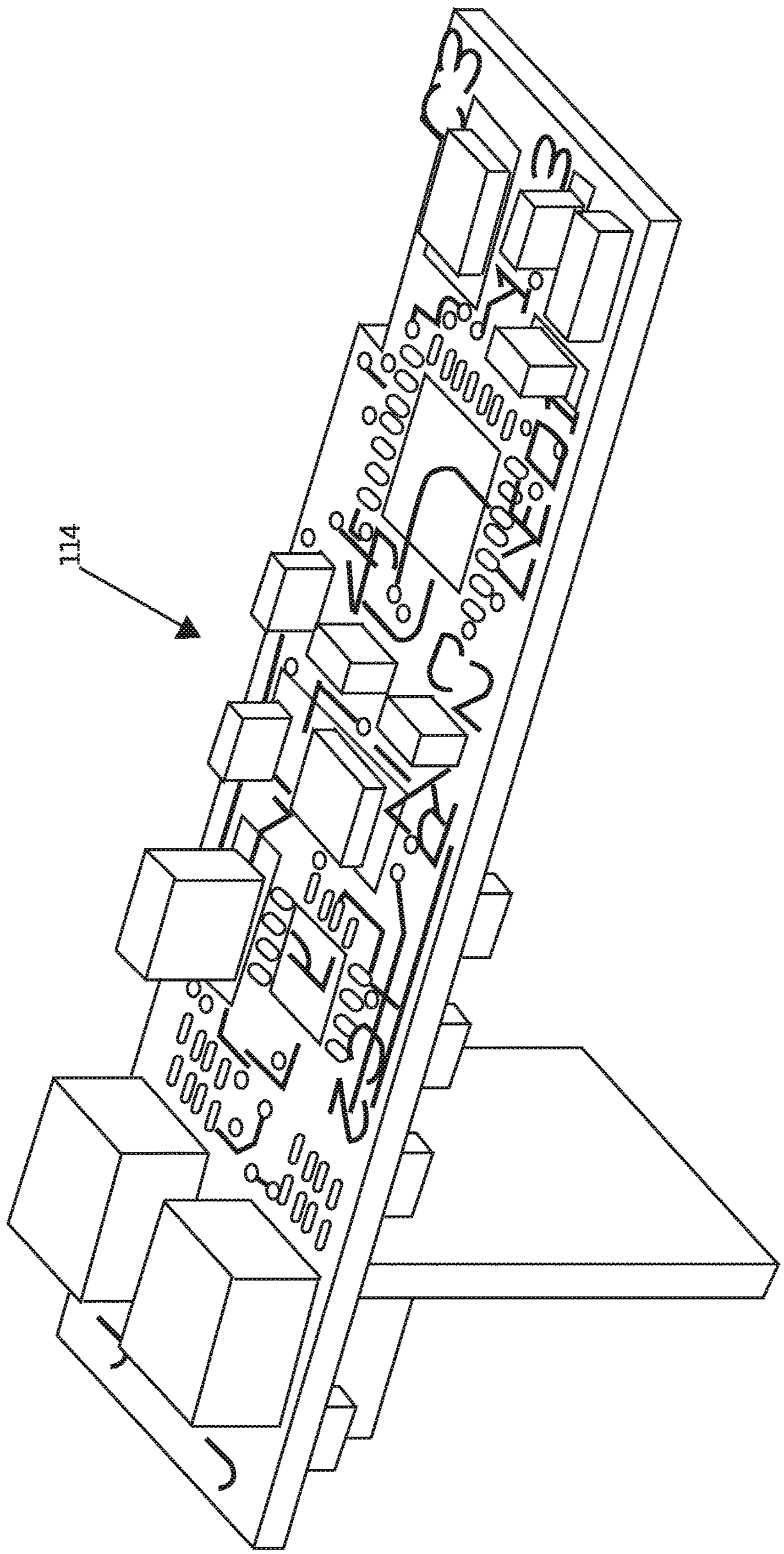

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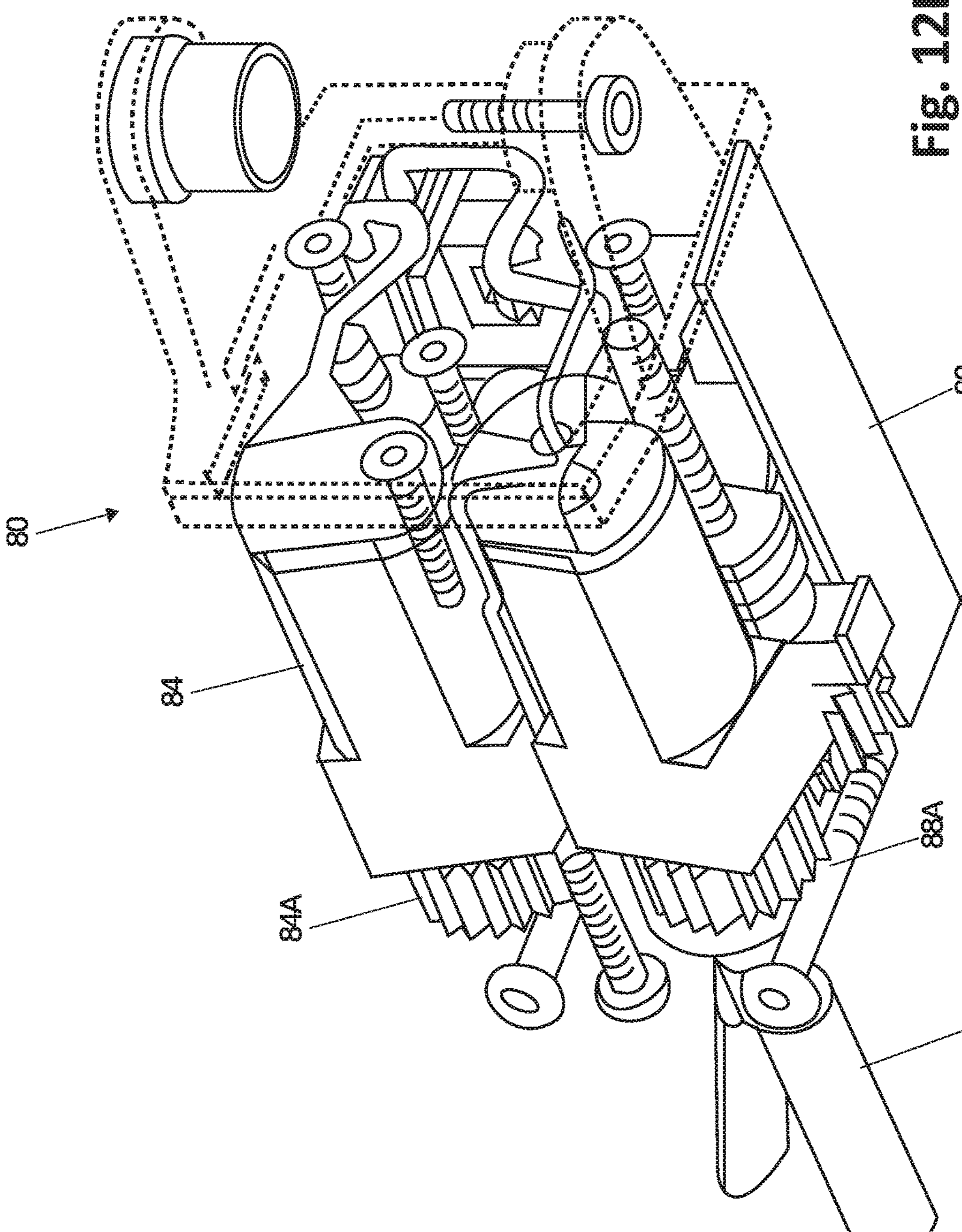

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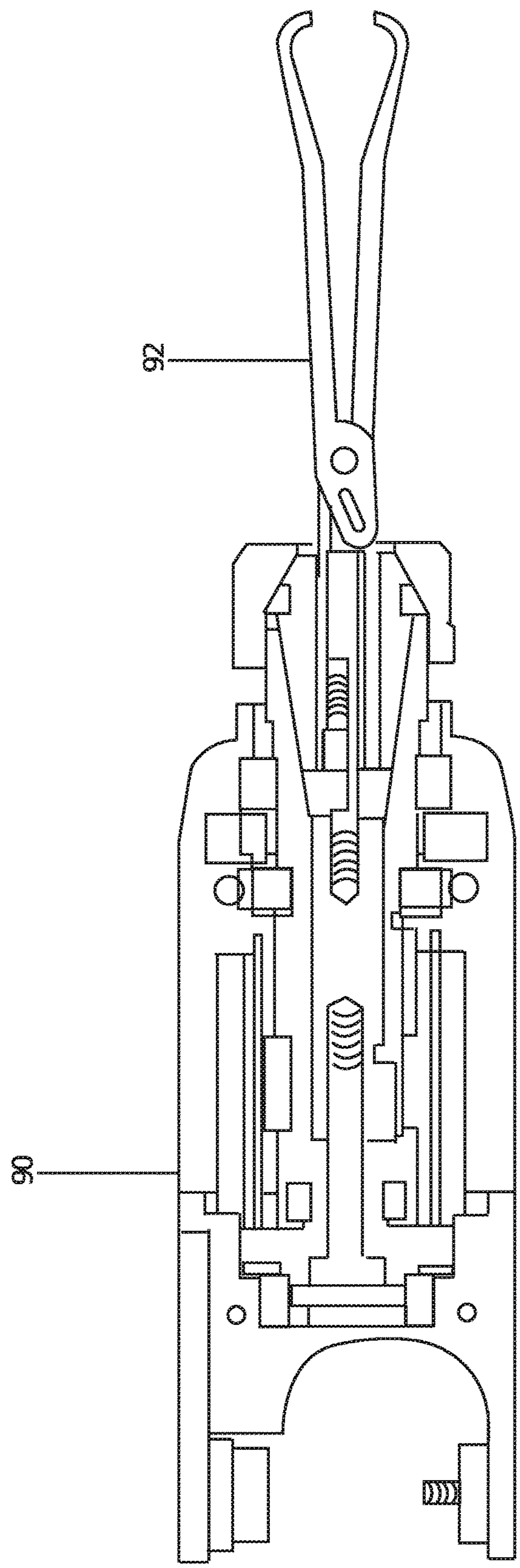

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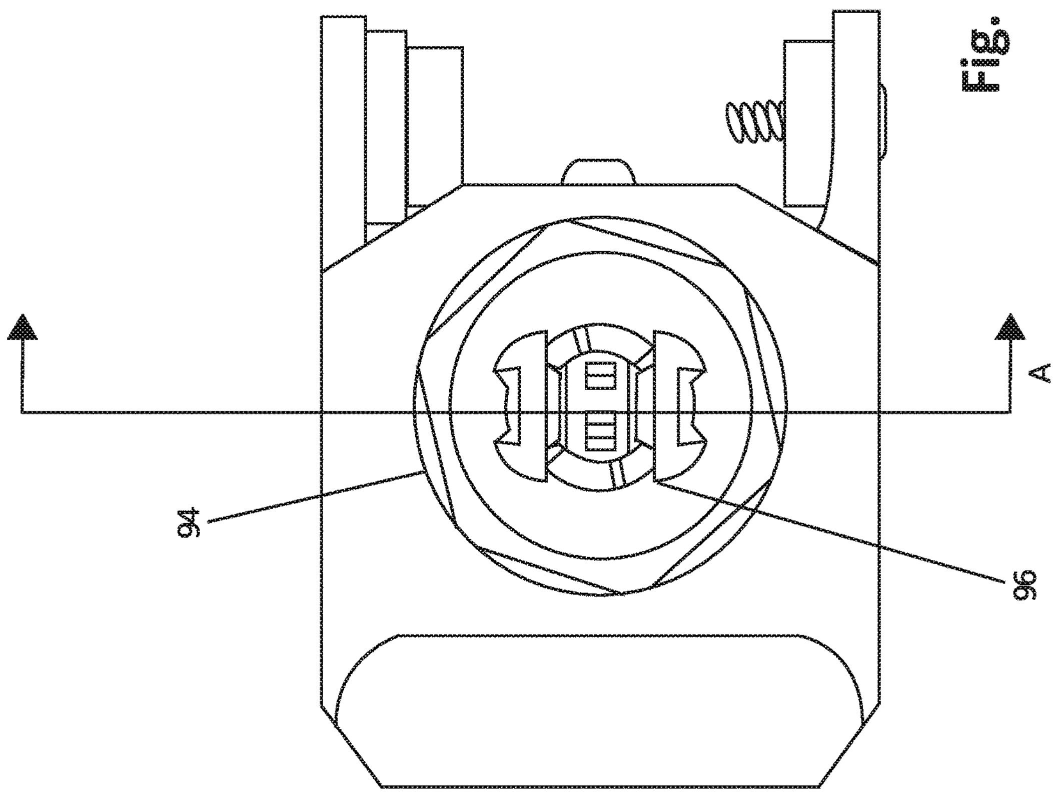

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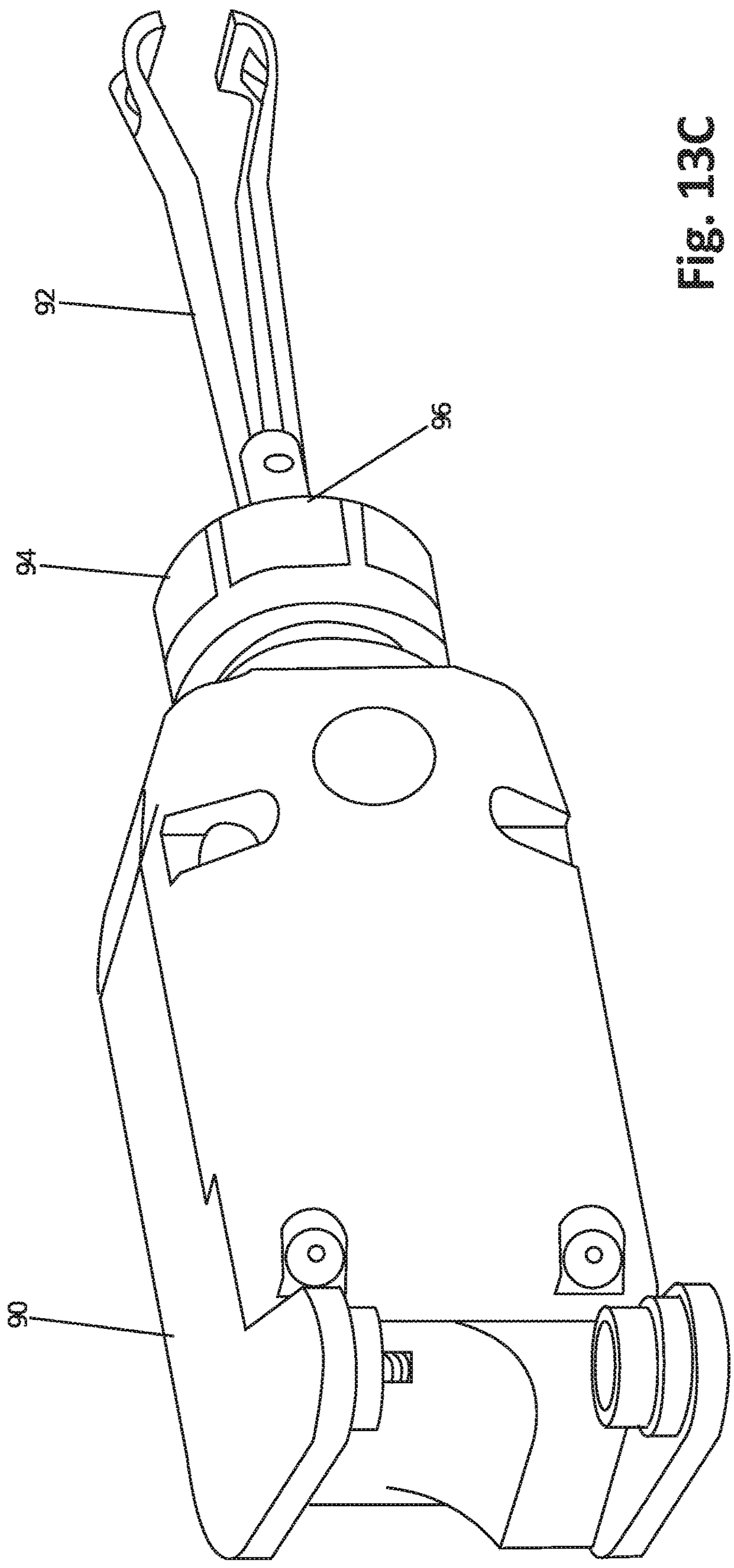

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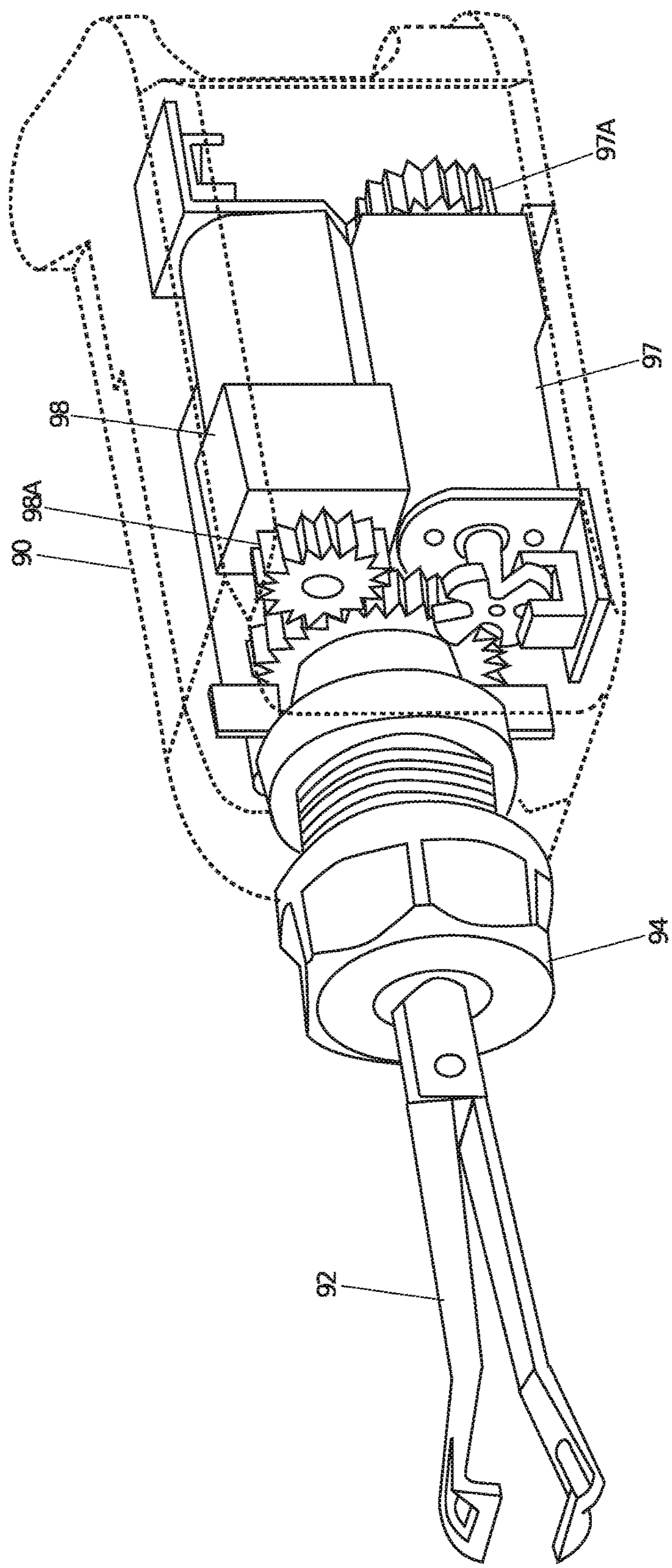

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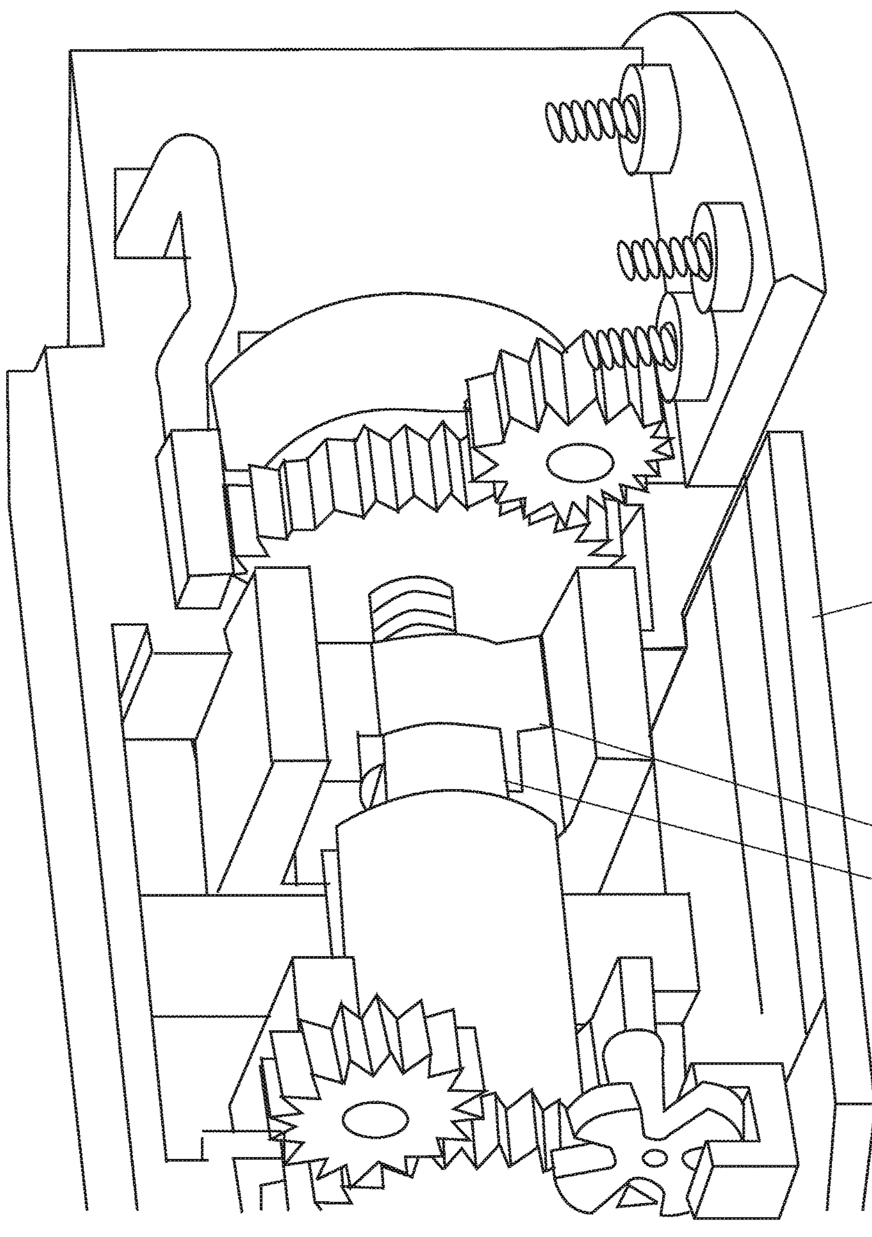

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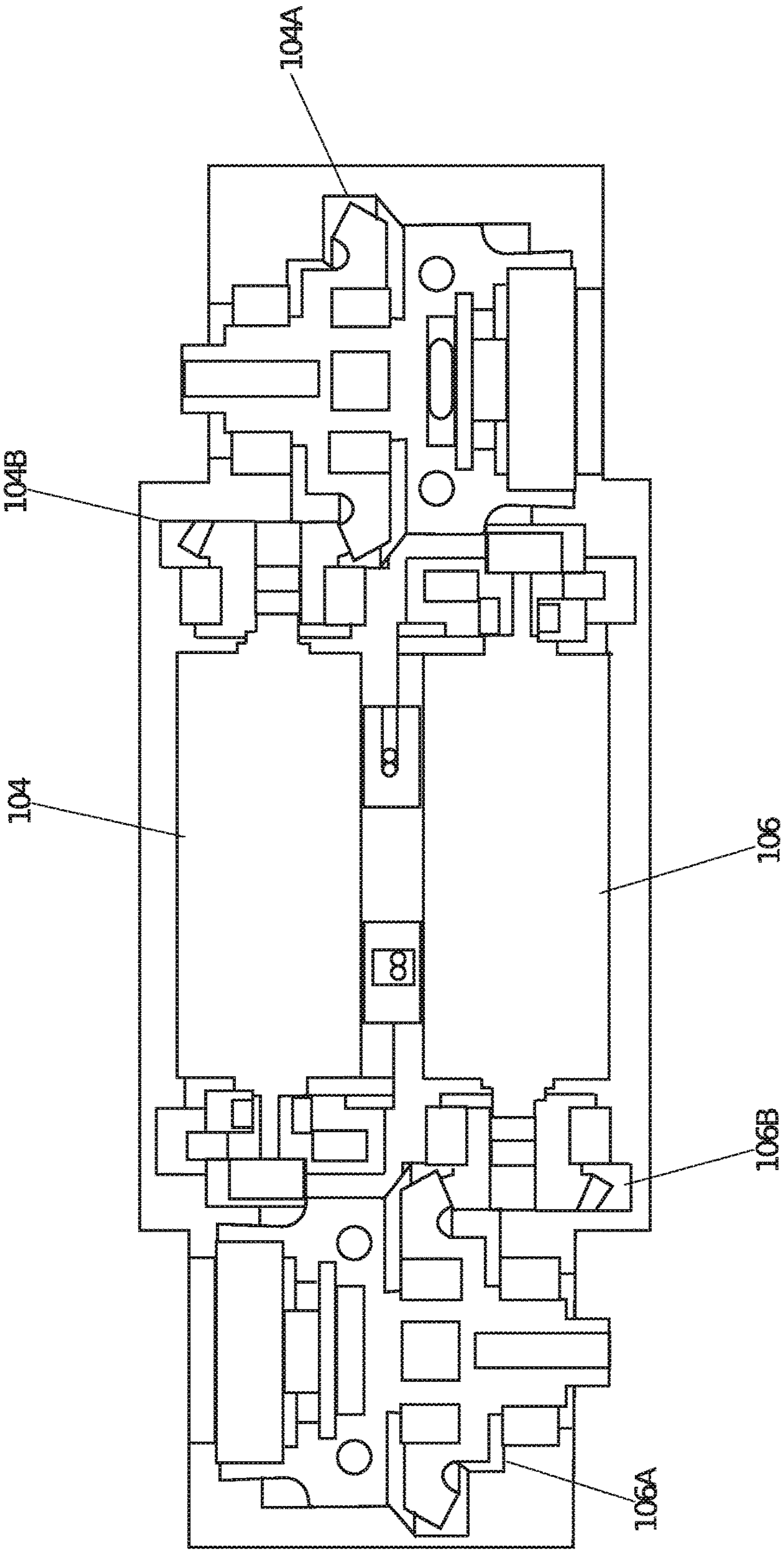

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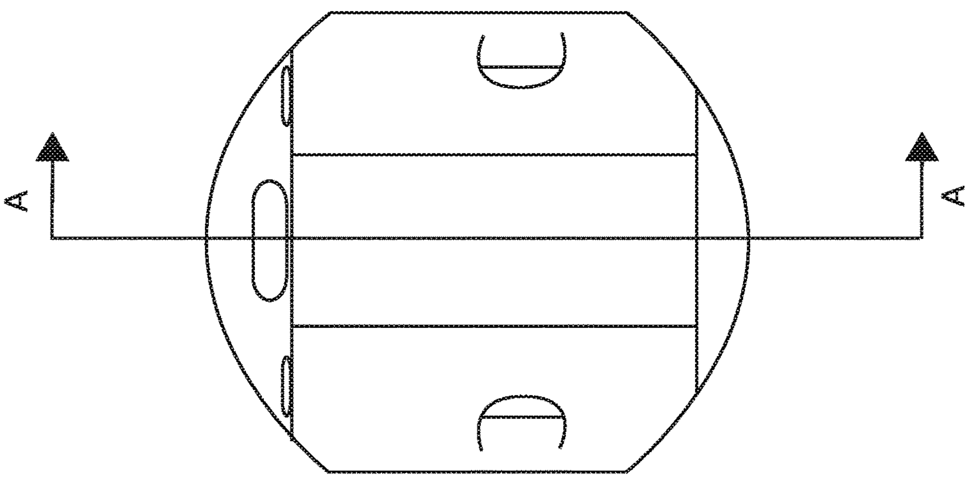

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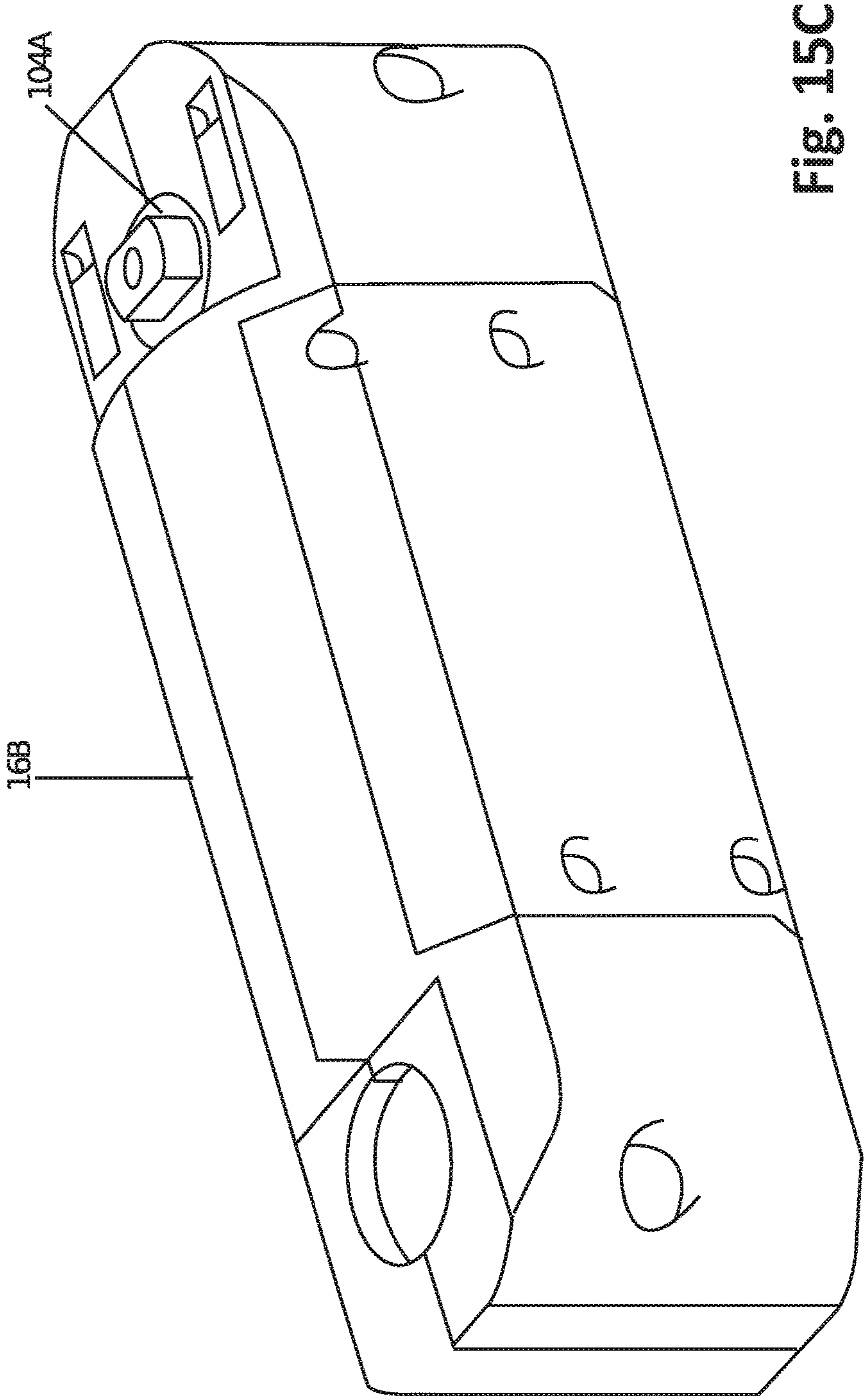

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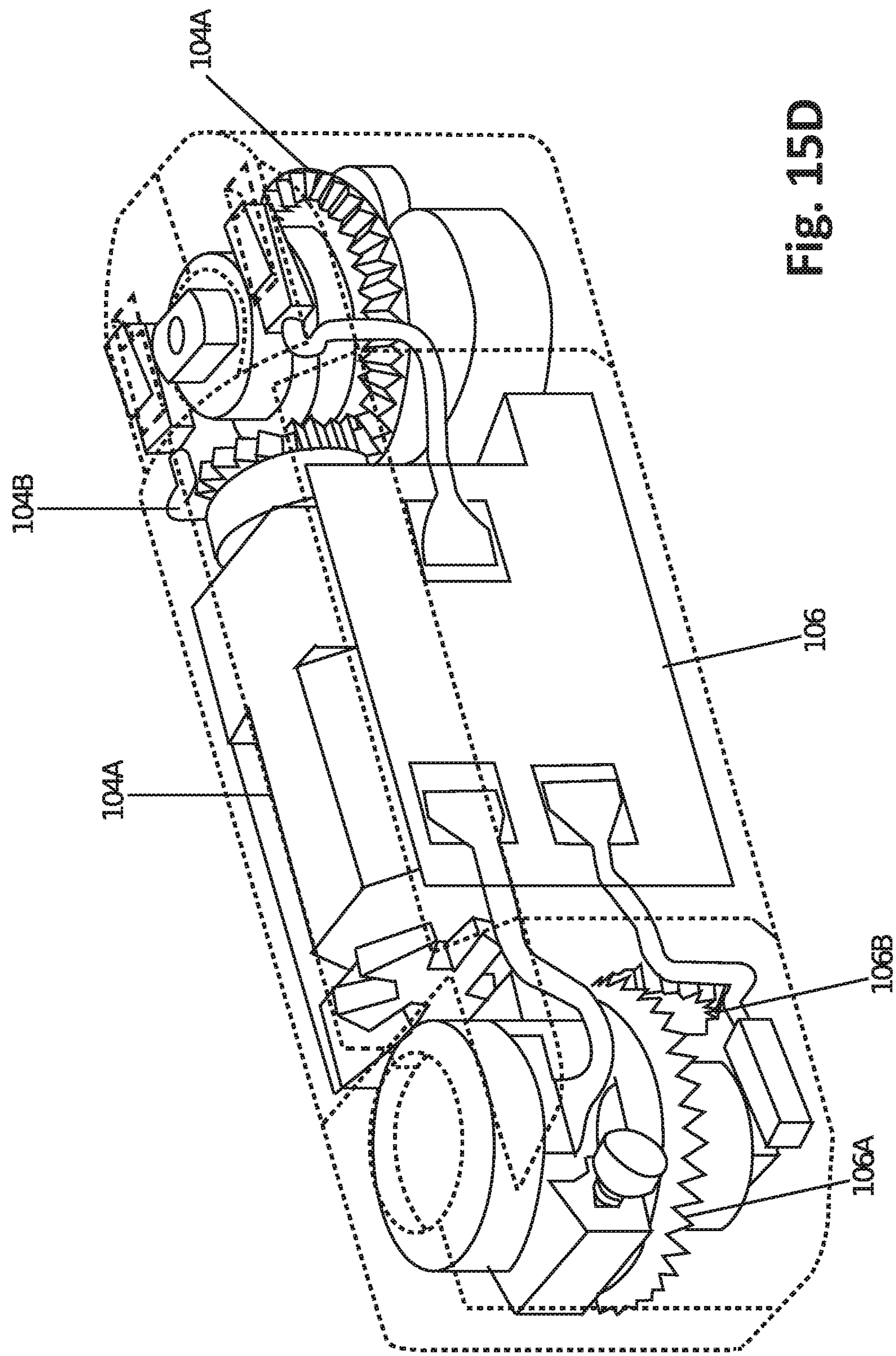

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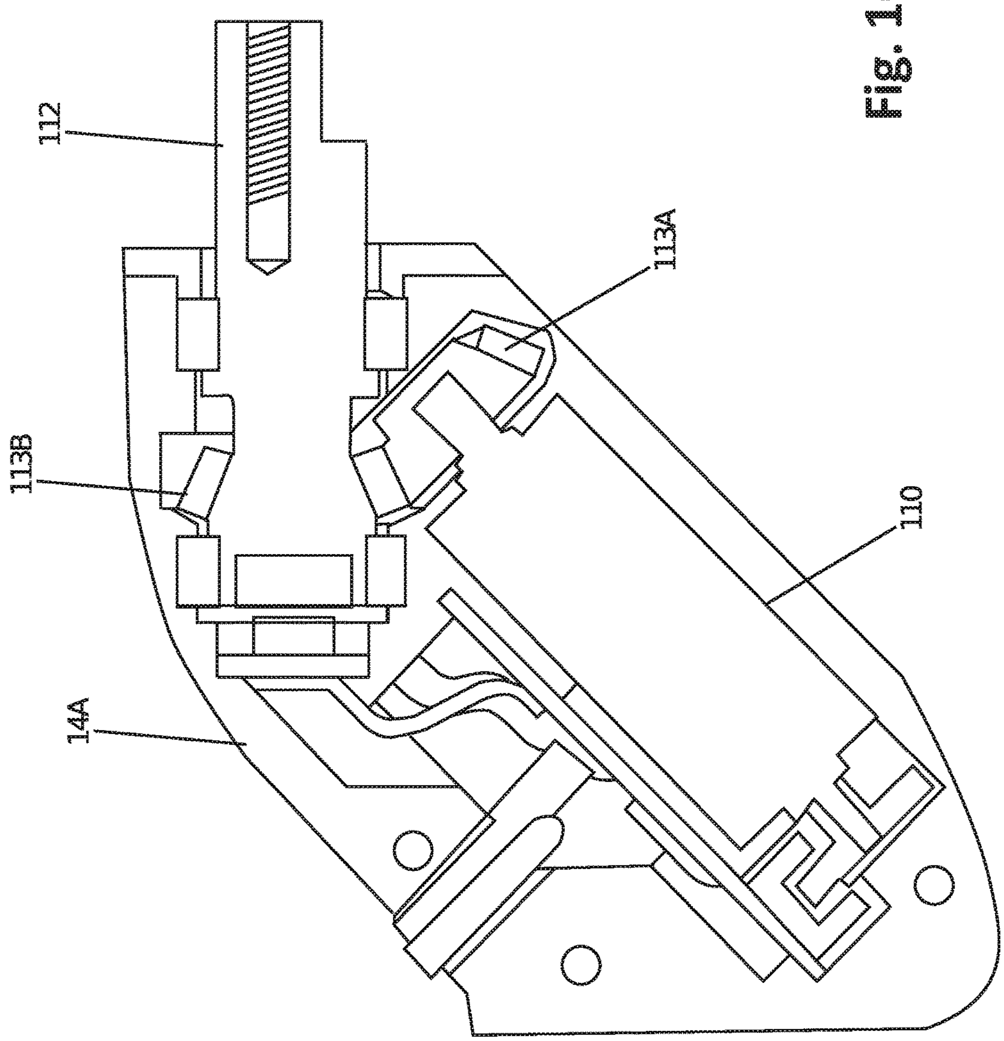

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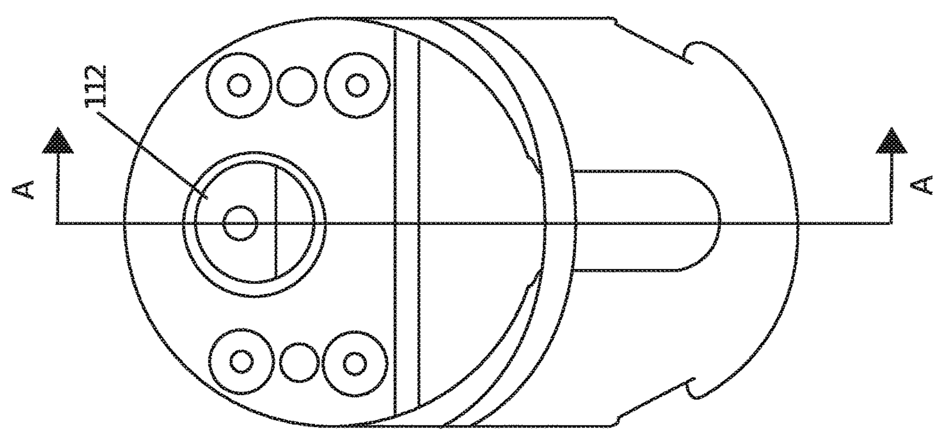

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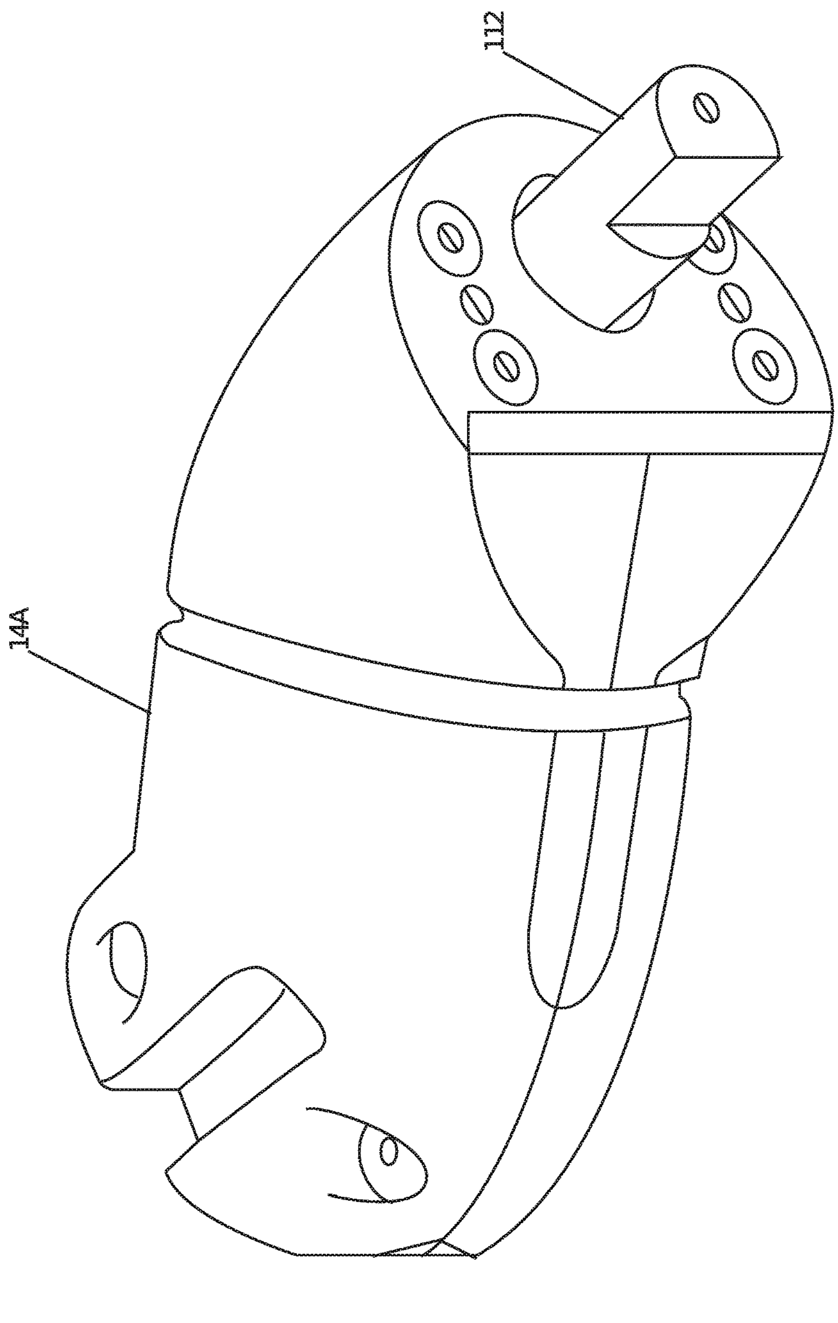

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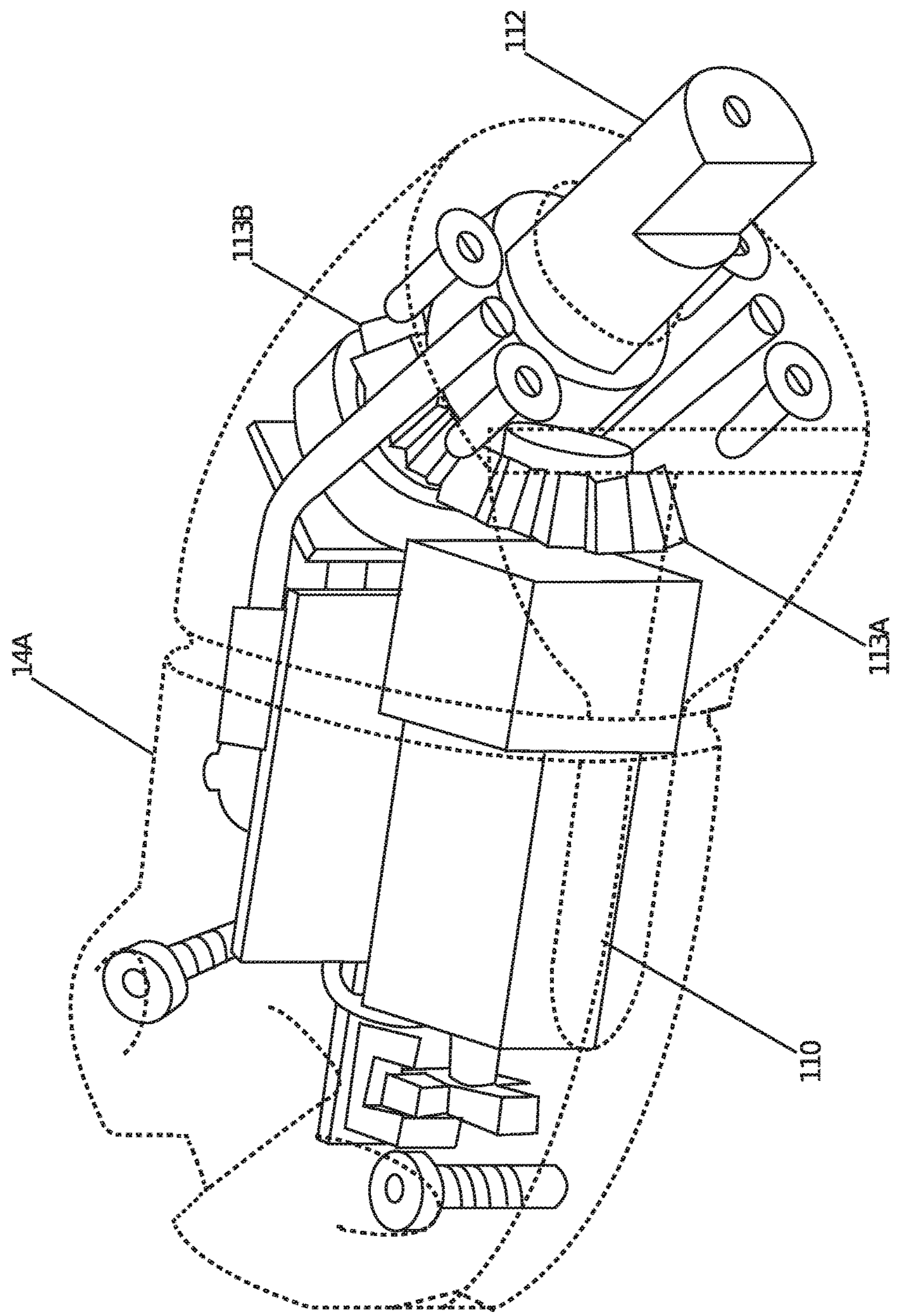

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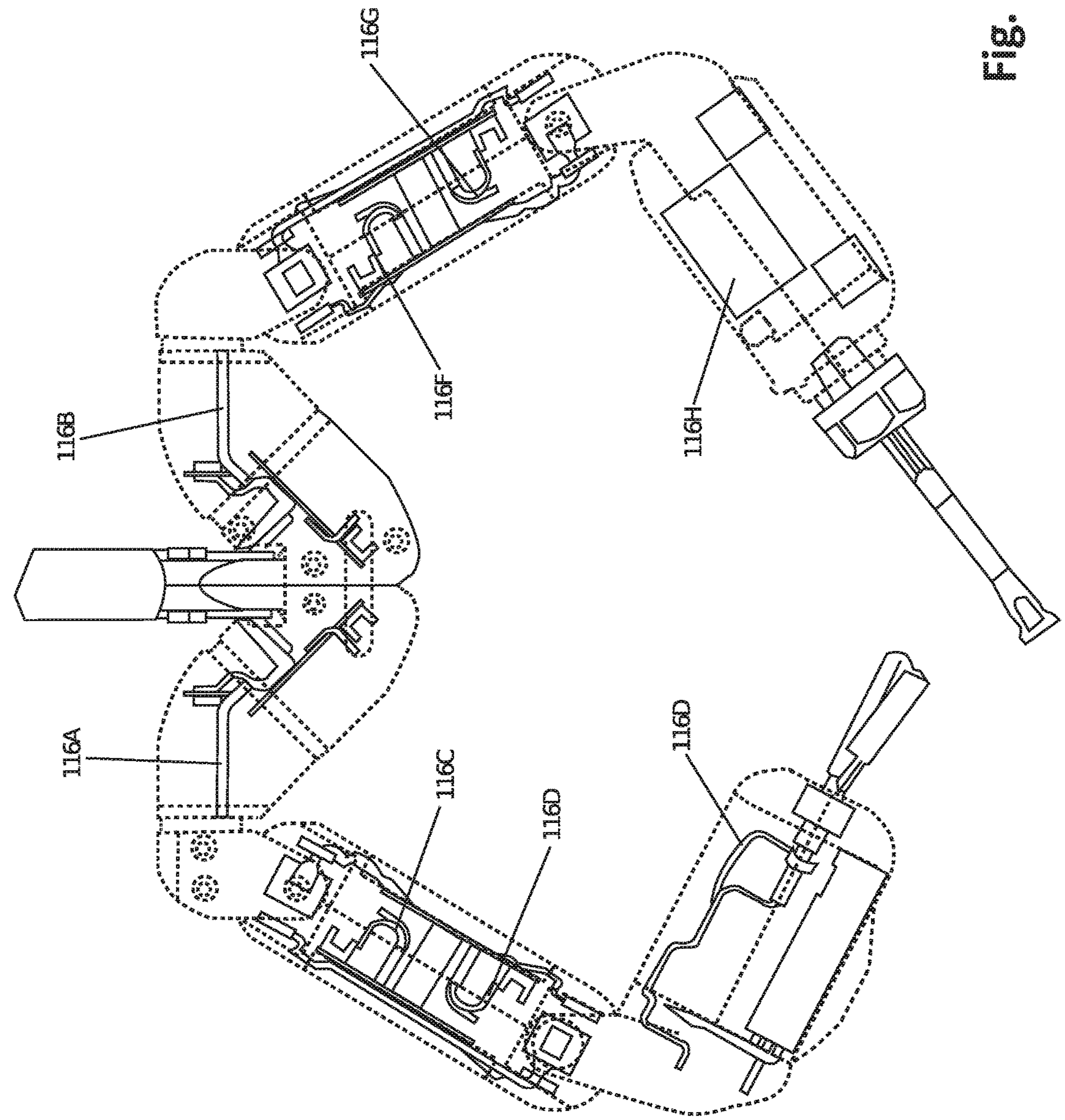

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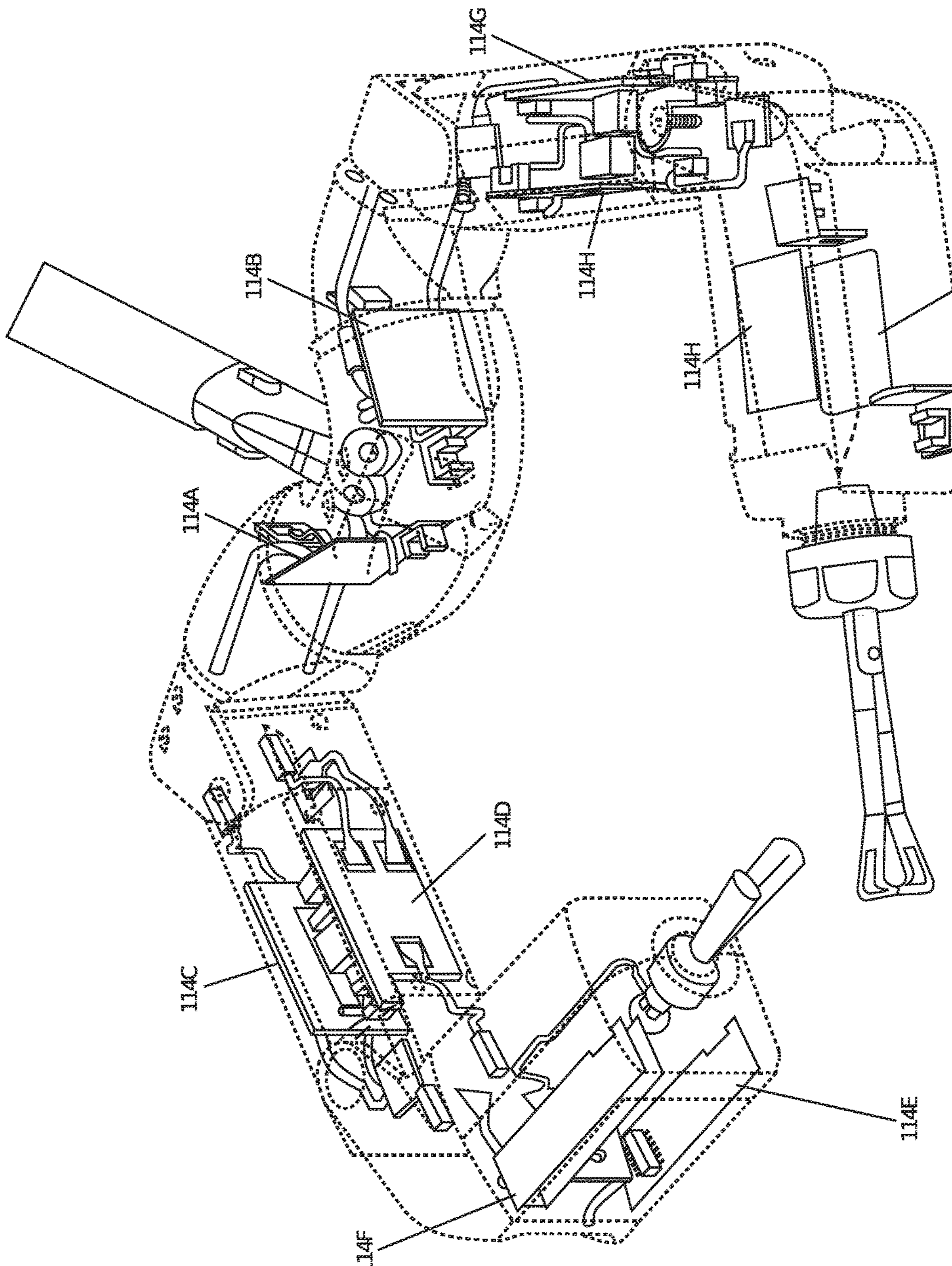

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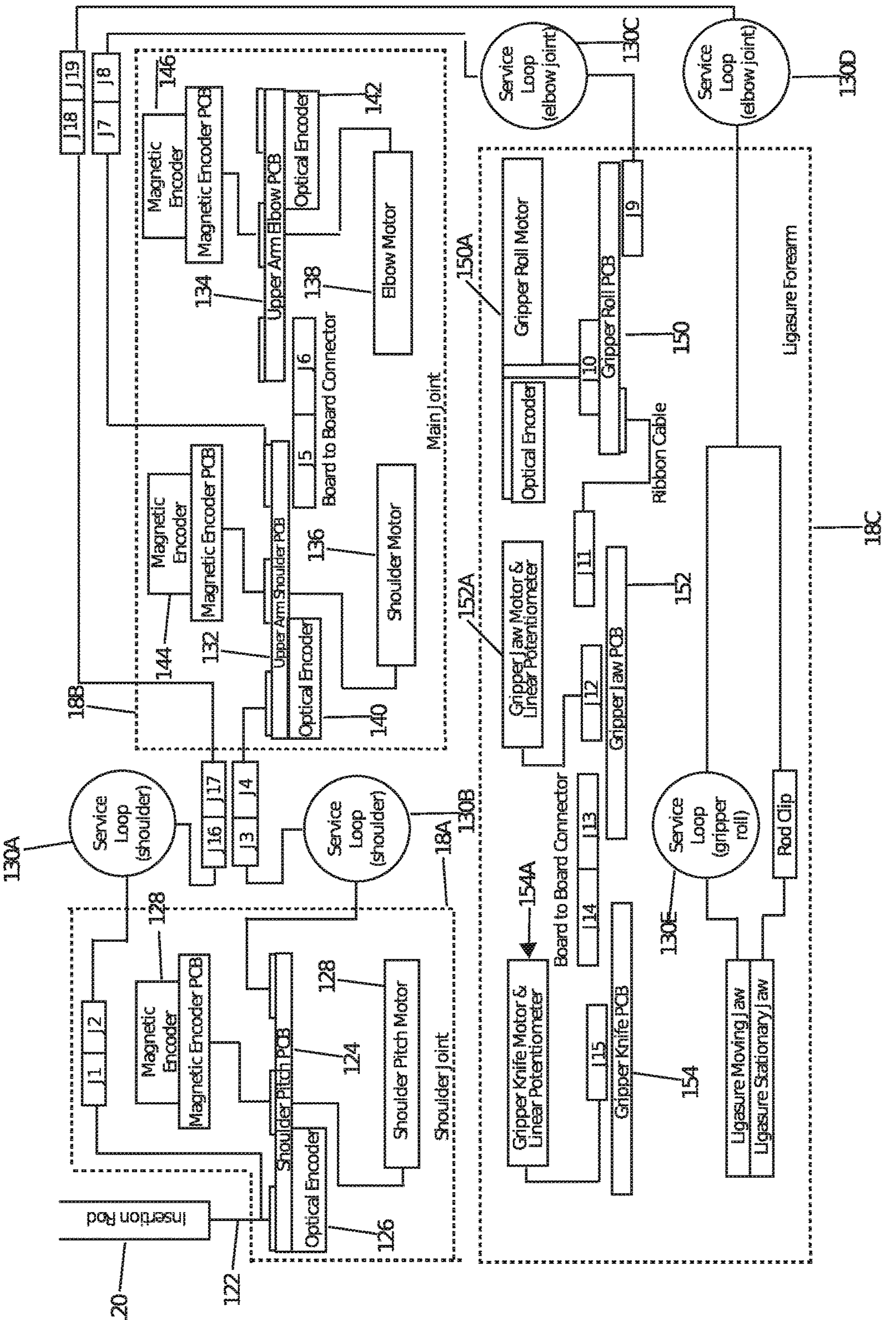
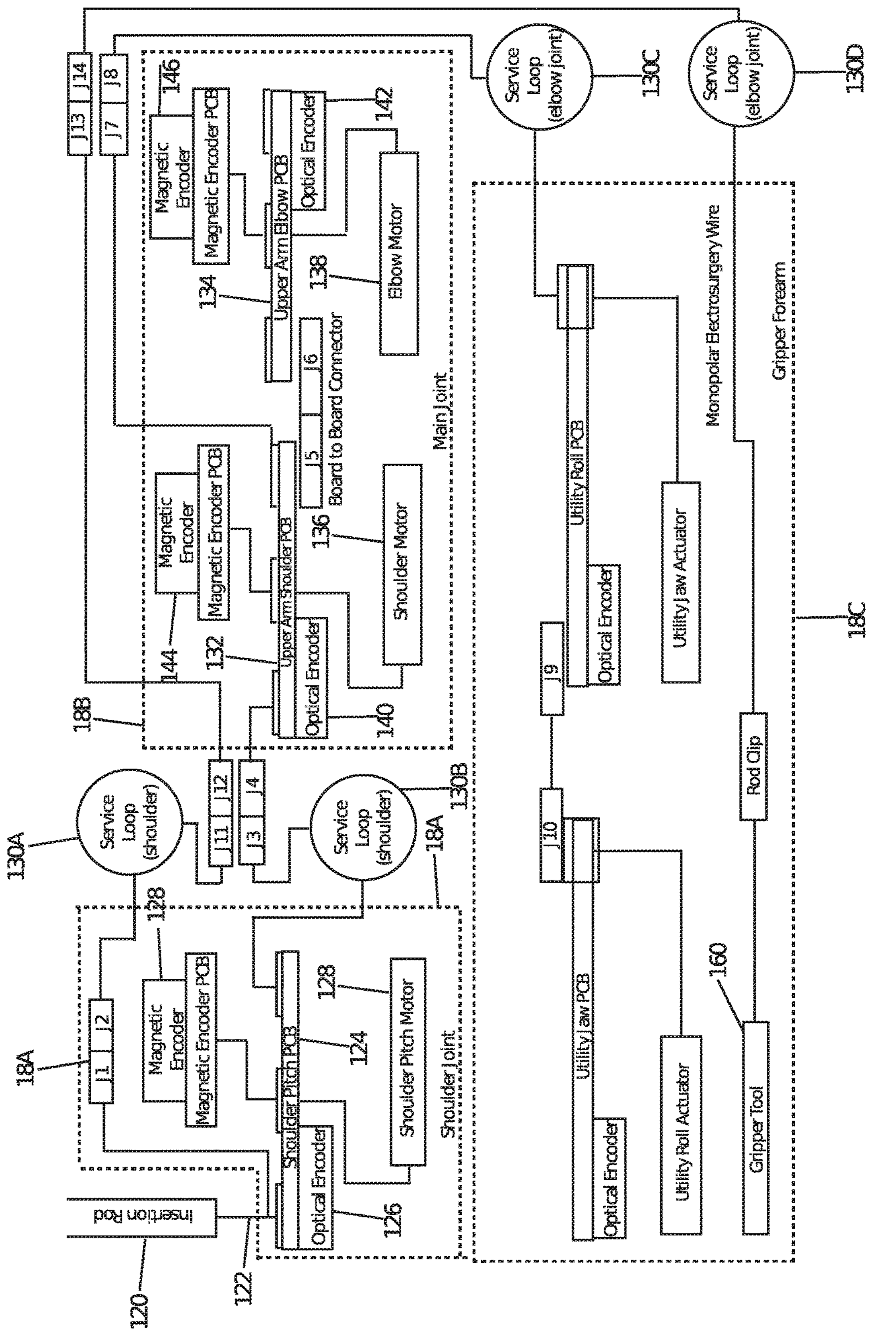


Insertion Rod
120
122
Shoulder Joint
18A
J1
J2
Magnetic Encoder
Magnetic Encoder PCB
128
Shoulder Pitch PCB
124
Optical Encoder
126
Shoulder Pitch Motor
128
Service Loop (shoulder)
130A
Service Loop (shoulder)
130B
J16
J17
J3
J4
18B
Main Joint
Magnetic Encoder
Magnetic Encoder PCB
144
Upper Arm Shoulder PCB
132
Optical Encoder
140
Shoulder Motor
136
J5
J6
Board to Board Connector
Upper Arm Elbow PCB
134
Elbow Motor
138
Optical Encoder
142
Magnetic Encoder
Magnetic Encoder PCB
146
J18
J19
J7
J8
Service Loop (elbow joint)
130C
Service Loop (elbow joint)
130D
Ligasure Forearm
18C
Gripper Roll Motor
150A
Optical Encoder
J10
Gripper Roll PCB
150
J9
Ribbon Cable
J11
Gripper Jaw Motor & Linear Potentiometer
152A
J12
Gripper Jaw PCB
152
J13
J14
Board to Board Connector
Gripper Knife Motor & Linear Potentiometer
154A
J15
Gripper Knife PCB
154
Service Loop (gripper roll)
130E
Rod Clip
Ligasure Moving Jaw
Ligasure Stationary Jaw

Fig. 18


Service Loop (elbow joint)
130C
Service Loop (elbow joint)
130D
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Optical Encoder
142
Upper Arm Elbow PCB
134
138
Elbow Motor
J6
J5
Board to Board Connector
Main Joint
Magnetic Encoder
Magnetic Encoder PCB
Upper Arm Shoulder PCB
136
Shoulder Motor
144
132
Optical Encoder
140
18B
Service Loop (shoulder)
130A
J11
J12
J3
J4
Service Loop (shoulder)
130B
18A
128
Magnetic Encoder
Magnetic Encoder PCB
J1
J2
18A
Shoulder Pitch PCB
124
128
Shoulder Pitch Motor
Shoulder Joint
Optical Encoder
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Insertion Rod
120
122
Monopolar Electrosurgery Wire
Gripper Forearm
Utility Roll PCB
Optical Encoder
Utility Jaw Actuator
J9
J10
Rod Clip
18C
Utility Jaw PCB
Optical Encoder
Utility Roll Actuator
160
Gripper Tool

Fig. 19

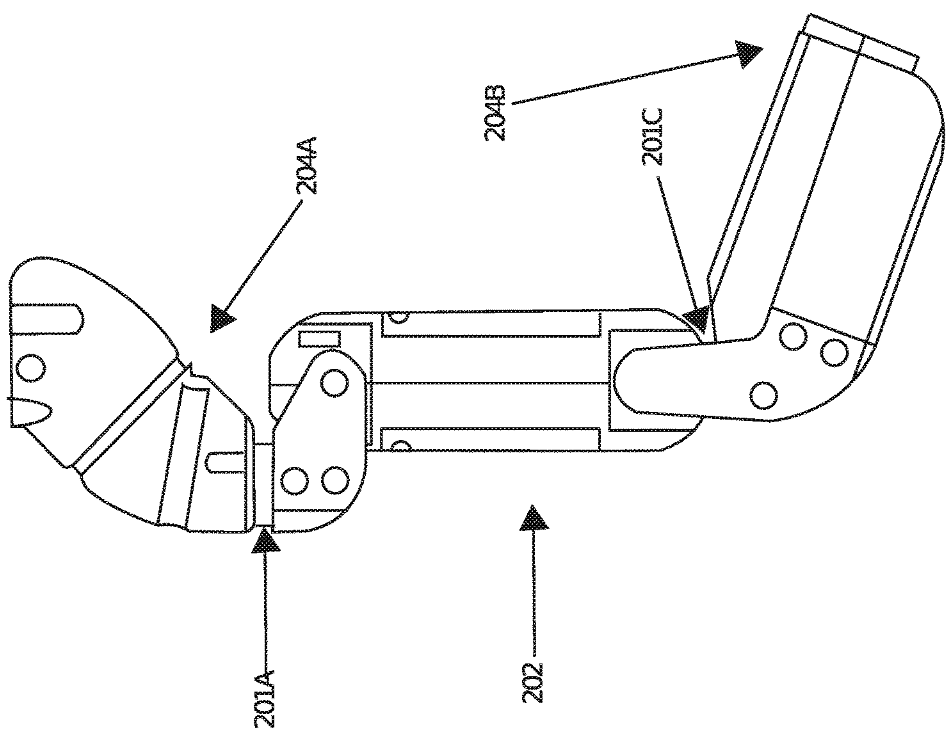

Fig. 20A

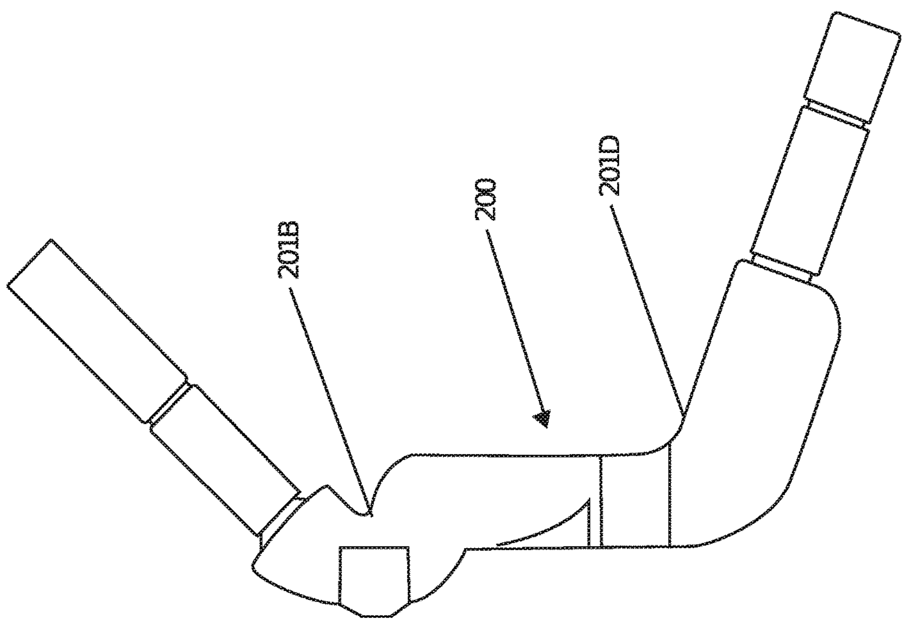

Fig. 20B

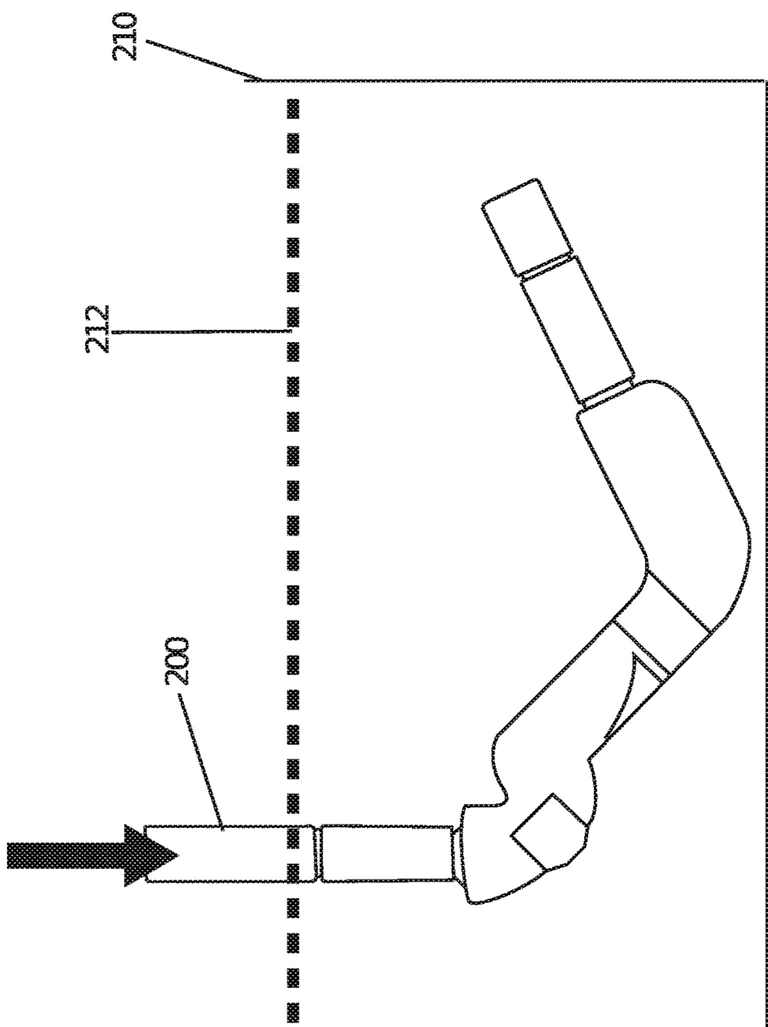

Fig. 21A

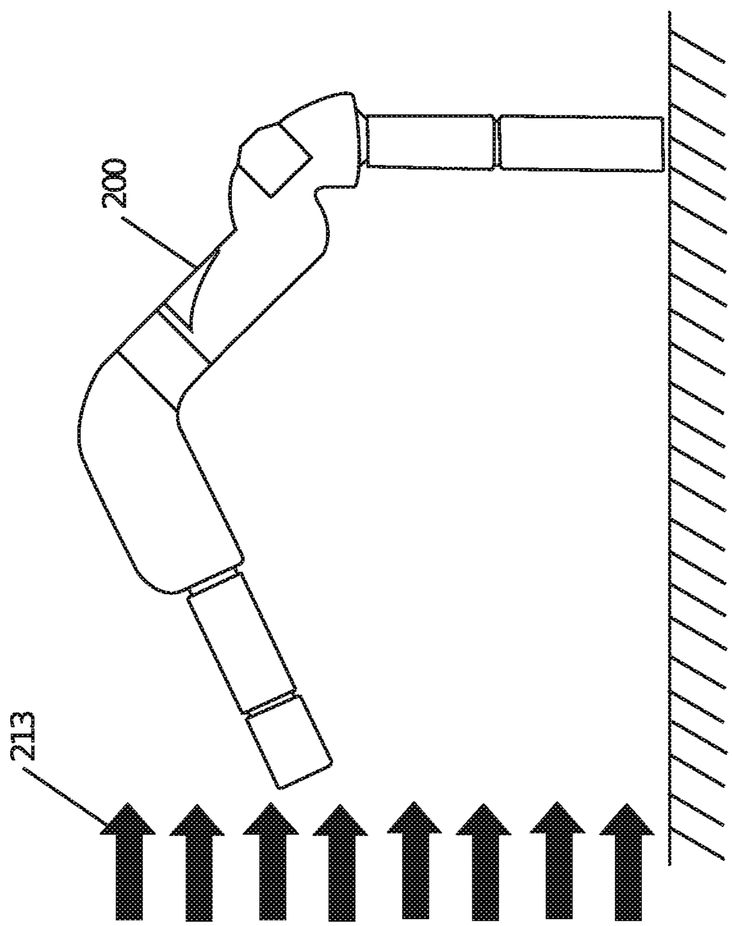

Fig. 21B

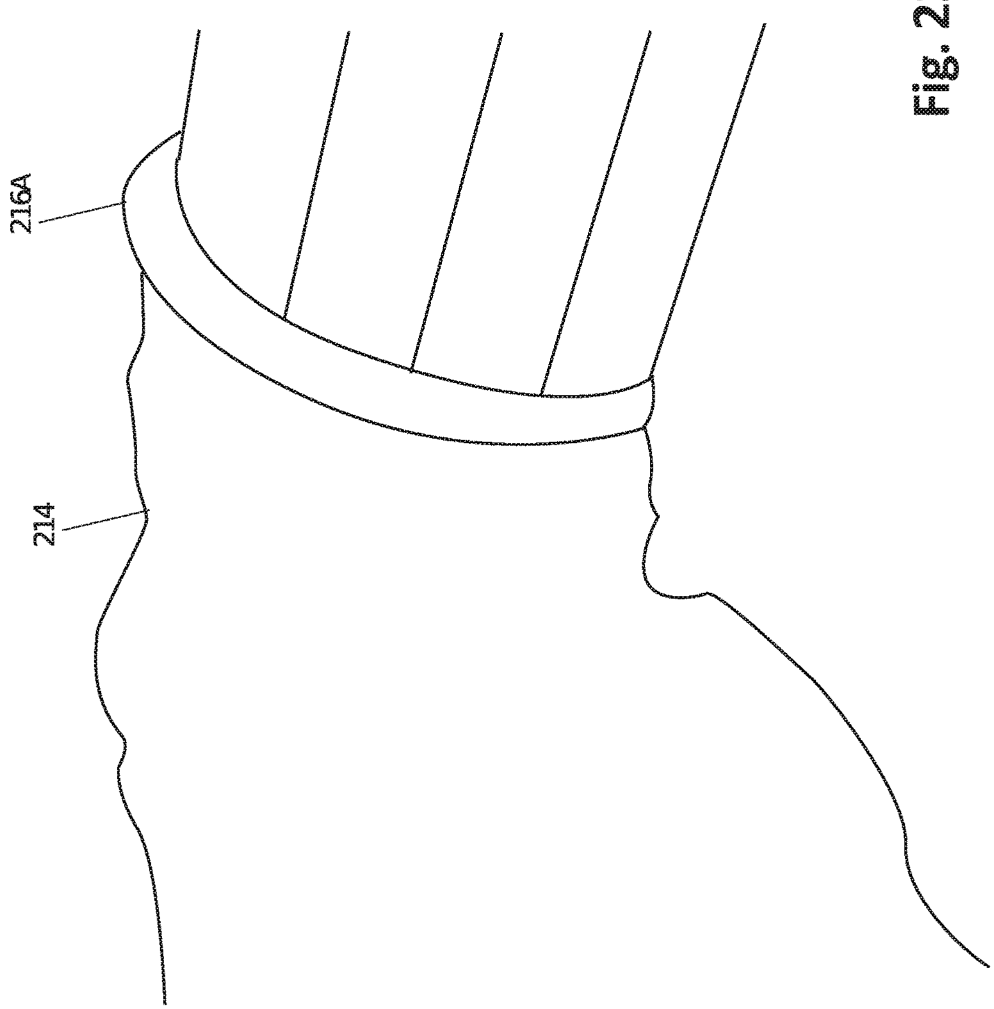

Fig. 22A

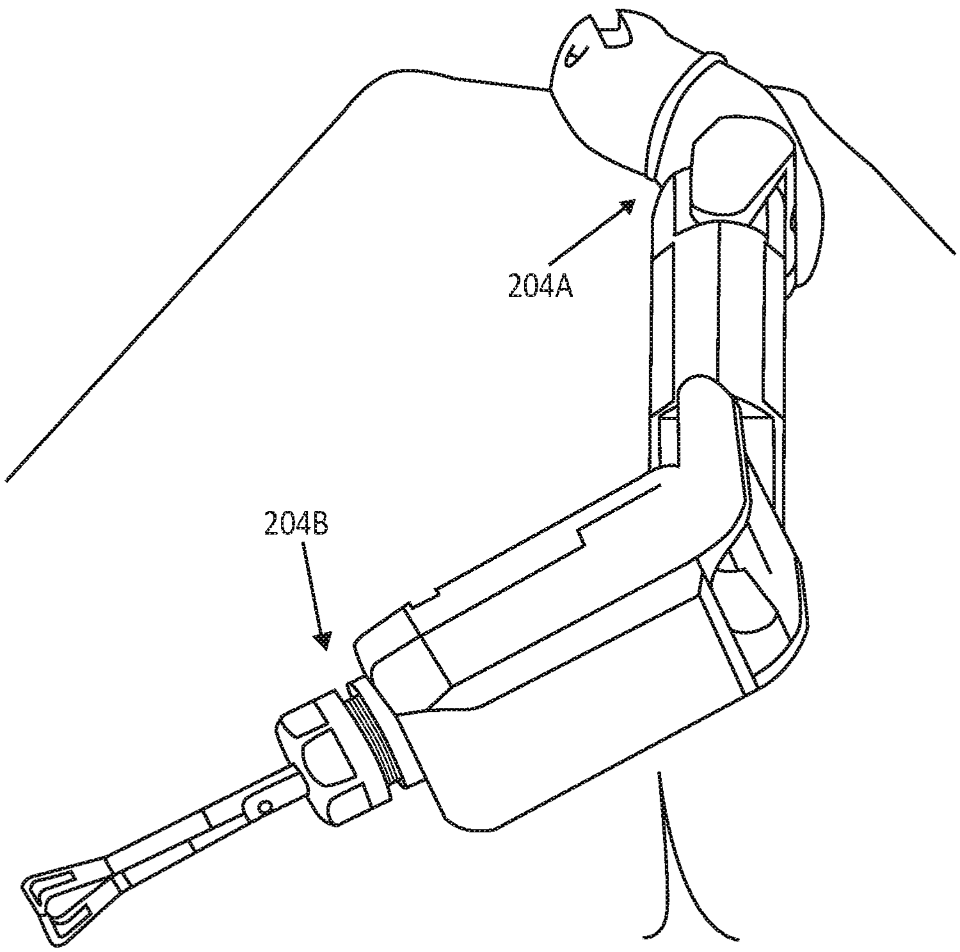

Fig. 22B

ROBOTIC DEVICES WITH ON BOARD CONTROL AND RELATED SYSTEMS AND DEVICES

CROSS REFERENCE TO RELATED APPLICATIONS

This application is a continuation of U.S. application Ser. No. 13/573,849, entitled "ROBOTIC SURGICAL DEVICES, SYSTEMS, AND RELATED METHODS," filed on Oct. 9, 2012, which claims priority to U.S. Provisional Application 61/680,809, filed Aug. 8, 2012, which is incorporated herein in its entirety by this reference.

GOVERNMENT SUPPORT

This invention was made with government support under Grant No. W81XWH-08-02-0043 awarded by the U.S. Army Medical Research and Materiel Command within the Department of Defense. Accordingly, the government has certain rights in this invention.

TECHNICAL FIELD

The embodiments disclosed herein relate to various medical devices and related components, including robotic and/or in vivo medical devices and related components. Certain embodiments include various robotic medical devices, including robotic devices that are disposed within a body cavity and positioned using a support component disposed through an orifice or opening in the body cavity. Further embodiment relate to methods of operating the above devices.

BACKGROUND

Invasive surgical procedures are essential for addressing various medical conditions. When possible, minimally invasive procedures such as laparoscopy are preferred.

However, known minimally invasive technologies such as laparoscopy are limited in scope and complexity due in part to 1) mobility restrictions resulting from using rigid tools inserted through access ports, and 2) limited visual feedback. Known robotic systems such as the da Vinci® Surgical System (available from Intuitive Surgical, Inc., located in Sunnyvale, Calif.) are also restricted by the access ports, as well as having the additional disadvantages of being very large, very expensive, unavailable in most hospitals, and having limited sensory and mobility capabilities.

There is a need in the art for improved surgical methods, systems, and devices.

BRIEF SUMMARY

Discussed herein are various robotic surgical devices and systems that can be disposed at least partially within a cavity of a patient and can be used for a variety of surgical procedures and tasks including, but not limited to, tissue biopsy, tissue dissection, or tissue retraction.

In Example 1, a modular surgical robotic system comprises a modular robotic device sized to be positioned completely within a patient further comprising a body component further comprising a first shoulder component and a second shoulder component, a first movable segmented robotic arm comprising a housing with at least one motor disposed within the housing and operationally connected to the body component by way of the first shoulder component, a second movable segmented robotic arm comprising a housing with at least one motor disposed within the housing and operationally connected to the body component by way of the second shoulder component, a first operational component operationally connected to the first robotic arm, and a second operational component operationally connected to the second robotic arm. The system further comprises a port configured for traversing the body of a patient, a support rod for crossing the port from the interior to exterior of the patient and connecting to the first and second body components, and an operations system for control of the modular robotic device from outside the patient by way of the port and support rod, the operations system in electrical communication with the modular robotic device.

Example 2 relates to the modular surgical robotic system of Example 1, wherein the modular robotic device may be assembled within the body cavity of the patient.

Example 3 relates to the modular surgical robotic system of Example 2, wherein the support rod is further comprised of a first support rod segment and a second support rod segment.

Example 4 relates to the modular surgical robotic system of Example 3, wherein the first support rod component and second support rod component are rotationally coupled to the first shoulder component and second shoulder component, respectively.

Example 5 relates to the modular surgical robotic system of Example 4, wherein the support rod is substantially enclosed in an overtube.

Example 6 relates to the modular surgical robotic system of Example 1, wherein the body component is cylindrical.

Example 7 relates to the modular surgical robotic system of Example 1, wherein the first shoulder component and second shoulder component are set at an obtuse angle from one another.

Example 8 relates to the modular surgical robotic system of Example 1, wherein the first operational component is chosen from a group consisting of a grasping component, a cauterizing component, a suturing component, an imaging component, an operational arm component, a sensor component, and a lighting component.

Example 9 relates to the modular surgical robotic system of Example 1, wherein the second operational component is chosen from a group consisting of a grasping component, a cauterizing component, a suturing component, an imaging component, an operational arm component, a sensor component, and a lighting component.

Example 10 relates to the modular surgical robotic system of Example 1, further comprising one or more motors for operation, rotation or movement of at least one of the first shoulder, the second shoulder, the first segmented arm, the second segmented arm, the first operational component, and the second operational component.

Example 11 relates to the modular surgical robotic system of Example 1, wherein the port creates an insufflation seal in the body.

In Example 12, a modular surgical robotic system comprises a modular robotic device sized to be positioned completely within a patient. The device comprises a first shoulder component, a second shoulder component, a body component, formed by the connection of the first shoulder component to the second shoulder component, a first movable segmented robotic arm comprising at least one motor and operationally connected to the body component by way of the first shoulder component, a second movable segmented robotic arm comprising at least one motor and operationally connected to the body component by way of the second shoulder component, a first operational component operationally connected to the first robotic arm, and a second operational component operationally connected to the second robotic arm. The system further comprises a port configured for traversing the body of a patient and an operations system for control of the modular robotic device from outside the patient by way of the port and support rod, the operations system in electrical communication with the modular robotic device.

Example 13 relates to the modular surgical robotic system of Example 12, wherein the modular robotic device may be assembled within the body cavity of the patient.

Example 14 relates to the modular surgical robotic system of Example 12, wherein the body component is cylindrical.

Example 15 relates to the modular surgical robotic system of Example 12, wherein the first shoulder component and second shoulder component are set at an obtuse angle from one another.

Example 16 relates to the modular surgical robotic system of Example 12, wherein the first operational component is chosen from a group consisting of a grasping component, a cauterizing component, a suturing component, an imaging component, an operational arm component, a sensor component, and a lighting component.

Example 17 relates to the modular surgical robotic system of Example 12, wherein the second operational component is chosen from a group consisting of a grasping component, a cauterizing component, a suturing component, an imaging component, an operational arm component, a sensor component, and a lighting component.

Example 18 relates to the modular surgical robotic system of Example 12, further comprising one or more motors for operation, rotation or movement of at least one of the first shoulder, the second shoulder, the first segmented arm, the second segmented arm, the first operational component, and the second operational component.

Example 19 relates to the modular surgical robotic system of Example 12, wherein the port is constructed and arranged to create an insufflation seal in the body of the patient.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1**A is a diagram showing a robotic surgical system, including a robotic device positioned inside a body, according to one embodiment.

FIG. **1**B is a perspective view of the device of FIG. **1**A.

FIG. **2**A is a perspective view of a robotic medical device, according to one embodiment.

FIG. **2**B is a perspective view of a robotic medical device showing the axes of rotation, according to one embodiment.

FIG. **3** is a perspective view of a robotic device and related equipment, according to one embodiment.

FIG. **4** is a perspective view of a robotic device and related equipment, according to one embodiment.

FIG. **5** is a perspective view of a robotic device and related equipment, according to one embodiment.

FIG. **6**A is a perspective view of the arm of a robotic device poised to be inserted into a patient's cavity, according to one embodiment.

FIG. **6**B is a perspective view of the arm of FIG. **6**A, rotated to show an alternate angle.

FIG. **7** is a side view of a robotic device during insertion and assembly, according to one embodiment.

FIG. **8** is another perspective view of the robotic device with an overtube for assembly, according to one embodiment.

FIG. **9** is another perspective view of the robotic device during assembly, according to one embodiment.

FIG. **10** is another perspective view of the robotic device and related equipment, according to one embodiment.

FIG. **11** is a view of a robotic device and related equipment, according to one embodiment.

FIG. **12**A is a perspective view of a robotic medical device, according to one embodiment.

FIG. **12**B is a cutaway perspective view of a robotic medical device, according to one embodiment.

FIG. **12**C is a perspective view of a printed circuit board of a robotic medical device, according to one embodiment.

FIG. **12**D is a cutaway perspective view of a robotic medical device, according to one embodiment.

FIG. **13**A is a side cutaway view of a robotic medical device, according to one embodiment.

FIG. **13**B is a front view of a forearm of a robotic medical device, according to one embodiment.

FIG. **13**C is a rear perspective view of a forearm of a robotic medical device, according to one embodiment.

FIG. **13**D is cutaway perspective view of a forearm of a robotic medical device, according to one embodiment.

FIG. **14** shows a cut away view of a robotic forearm, according to one embodiment.

FIG. **15**A shows a cutaway side view of a robotic upper arm, according to one embodiment.

FIG. **15**B shows an end view of a robotic upper arm, according to one embodiment.

FIG. **15**C shows a perspective view of a robotic upper arm, according to one embodiment.

FIG. **15**D shows a cutaway perspective view of a robotic upper arm, according to one embodiment.

FIG. **16**A shows a cutaway side view of a robotic shoulder, according to one embodiment.

FIG. **16**B shows an end view of a robotic shoulder, according to one embodiment.

FIG. **16**C shows a perspective view of a robotic shoulder, according to one embodiment.

FIG. **16**D shows a perspective cutaway view of a robotic shoulder, according to one embodiment.

FIG. **17**A shows a top cutaway view of robotic device cabling, according to one embodiment.

FIG. **17**B shows a cutaway perspective view of robotic device circuit boards, according to one embodiment.

FIG. **18** shows a block diagram of electronics for a robotic device/arm, according to one embodiment.

FIG. **19** shows a block diagram of electronics for a robotic device/arm, according to one embodiment.

FIG. **20**A shows a robotic arm according to one embodiment.

FIG. **20**B shows a robotic arm sleeve mold, according to one embodiment.

FIG. **21**A shows a robotic arm and sleeve making process overview, according to one embodiment.

FIG. **21**B shows a robotic arm and sleeve making process overview, according to one embodiment.

FIG. **22**A shows the rolled edge of the protective sleeve and the sleeve placed on the robotic arm, according to one embodiment.

FIG. **22**B shows the robotic arm, according to one embodiment.

DETAILED DESCRIPTION

The various systems and devices disclosed herein relate to devices for use in medical procedures and systems. More specifically, various embodiments relate to various medical devices, including robotic devices and related methods and systems.

It is understood that the various embodiments of robotic devices and related methods and systems disclosed herein can be incorporated into or used with any other known medical devices, systems, and methods.

For example, the various embodiments disclosed herein may be incorporated into or used with any of the medical devices and systems disclosed in copending U.S. application Ser. No. 12/192,779 (filed on Aug. 15, 2008 and entitled "Modular and Cooperative Medical Devices and Related Systems and Methods"), U.S. Pat. No. 7,492,116 (filed on Oct. 31, 2007 and entitled "Robot for Surgical Applications"), U.S. Pat. No. 7,772,796 (filed on Apr. 3, 2007 and entitled "Robot for Surgical Applications"), Ser. No. 11/947,097 (filed on Nov. 27, 2007 and entitled "Robotic Devices with Agent Delivery Components and Related Methods"), Ser. No. 11/932,516 (filed on Oct. 31, 2007 and entitled "Robot for Surgical Applications"), Ser. No. 11/766,683 (filed on Jun. 21, 2007 and entitled "Magnetically Coupleable Robotic Devices and Related Methods"), Ser. No. 11/766,720 (filed on Jun. 21, 2007 and entitled "Magnetically Coupleable Surgical Robotic Devices and Related Methods"), Ser. No. 11/966,741 (filed on Dec. 28, 2007 and entitled "Methods, Systems, and Devices for Surgical Visualization and Device Manipulation"), Ser. No. 12/171,413 (filed on Jul. 11, 2008 and entitled "Methods and Systems of Actuation in Robotic Devices"), 60/956,032 (filed on Aug. 15, 2007), 60/983,445 (filed on Oct. 29, 2007), 60/990,062 (filed on Nov. 26, 2007), 60/990,076 (filed on Nov. 26, 2007), 60/990,086 (filed on Nov. 26, 2007), 60/990,106 (filed on Nov. 26, 2007), 60/990,470 (filed on Nov. 27, 2007), 61/025,346 (filed on Feb. 1, 2008), 61/030,588 (filed on Feb. 22, 2008), 61/030,617 (filed on Feb. 22, 2008), U.S. Pat. No. 8,179,073 (issued May 15, 2011, and entitled "Robotic Devices with Agent Delivery Components and Related Methods"), Ser. No. 12/324,364 (filed Nov. 26, 2008, U.S. Published App. 2009/0171373 and entitled "Multifunctional Operational Component for Robotic Devices"), and Ser. No. 13/493,725 (filed Jun. 11, 2012 and entitled "Methods, Systems, and Devices Relating to Surgical End Effectors"), all of which are hereby incorporated herein by reference in their entireties.

Certain device and system implementations disclosed in the applications listed above can be positioned within a body cavity of a patient in combination with a support component similar to those disclosed herein. An "in vivo device" as used herein means any device that can be positioned, operated, or controlled at least in part by a user while being positioned within a body cavity of a patient, including any device that is coupled to a support component such as a rod or other such component that is disposed through an opening or orifice of the body cavity, also including any device positioned substantially against or adjacent to a wall of a body cavity of a patient, further including any such device that is internally actuated (having no external source of motive force), and additionally including any device that may be used laparoscopically or endoscopically during a surgical procedure. As used herein, the terms "robot," and "robotic device" shall refer to any device that can perform a task either automatically or in response to a command.

Certain embodiments provide for insertion of the present invention into the cavity while maintaining sufficient insufflation of the cavity. Further embodiments minimize the physical contact of the surgeon or surgical users with the present invention during the insertion process. Other implementations enhance the safety of the insertion process for the patient and the present invention. For example, some embodiments provide visualization of the present invention as it is being inserted into the patient's cavity to ensure that no damaging contact occurs between the system/device and the patient. In addition, certain embodiments allow for minimization of the incision size/length. Further implementations reduce the complexity of the access/insertion procedure and/or the steps required for the procedure. Other embodiments relate to devices that have minimal profiles, minimal size, or are generally minimal in function and appearance to enhance ease of handling and use.

Certain implementations disclosed herein relate to "combination" or "modular" medical devices that can be assembled in a variety of configurations. For purposes of this application, both "combination device" and "modular device" shall mean any medical device having modular or interchangeable components that can be arranged in a variety of different configurations. The modular components and combination devices disclosed herein also include segmented triangular or quadrangular-shaped combination devices. These devices, which are made up of modular components (also referred to herein as "segments") that are connected to create the triangular or quadrangular configuration, can provide leverage and/or stability during use while also providing for substantial payload space within the device that can be used for larger components or more operational components. As with the various combination devices disclosed and discussed above, according to one embodiment these triangular or quadrangular devices can be positioned inside the body cavity of a patient in the same fashion as those devices discussed and disclosed above.

FIGS. **1**A and **1**B depict an exemplary system **1** that includes a robotic surgical device **10** disposed within the inflated peritoneal cavity **2** of a patient. It is understood that the various device and system embodiments disclosed herein, including the system **1** of FIGS. **1**A and **1**B, can be used for a variety of surgical procedures and tasks including, but not limited to, tissue biopsy, tissue dissection, or tissue retraction. For example, as shown in FIGS. **1**A and **1**B in accordance with one embodiment, the device **10** can be used to dissect tissue in the peritoneal cavity **2**. In this system embodiment, a user (such as, for example, a surgeon) **3** operates a user interface **4** to control the device **10**. The interface **4** is operably coupled to the device **10** by a cable **5** or other type of physical connection that provides for electronic power and/or electrical communication back and forth between the interface **4** and the device **10**. Alternatively, the interface **4** can be operably coupled to the device **10** wirelessly. It is understood that the device embodiments disclosed herein can also be used with any other known system, including any of the systems disclosed in the various patent applications incorporated by reference above and elsewhere herein.

FIG. **2**A depicts a robotic medical device **10**, in accordance with one implementation. According to one embodiment, the device is an in vivo device. This device **10** embodiment as shown includes a body **12** that has two components **14**A, **14**B, which in this embodiment are cylindrical components **14**A, **14**B at an approximately 120 degree angle to each other. The cylindrical components **14**A, **14**B can also be referred to herein as shoulders, including a right shoulder **14**A and a left shoulder **14**B. In the embodiment depicted in FIG. **2**A, the two components **14**A, **14**B are coupled directly to each other. Alternatively, the two components are not coupled to each other or, in another option, can be individually coupled to an access port used in the surgery. In a further alternative, the body **12** (and any body of any device embodiment disclosed herein) can be a single component and further can be any of the device body embodiments disclosed in the various patent applications incorporated by reference above and elsewhere herein.

The body **12** is connected to two arms **16**, **18** in one example of the device. In the implementation shown, the right shoulder **14**A is coupled to right arm **16** and left shoulder **14**B is coupled to left arm **18**. In addition, the body **12** is also coupled to a support component **20**, as best shown in FIG. **8**. In accordance with one implementation as shown in FIGS. **6**A and **6**B and described in additional detail below, the support rod **20** as configured is a support rod **20** that is made of two coupleable support rod components **20**A, **20**B, each of which is independently attached to one of the body components **14**A, **14**B. More specifically, the support component **20** has a first support rod component **20**A that is coupled to the first shoulder **14**A and a second support rod component **20**B that is coupled to the second shoulder component **14**B. Alternatively, the support component **20** can be a single, integral component coupled to the body **12**. In certain implementations, the support component **20** can be a rod, tube, or other applicable shape.

Returning to FIG. **2**A, each of the arms **16**, **18** have a first joint **16**A, **18**A (each of which can also be referred to as a "shoulder joint") that is coupled to the body components **14**A, **14**B. Each first joint **16**A, **18**A is coupled to a first link **16**B, **18**B (also referred to as a "first segment," an "upper segment," or an "upper arm"), each of which is rotatably coupled to a second link **16**C, **18**C (also referred to as a "second segment," a "lower segment," or a "forearm") via a second joint **16**D, **18**D (each of which can also be referred to as an "elbow joint"). In addition, each arm **16**, **18** also has an operational component (also referred to as an "end effector") **16**E, **18**E coupled to the forearm **16**C, **18**C. It is understood that the operational components **16**E, **18**E (and any of the operational components on any of the embodiments disclosed herein) can be any known operational components, including any of the operational components disclosed in the various patent applications incorporated by reference above and elsewhere herein. By way of example, the components **16**E, **18**E can be cautery devices, suturing devices, grasping devices, imaging devices, operational arm devices, sensor devices, lighting devices or any other known types of devices or components for use in surgical procedures.

As mentioned above and as shown in FIG. **2**B, the first links **16**B, **18**B are coupled to the body **12** via shoulder joints **16**A, **18**A. In one embodiment, each shoulder joint **16**A, **16**B is a joint having two axes of rotation. For example, as will be described in further detail below, the left shoulder joint **18**A can be configured to result in rotation of the upper arm **18**B as shown by arrow A around axis AA (that substantially corresponds to the longitudinal axis of the body **12**) and also as shown by arrow B around axis BB, which is substantially perpendicular to axis AA. Because right shoulder joint **16**A and right upper arm **16**B are substantially the same as the left shoulder joint **18**A and the left upper arm **18**B, the above description also applies to those substantially similar (or identical) components. Alternatively, any known joint can be used to couple the upper arms **16**B, **18**B to the body **12**.

Continuing with FIG. **2**B, the upper arms **16**B, **18**B, according to one implementation, are coupled to the forearms **16**C, **18**C, respectively, at the elbow joints **16**D, **16**D such that each of the forearms **16**C, **18**C can rotate. For example, the forearms **16**C, **18**C can rotate as shown by arrow C around axis CC. Further, the end effectors **16**E, **18**E can also rotate relative to the forearms **16**C, **18**C, respectively, as shown by arrow D around axis DD. In addition, each of the operational components **16**E, **18**E can also be actuated to move between at least two configurations, such as an open configuration and a closed configuration. Alternatively, the operational components **16**E, **18**E can be coupled to the forearms **16**C, **18**C, respectively, such that the operational components **16**E, **18**E can be moved or actuated in any known fashion.

According to one embodiment, the operational components **16**E, **18**E, such as graspers or scissors, are also removable from the forearms **16**C, **18**C, such that the operational components **16**E, **18**E are interchangeable with other operational components configured to perform other/different types of procedures. Returning to FIG. **2**A, one operational component **16**E is a grasper **16**E commonly known as a babcock grasper and the other **18**E is a vessel sealing grasper **18**E. Alternatively, either or both of the components **16**E, **18**E can be cautery devices, suturing devices, grasping devices, or any other known types of devices or components for use in surgical procedures, or can be easily replaced with such components.

It is understood that the device **10** in this embodiment contains the motors (also referred to as "actuators," and intended to include any known source of motive force) that provide the motive force required to move the arms **16**, **18** and the operational components **16**E, **18**E. In other words, the motors are contained within the device **10** itself (either in the body, the upper arms, the forearms or any and all of these), rather than being located outside the patient's body. Various motors incorporated into various device embodiments will be described in further detail below.

In use, as in the example shown in FIG. **3**, the device **10** is positioned inside a patient's body cavity **30**. For example, in FIG. **3**, the body cavity **30** is the peritoneal cavity **30**.

According to one implementation, the device **10** can be sealed inside the insufflated abdominal cavity **30** using a port **32** designed for single incision laparoscopic surgery. Alternatively, the device **10** can be inserted via a natural orifice, or be used in conjunction with other established methods for surgery. The device **10** is supported inside the abdominal cavity using the support rod **20** discussed above. The laparoscopic port **32** can also be used for insertion of an insufflation tube **34**, a laparoscope **36** or other visualization device that may or may not be coupled to the device assembly. As an example, a 5 mm laparoscope **36** is shown in FIG. **3**.

Alternatively, as shown in FIG. **4**, a cannula or trocar **40** can be used in conjunction with the port device **32** to create a seal between the cavity and the external environment. Alternatively, any other known surgical instrument designed for such purposes can be used in conjunction with the port device **32** to create a seal between the cavity and the external environment, as is discussed below with regard to FIG. **9**.

According to one alternative embodiment as shown in FIG. **5**, a suction/irrigation tube **50** can be coupled with the device **10** and used for surgical suction and/or irrigation. In this embodiment, the tube **50** is coupled to the forearm **16**C of the right arm **16**. More specifically, the forearm **16**C has a channel **52** defined on an exterior surface of the forearm **16**C that is configured to receive and removably hold the tube **50**. In use, the tube **50** can extend from the device **10** and through an orifice to an external device or system for use for surgical suction and/or irrigation. Alternatively, the tube **50** can be coupled to the left arm **18** or some other portion of the device **10**. In a further alternative, the tube **50** can be disposed internally within the arm **16** or other component of the device **10**.

In use, the device **10** can first be separated into the two smaller components as described above and then each of the two components are inserted in consecutive fashion through the orifice into the body cavity. In accordance with one implementation, due to the limitations associated with the amount of space in the cavity, each of the components can form a sequence of various configurations that make it possible to insert each such component into the cavity. That is, each component can be "stepped through" a sequence of configurations that allow the component to be inserted through the orifice and into the cavity.

For example, according to one implementation shown in FIGS. **6**A and **6**B, the device **10** can be inserted through a single orifice by physically separating the device **10** into separate, smaller components and inserting those components through the single orifice. In one example, the device can be separated into two "halves" or smaller components, in which one half **10**A as shown in FIGS. **6**A and **6**B consists of the right shoulder **14**A coupled to the right arm **16**. Similarly, while not depicted in FIGS. **6**A and **6**B, the other half consists of the left shoulder **14**B coupled to the left arm **18**. It is understood that the left arm **18** is substantially similar to or the same as the right arm **16** such that the description of the right arm herein and the depiction in FIGS. **6**A and **6**B apply equally to the left arm **18** as well. In this implementation, the right shoulder **14**A is coupled to the right support rod component **20**A (and the left shoulder **14**B is similarly coupled to the left support rod component **20**B). Alternatively, this device **10** or any device contemplated herein can be separated into any two or more separable components.

FIGS. **6**A and **6**B show how the right support component **20**A can be rotationally coupled to the shoulder **14**A, thereby resulting in movement of the shoulder **14**A in relation to the right support component **20**A between at least two configurations, making insertion of the overall device into a patient's cavity easier. More specifically, the right device half **10**A is shown in FIG. **6**A in its operational configuration in relation to the right support component **20**A such that the right device half **10**A can be coupled to the left device half **10**B (not shown) and thereby used to perform a procedure in the patient's cavity. Note the arrow **21** in FIG. **6**A illustrating how the right support component **20**A can rotate in relation to the right shoulder **14**A. FIG. **6**B, on the other hand, depicts the right device half **10**A in its insertion configuration in which the right shoulder **14**A has been rotated in relation to the right support component **20**A, thereby making the device half **10**A easier to insert through an orifice and into a patient's cavity. In use, the device half **10**A is "stepped through" the two configurations to ease insertion. First, the device half **10**A is placed in the insertion configuration of FIG. **6**B and inserted through the orifice. Subsequently, once the right arm **16** is positioned inside the patient's cavity, the right shoulder **14**A can be rotated in relation to the right support component **20**A to move the device half **10**A into the operational configuration of FIG. **6**A such that the device half **10**A can be coupled to the other half **10**B and subsequently be used to perform a procedure.

When the device half **10**A is properly positioned in the patient's cavity, the first support rod component **20**A, which is coupled to the right shoulder **14**A, is disposed through an orifice or any other kind of opening in the body cavity wall (shown as a dashed line in FIG. **7**) such that the distal portion of the support rod component **20**A coupled to the first shoulder **14**A is disposed within the body cavity **30** while the proximal portion is disposed outside of the patient's body and can be attached to an external component (not shown) so as to provide stability or fixed positioning for the device.

As discussed above, in this example, the two coupleable support rod components (such as **20**A as shown in FIGS. **6**A, **6**B, and **7**) can be positioned next to one another or coupled to each other form a cylindrical shape or a complete rod **20**. In the example in FIG. **8**, an overtube **60** can then be placed over the rod **20**. As best shown in FIG. **9**, this overtube **60** can be held in place with a threaded thumbscrew **61** and the entire rod **20** and overtube **60** assembly can then be inserted into the laparoscopic port **32**. As best shown in FIG. **10**, once assembled, other tools can then be inserted into the port such as a cannula for a suction/irrigation tube **34** as described above, a laparoscope **36** as described above, and/or other surgical instruments, and positioned through the port **32** via port openings **32**A, **32**B, **32**C (as best shown in FIG. **9**). These figures illustrate one example of how this assembly can be configured to accept a cannula for suction and irrigation or other component **33**.

Alternatively, the device body **10** can be a single component that is coupled to both support rod components **20**A, **20**B, which are coupled to each other to form a full support rod **20**.

Once assembled, an external device (not shown) can be used to stabilize the support component assembly. According to this implementation, the device **10** is maintained in a desired position or location within the body cavity of the patient using an external component that has a clamp that is removably attached to the support component **20**. Alternatively, the external component can have any known attachment component that is capable of removably coupling to or attaching to support component.

As an example, the external component can be an iron intern (commercially available from Automated Medical Products Corp.) that includes several sections connected by joints that can be loosened and locked using knobs to allow the iron intern to be positioned in various orientations. The iron intern can be attached to rails on any standard surgical table or any other appropriate surface to provide support for device.

In use, according to one embodiment, the device **10** is positioned within the body cavity of the patient and the support component assembly **20** is positioned through a port **32** positioned in the hole or opening in the body cavity wall, as shown, for example, in FIG. **3**. In one embodiment, the port **32** is a gel port through which the support component **20** can be disposed while still maintaining a fluidic seal that allows for the body cavity **30** of the patient to be inflated. Alternatively, any known port **32** that provides access for the support component **20** while maintaining a fluidic seal can be used. Also, any cables, electrical or otherwise, can be coupled to the device **10** via this port **32**. In one embodiment, electrical cables pass through the support rod **20** or other support components.

FIG. **11** depicts one example of how a laparoscope **36** in one embodiment can be used in conjunction with the device **10** to provide visualization of the working space of the robotic assembly. More specifically, FIG. **11** shows how a "zero degree" laparoscope **36** can provide a large field of view (shown as cone **70**) enabling the user to view the surgical environment. Other visualization means are also possible and these can either be separate from or attached to the robotic device **10**. The visualization means can also enter though other orifices in the body cavity to be used independently or in conjunction with the robotic device **10**.

FIGS. **12**A-**17** depict exemplary embodiments of how such a medical device can be mechanically and electrically constructed.

FIGS. **12**A-**12**D show one design of a forearm **80** having a vessel sealing operational component or end effector **82**. The vessel sealing device **82** may or may not include a cutting component and different types of cautery techniques. In this example, as best shown in FIGS. **12**B and **12**D, a first actuator **84** is coupled to the end effector **82** by spur gears **84**A, a second actuator **86** is coupled to the end effector **82** by spur gears **86**A, and a third actuator **88** is coupled to the end effector by spur gears **88**A. These first, second and third actuators **84**, **86**, **88** provide rotation of the end effector **82** along the axis of the forearm **80** (axis DD as described in FIG. **2**), opening and closing motion for the end effector **82**, and can cause a cutting device (not shown) to translate through the end effector **82**.

FIGS. **12**A-**17** also show various printed circuit boards **114**A-**114**J used to power and control the actuators. Each actuator has one or more sensors to measure the position of the components for control. These can include, but are not limited to, optical encoders, mechanical encoders, or potentiometers. Each sensor can either measure relative or absolute position.

FIGS. **13**A-**13**D depict another embodiment of a forearm **90** for a robotic medical device. This embodiment shows an interchangeable operational component **92**, which, in this specific example, is a grasper **92** commonly called a Babcock grasper. These interchangeable operational components can be similar to the interchangeable tools called Microline made by the Pentax Company. In this embodiment, as best shown in FIGS. **13**B and **13**C, the interchangeable tools are held in place using a known tapered collect device **94** (commonly used in machine tools) to hold the operational component in place. Here, the operational component is inserted into a tapered collect **94** that is then tightened in place using a threaded nut and a tapered slot **96**. In this example, as best shown in FIG. **13**D, there are two actuators **97**, **98** that actuate open and closing of the operating component and rotation of the operating component (about axis DD as described above) by way of corresponding spur gears **97**A, **98**A with respect to the forearm **90**. In this design, as an example, the operational component can be electrified for either mono-polar or bipolar cautery.

FIG. **14** shows how a fuse clip **100**, or similar sliding contact device, can be used to provide an electrical connection to one or more portions of the operational component (not shown) to provide electricity for cautery. For example, as shown in the figure, the fuse clip **100** is coupled to a shaft **102** which may spin or rotate, the fuse clip **100** acting to maintain electrical connectivity to the shaft **102** for supply to the operational component (not shown) for cautery without the use of wires that may tangle and bunch. FIG. **14** also shows a printed circuit board (PCB) **114** that contains electronics to power and control the actuators as described previously. More specifically, in this particular figure, the PCB **114** is coupled to the actuator (not shown) such that it may control the electrification of the shaft **102** and ultimately the operational component (not shown).

FIGS. **15**A-**15**D show one possible upper arm segment **16**B embodiment. This segment **16**B has two actuators **104**, **106** that provide rotation of the forearm segment relative to the upper arm **16**B and the upper arm **16**B relative to the body **14**, as described, for example, as axis CC and axis BB in FIG. **3**, respectively. In this design, the two actuators **104**, **106** are operably coupled to bevel gears **104**A, **106**A by way of drive gears **104**B, **106**B to change the axis of rotation of

the motors **104**, **106** by ninety degrees and make the two axes of rotation (CC & BB) perpendicular to the axes of the segment **16**B. Also shown are the sensors and electronics used to control the segment **16**B as described above.

FIGS. **16**A-**16**D show one possible device body segment **14**A embodiment. Here, an actuator **110** is coupled to the output shaft **112** by bevel gears **113**A, **113**B such that the axis of actuator **110** rotation is approximately 30 degrees from the axis of rotation of the output shaft **112**. Also shown are the sensors and electronics used to control the actuator **110** in the body segment **14**A in a fashion similar to that described above.

FIGS. **17**A and **17**B depict one possible implementation of a device **10** having printed circuit boards **114**A-J and connective electrical cables **116**A-J that are contained and routed inside the device **10** to provide electrical power and control. More specifically, FIG. **17**A depicts the cables **116**A-**116**J and FIG. **17**B depicts the PCBs **114**A-**114**J. In this example, "service loops" are provided at each joint to allow for relative motion between the links while not placing the cables in excessive bending or tension (not shown). Alternatively, the circuit boards and cabling can be positioned outside the robot.

FIG. **18** shows a general schematic for one possible design of the electrical sub-system of a robotic device in accordance with one embodiment. The schematic shows an example of the electronics for a vessel sealing arm, such as, for example, the right arm in the robot **10** depicted in FIGS. **2**A and **2**B. In this example as shown schematically in FIG. **18**, the connection cable **122** enters through the support rod **120**. This cable **122** can contain conductors for electrical power and electrical signals and other wires of various forms as required for operation of the device **10**. This cable **122** interfaces with the shoulder pitch PCB **124**. This shoulder pitch PCB **124** supports both an optical encoder **126** and a magnetic encoder **128** for redundant measurement of rotation of the first shoulder joint **18**A (around axis AA) as shown in FIGS. **2**A and **2**B. This PCB **124** provides power to the shoulder pitch motor **128** (for rotation around axis AA). It can also be seen that the cable **122** (via connectors J**1** and J**2**) passes via a service loop **130** into the main joint **18**B (described as the upper arm above). Here a "service loop" **130**A, **130**B, **130**C, **130**D, **130**E is provided at each joint to allow for relative motion between the links while not placing the cables in excessive bending or tension.

The shoulder pitch PCB is also connected to the upper arm via a service loop **130**B and connectors (J**3** & J**4**). In the upper arm **18**B there is an upper arm shoulder PCB **132** (for axis BB in FIG. **2**B) and an upper arm elbow PCB **134** (for axis CC). This link also has internal connectors J**5** & J**6**. All connectors generally aid and allow for assembly and repair. Both PCBs **132**, **134** in this link power an actuator **136**, **138** for each joint (axis BB & CC) as well as both optical **140**, **142** and magnetic **144**, **146** encoders to measure joint position. The sensors in this arm and throughout the robot can be used redundantly and or individually or in combination. They can be either relative or absolute or in any combination. There are also connections from the upper arm to the lower arm via connectors listed as J**7**, J**8**, J**18** & J**19** and via service loops.

Here and throughout the robot service loops may or may not be required. The forearm contains three PCBs **150**, **152**, **154** to drive/control the gripper cutting device **154**A, the gripper jaws **152**A and the gripper roll **150**A (axis DD). As before various sensors **156** and motors **150**A, **152**A, **154**A are powered and used with the PCBs and various service loops **130**C, **130**D, **130**E are used. As shown previously, the gripper can be electrified for cautery with one or more clips or connectors (or with a direct connection) that may or may not allow relative motion of the gripper jaws (axis DD). This example design shows a PCB for each joint. Alternatively a PCB could be used for each link, or each arm, or any combination of the above. The description above and shown in FIG. 21 is just one example of the electrical design that is possible.

FIG. 19 shows a general schematic for yet another possible design of the electrical sub system of the robotic device. The schematic in FIG. 19 shows an example of the electronics for an arm with interchangeable tools, also referred to as the utility arm or left arm 18 in the design of FIGS. 2A-2B. In this example the electronics, PCBs, connectors, and service loops, etc are similar to the schematic described in FIG. 18 but this arm does not have a cutting device and hence does not have on actuator and supporting mechanical and electrical components. Again, as shown previously, the gripper can be electrified for cautery with one or more clips or connectors (or with a direct connection) that may or may not allow relative motion of the gripper jaws (axis DD).

Again, in this version both operating components (vessel sealing and interchangeable Babcock grasper) can be electrified for cautery. In general any and combination of the operating components can be electrified with either no cautery, mono-polar cautery, bi-polar cautery, or other surgical treatment technique.

The robotic surgical device described here can be either single use and be designed to be disposed of after its use, or can be made so it can be re-used and sterilized between uses. In one embodiment, to ease cleaning of the device between uses, a protective sleeve is disclosed here that covers the majority of the outer surfaces of the robotic device.

According to one embodiment, shown in FIGS. 20A-20B, a dip mold pattern 200 (best shown in FIG. 20B) is created with a shape and size that is similar to the robotic arm 202 (best shown in FIG. 20A) (also called a utility arm or ligisure arm or other arm, for example 16, 18 in FIGS. 2A-2B) for which a protective sleeve is needed. The dip mold pattern 200 is designed in such a way as to be thicker and larger than the arm 202 in specific areas, such as, for example, around the joints 201A-D. This larger size will result in a protective sleeve 200 that is larger in these areas so it will provide slack for the robotic arm 202 to articulate.

Also, according to one embodiment, FIG. 20A shows how features 204A, 204B (or "grooves") are designed into the robotic device 202. In this embodiment, one groove 204A is at the proximal end of the robotic arm 202 and a second 204B is at the distal end of the arm 202. These grooves 204A, 204B are designed so the protective sleeve 200 will form a tight seal and mechanical connection with the robotic arm 202 to make the arm fluidically sealed.

In another embodiment, a mold, grooves, and sleeve could be created at each the proximal and distal ends of the joints so smaller protective sleeves would be created that would only cover the joint areas. Other combinations are also possible. For example one sleeve could cover two proximal joints and a second sleeve could cover a distal joint.

In use according to one embodiment as shown in FIGS. 21A and 21B, the dip mold pattern 200 can be placed into a vat 210 of dip mold material 212. In one embodiment, this mold material 212 could be a latex or similar material. The pattern can then be removed from the vat 210 and the mold material 212 is then cured in a heated oven 213. The process can be repeated to create multiple layers and thereby a thicker sleeve.

When the mold material is cured, according to one embodiment and shown in FIGS. 22A and 22B, the resulting protective sleeve 214 can be trimmed at each end and then the ends can be rolled 216A, 216B. Rolling the ends creates "beads" at both the proximal 216A and distal 216B ends of the protective sleeve. These "beads" 216A, 216B are designed to fit in the grooves 204A, 204B or other external features or contours (shown as an example in FIG. 20) on the robotic device. The sleeve 214 is then removed from the dip mold 200 and placed onto the robotic arm 202. It can be seen how the protective sleeve 214 now covers and protects most or all of the robotic arm 202 (including the moving joints) from fluid ingress during surgery.

While multiple embodiments are disclosed, still other embodiments of the present invention will become apparent to those skilled in the art from the following detailed description, which shows and describes illustrative embodiments of the invention. As will be realized, the invention is capable of modifications in various obvious aspects, all without departing from the spirit and scope of the present invention. Accordingly, the drawings and detailed description are to be regarded as illustrative in nature and not restrictive.

Although the present invention has been described with reference to preferred embodiments, persons skilled in the art will recognize that changes may be made in form and detail without departing from the spirit and scope of the invention.

We claim:

1. A modular surgical robotic system, comprising:
  a. a modular robotic device sized to be positioned completely within a patient further comprising:
    i. a body component further comprising a first shoulder component and a second shoulder component;
    ii. a first movable segmented robotic arm comprising a housing with at least one motor disposed within the housing and operationally connected to the body component by way of the first shoulder component;
    iii. a second movable segmented robotic arm comprising a housing with at least one motor disposed within the housing and operationally connected to the body component by way of the second shoulder component;
    iv. a first operational component operationally connected to the first robotic arm; and
    v. a second operational component operationally connected to the second robotic arm;
  b. a port configured for traversing the body of a patient;
  c. a support rod for crossing the port from the interior to exterior of the patient and connecting to the first and second body components; and
  d. an operations system for control of the modular robotic device from outside the patient by way of the port and support rod, the operations system in electrical communication with the modular robotic device.

2. The modular surgical robotic system of claim 1, wherein the modular robotic device may be assembled within the body cavity of the patient.

3. The modular surgical robotic system of claim 2, wherein the support rod is further comprised of a first support rod segment and a second support rod segment.

4. The modular surgical robotic system of claim 3, wherein the first support rod component and second support

rod component are rotationally coupled to the first shoulder component and second shoulder component, respectively.

5. The modular surgical robotic system of claim **4**, wherein the support rod is substantially enclosed in an overtube.

6. The modular surgical robotic system of claim **1**, wherein the body component is cylindrical.

7. The modular surgical robotic system of claim **1**, wherein the first shoulder component and second shoulder component are set at an obtuse angle from one another.

8. The modular surgical robotic system of claim **1**, wherein the first operational component is chosen from a group consisting of a grasping component, a cauterizing component, a suturing component, an imaging component, an operational arm component, a sensor component, and a lighting component.

9. The modular surgical robotic system of claim **1**, wherein the second operational component is chosen from a group consisting of a grasping component, a cauterizing component, a suturing component, an imaging component, an operational arm component, a sensor component, and a lighting component.

10. The modular surgical robotic system of claim **1**, further comprising one or more motors for operation, rotation or movement of at least one of the first shoulder, the second shoulder, the first segmented arm, the second segmented arm, the first operational component, and the second operational component.

11. The modular surgical robotic system of claim **1**, wherein the port creates an insufflation seal in the body.

12. A modular surgical robotic system, comprising:

a. a modular robotic device sized to be positioned completely within a patient further comprising:

i. a first shoulder component;

ii. a second shoulder component;

iii. a body component, formed by the connection of the first shoulder component to the second shoulder component;

iv. a first movable segmented robotic arm comprising at least one motor and operationally connected to the body component by way of the first shoulder component;

v. a second movable segmented robotic arm comprising at least one motor and operationally connected to the body component by way of the second shoulder component;

vi. a first operational component operationally connected to the first robotic arm; and

vii. a second operational component operationally connected to the second robotic arm;

b. a port configured for traversing the body of a patient; and

c. an operations system for control of the modular robotic device from outside the patient by way of the port and support rod, the operations system in electrical communication with the modular robotic device.

13. The modular surgical robotic system of claim **12**, wherein the body component is cylindrical.

14. The modular surgical robotic system of claim **12**, wherein the first shoulder component and second shoulder component are set at an obtuse angle from one another.

15. The modular surgical robotic system of claim **12**, wherein the first operational component is chosen from a group consisting of a grasping component, a cauterizing component, a suturing component, an imaging component, an operational arm component, a sensor component, and a lighting component.

16. The modular surgical robotic system of claim **12**, wherein the second operational component is chosen from a group consisting of a grasping component, a cauterizing component, a suturing component, an imaging component, an operational arm component, a sensor component, and a lighting component.

17. The modular surgical robotic system of claim **12**, further comprising one or more motors for operation, rotation or movement of at least one of the first shoulder, the second shoulder, the first segmented arm, the second segmented arm, the first operational component, and the second operational component.

18. The modular surgical robotic system of claim **12**, wherein the port is constructed and arranged to create an insufflation seal in the body of the patient.

19. The modular surgical robotic system of claim **12**, wherein the modular robotic device may be assembled within the body cavity of the patient.

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