



(12) **DEMANDE DE BREVET CANADIEN
CANADIAN PATENT APPLICATION**

(13) **A1**

(86) **Date de dépôt PCT/PCT Filing Date:** 2016/08/17
(87) **Date publication PCT/PCT Publication Date:** 2018/02/22
(85) **Entrée phase nationale/National Entry:** 2019/02/18
(86) **N° demande PCT/PCT Application No.:** IB 2016/054931
(87) **N° publication PCT/PCT Publication No.:** 2018/033775

(51) **Cl.Int./Int.Cl.** **A61B 1/04** (2006.01),
A61B 1/005 (2006.01), **A61B 1/045** (2006.01),
A61B 1/07 (2006.01)
(71) **Demandeur/Applicant:**
SYNAPTIVE MEDICAL (BARBADOS) INC., BB
(72) **Inventeurs/Inventors:**
CHEN, SEAN JY-SHYANG, CA;
ABHARI, KAMYAR, CA;
WOOD, MICHAEL FRANK GUNTER, CA;
SELA, GAL, CA
(74) **Agent:** VUONG, THANH VINH

(54) **Titre : ENDOSCOPE SOUPLE A HAUTE RESOLUTION**
(54) **Title: A FLEXIBLE HIGH RESOLUTION ENDOSCOPE**

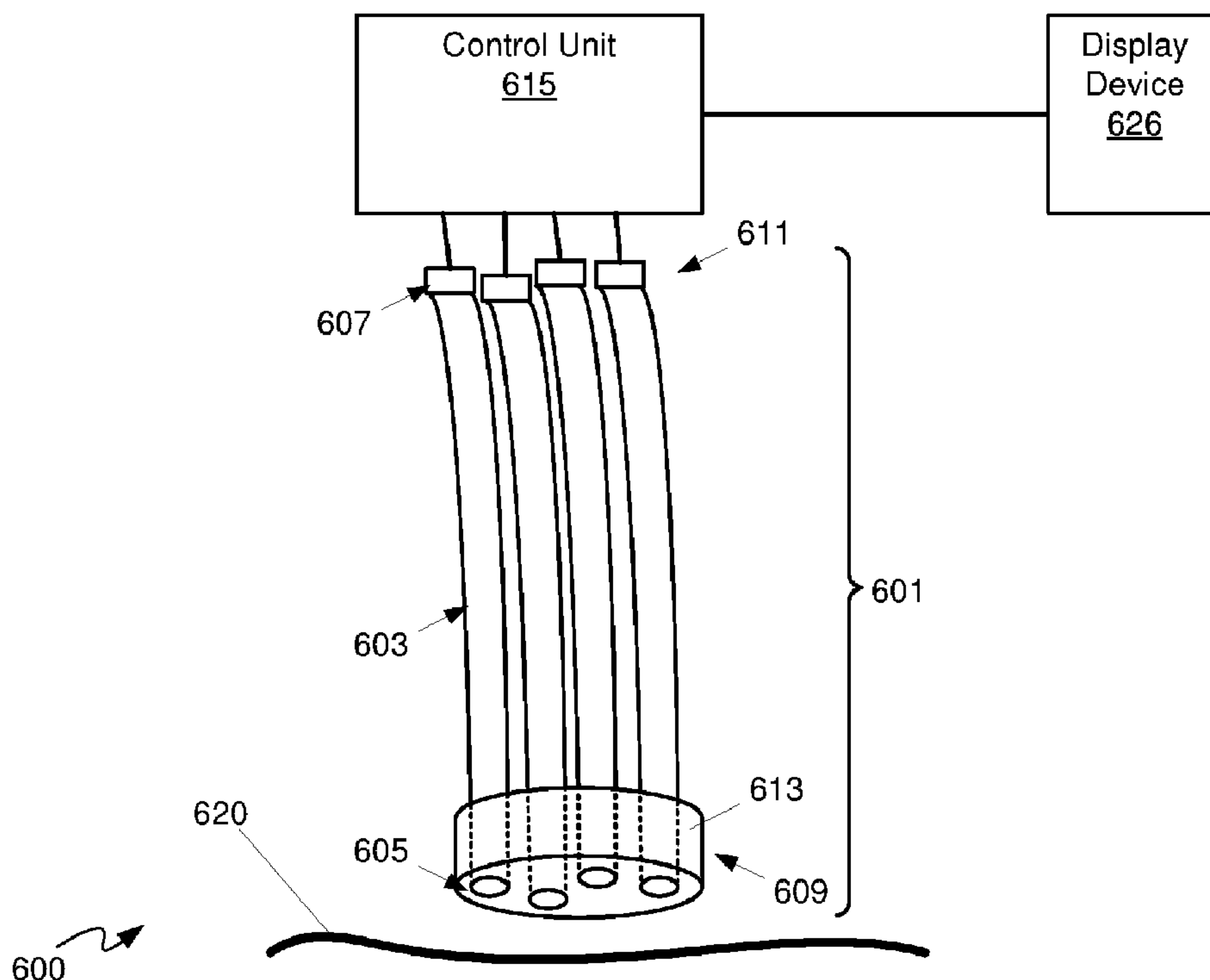


Figure 6

(57) **Abrégé/Abstract:**

A flexible high resolution endoscope is provided herein. The endoscope comprises: a plurality of optical fiber bundles; a plurality of lenses in a one-to-one relationship with the plurality of optical fiber bundles; and, a plurality of cameras in a one-to-one relationship

(57) Abrégé(suite)/Abstract(continued):

with the plurality of optical fiber bundles, each respective optical fiber bundle, of the plurality of optical fiber bundles, having a respective lens, of the plurality of lenses, located at a respective distal end, and a camera, of the plurality of cameras, located at a respective proximal end, the plurality of optical fiber bundles being coupled together at a common distal end, and otherwise being uncoupled from one another, a bending radius of the endoscope defined by a largest respective bending radius of each of the plurality of optical fiber bundles.

(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property
Organization
International Bureau

(43) International Publication Date
22 February 2018 (22.02.2018)



(10) International Publication Number
WO 2018/033775 A1

(51) International Patent Classification:

A61B 1/04 (2006.01) *A61B 1/045* (2006.01)
A61B 1/005 (2006.01) *A61B 1/07* (2006.01)

(21) International Application Number:

PCT/IB2016/054931

(22) International Filing Date:

17 August 2016 (17.08.2016)

(25) Filing Language:

English

(26) Publication Language:

English

(71) Applicant (for all designated States except US): **SY-
NAPTIVE MEDICAL (BARBADOS) INC.** [BB/BB];
Chancery House, High Street, Bridgetown (BB).

(72) Inventors; and

(71) Applicants (for US only): **CHEN, Sean Jy-Shyang**
[CA/CA]; 555 Richmond St. West, 8th Floor, Toronto, On-
tario M5V 3B1 (CA). **ABHARI, Kamyar** [CA/CA]; 555

Richmond Street West, 8th Floor, Toronto, Ontario M5V
3B1 (CA). **WOOD, Michael Frank Gunter** [CA/CA]; 555
Richmond Street West, 8th Floor, Toronto, Ontario M5V
3B1 (CA). **SELA, Gal** [CA/CA]; 555 Richmond St. West,
8th Floor, Toronto, Ontario M5V 3B1 (CA).

(74) Agent: **PERRY + CURRIER**; 1300 Yonge Street, Suite
500, Toronto, Ontario M4T 1X3 (CA).

(81) Designated States (unless otherwise indicated, for every
kind of national protection available): AE, AG, AL, AM,
AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY, BZ,
CA, CH, CL, CN, CO, CR, CU, CZ, DE, DK, DM, DO, DZ,
EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR,
HU, ID, IL, IN, IR, IS, JP, KE, KG, KN, KP, KR, KZ, LA,
LC, LK, LR, LS, LU, LY, MA, MD, ME, MG, MK, MN,
MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PA, PE,
PG, PH, PL, PT, QA, RO, RS, RU, RW, SA, SC, SD, SE,

(54) Title: A FLEXIBLE HIGH RESOLUTION ENDOSCOPE

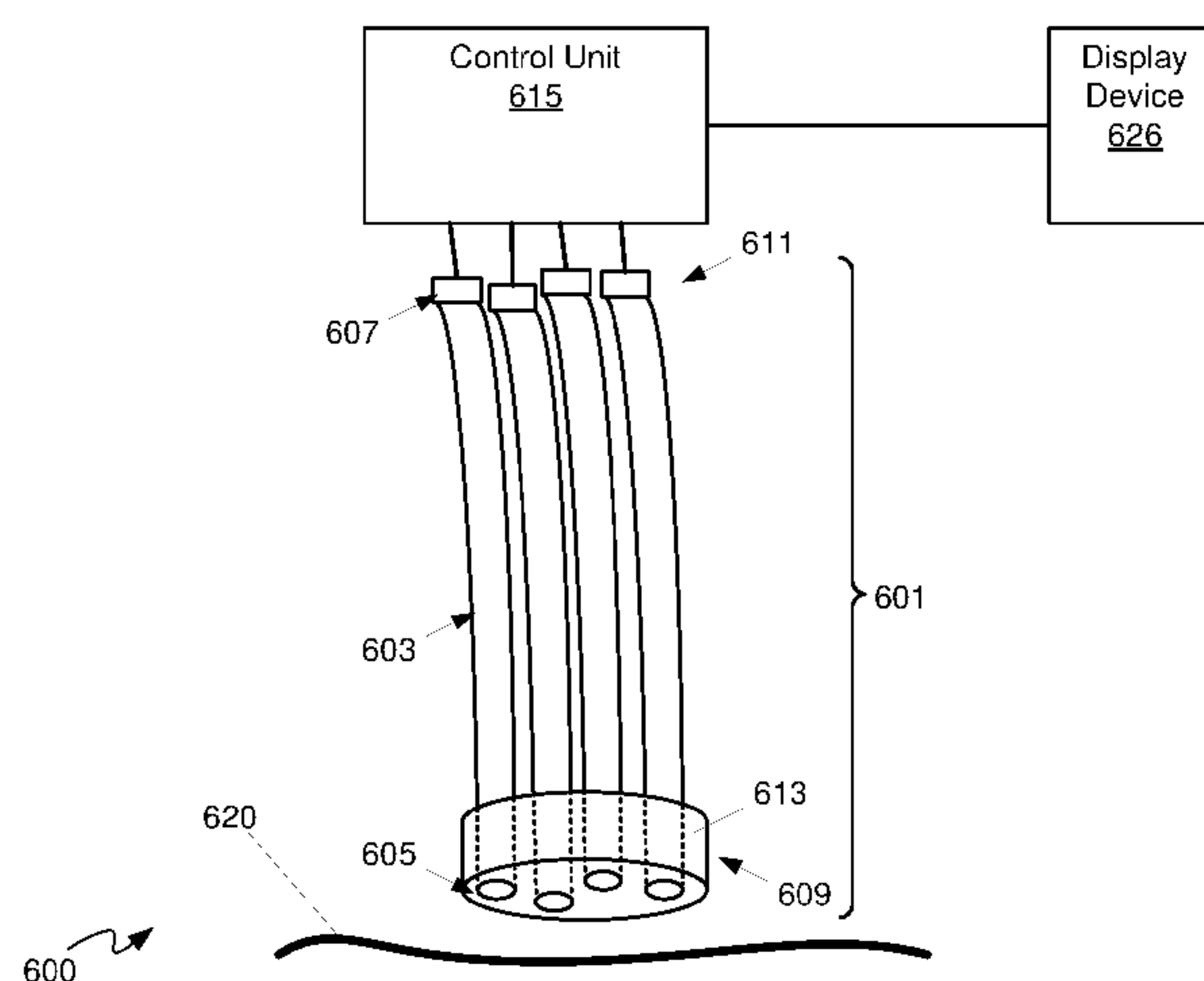


Figure 6

(57) Abstract: A flexible high resolution endoscope is provided herein. The endoscope comprises: a plurality of optical fiber bundles; a plurality of lenses in a one-to-one relationship with the plurality of optical fiber bundles; and, a plurality of cameras in a one-to-one relationship with the plurality of optical fiber bundles, each respective optical fiber bundle, of the plurality of optical fiber bundles, having a respective lens, of the plurality of lenses, located at a respective distal end, and a camera, of the plurality of cameras, located at a respective proximal end, the plurality of optical fiber bundles being coupled together at a common distal end, and otherwise being uncoupled from one another, a bending radius of the endoscope defined by a largest respective bending radius of each of the plurality of optical fiber bundles.

[Continued on next page]

WO 2018/033775 A1

WO 2018/033775 A1

SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ,
UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

(84) Designated States *(unless otherwise indicated, for every kind of regional protection available):* ARIPO (BW, GH, GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, ST, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, KM, ML, MR, NE, SN, TD, TG).

Published:
— *with international search report (Art. 21(3))*

A Flexible High Resolution Endoscope

FIELD

[0001] The specification relates generally to medical imaging and methods for minimally invasive therapy and image guided medical procedures, and specifically to a flexible high resolution endoscope.

BACKGROUND

[0002] Traditional flexible endoscopes, also known as fibrescopes, allow for visualization during minimally invasive procedure. However, these fiberscopes produce two-dimensional images devoid of three-dimensional depth information, which is critical to a surgeon attempting to identify and operate on small or difficult to see structures. Images acquired by these state-of-the-art fiberscopes are also relative low in quality due to the limited resolution of the fibre bundle use to transmit the image to the sensor, with higher resolution image guides still much lower in resolution than current imaging standards. Typical fibre image guides provide images having a resolution of about 18 kilopixels compared to the megapixel resolutions displayed in high-definition video. Furthermore, while some higher resolution image guides are available, this higher resolution is achieved using thicker optical fiber-bundles than those used with typical fibre image guides, and hence higher resolution image guides are constrained in their bending, with much larger turning radii that limits where they can be used in a surgical case.

SUMMARY

[0003] The present disclosure is generally directed to image guided medical procedures using an access port. This port-based surgery approach allows a surgeon, or robotic surgical system, to perform a surgical procedure involving tumor resection in which the residual tumor remaining after is minimized, while also minimizing the trauma to the intact white and grey matter of the brain. In such procedures, trauma may occur, for example, due to contact with the access port, stress to the brain matter, unintentional impact with surgical devices, and/or accidental resection of healthy tissue.

1 [0004] Hence, an aspect of the present specification provides a flexible endoscope that
2 can produce three-dimensional images, the endoscope comprising multiple fibre-bundle
3 image guides (each of which can be around 18 kilopixels resolution), coupled to a multi-
4 lens array on one end and multiple camera sensors on the other. The fibre-bundles in the
5 endoscope are coupled together at a common distal end, and are otherwise uncoupled
6 from one another. Each lens on the array projects a separate image to a different fiber-
7 bundle at the distal scope end of each fibre-bundle, each of which respectively conveys a
8 respective image to a respective camera sensor are coupled to an opposite proximal end
9 of each fiber-bundle, such that the endoscope acquires a plurality of separate pixelated
10 images. These images, acquired by each of the sensors, can then be merged and
11 reconstructed using, for example, principles of light field imaging and processing, to
12 produce a super-resolution image. This can allow for much higher resolution imaging
13 than is possible with conventional fibrescopes, which can allow for better diagnosis and
14 treatment. Furthermore, the endoscope provided herein can be more flexible than high
15 resolution endoscopes as the flexibility is determined by each individual fiber-bundle
16 which are coupled together only at a distal end.

17 [0005] An aspect of the specification provides an endoscope comprising: a plurality of
18 optical fiber bundles; a plurality of lenses in a one-to-one relationship with the plurality
19 of optical fiber bundles; and, a plurality of cameras in a one-to-one relationship with the
20 plurality of optical fiber bundles, each respective optical fiber bundle, of the plurality of
21 optical fiber bundles, having a respective lens, of the plurality of lenses, located at a
22 respective distal end, and a camera, of the plurality of cameras, located at a respective
23 proximal end, the plurality of optical fiber bundles being coupled together at a common
24 distal end, and otherwise being uncoupled from one another, a bending radius of the
25 endoscope defined by a largest respective bending radius of each of the plurality of
26 optical fiber bundles.

27 [0006] The plurality of optical fiber bundles can comprise a first optical fiber bundle and
28 a second optical fiber bundle, each having the respective lens located at the respective
29 distal end, and the respective camera located at the respective proximal end, thereby
30 forming a three-dimensional camera.

1 [0007] Respective distal ends of the plurality of optical fiber bundles, and respective
2 lenses located at the respective distal ends, can be spaced apart from one another to
3 provide different views of objects in front of the respective distal ends, thereby forming a
4 plenoptic camera.

5 [0008] The plurality of lenses is each formed in a common optical element can be located
6 at the common distal end.

7 [0009] The plurality of lenses can each be formed in a common optical element located at
8 the common distal end, the common optical element being one or more of: removable
9 from the common distal end of the plurality of optical fiber bundles; and disposable.

10 [0010] Two or more of the plurality of lenses can have one or more of: different depths
11 of field, different fields of view of objects in front of the plurality of lenses; and different
12 angular view of objects in front of the plurality of lenses.

13 [0011] The endoscope can further comprise a controller configured to: receive respective
14 images from each of the plurality of cameras; and combine the respective images into a
15 single higher resolution image.

16 [0012] The endoscope can further comprise a controller configured to: receive respective
17 images from each of the plurality of cameras; remove dead pixels from the respective
18 images; and combine the respective images into a single higher resolution image.

19 [0013] The endoscope can further comprise a controller configured to: receive respective
20 images from each of the plurality of cameras; and combine the respective images into a
21 depth-map of objects in front of the plurality of lenses.

22 [0014] The endoscope can further comprise a controller configured to: receive respective
23 images from each of the plurality of cameras; and combine the respective images into a
24 depth-map of objects in front of the plurality of lenses using light field processing.

25 [0015] Each respective diameter of the plurality of optical fiber bundles can be less than
26 or equal to about 2mm.

27 [0016] Another aspect of the specification provides a method comprising: at an
28 endoscope having: a plurality of optical fiber bundles; a plurality of lenses in a one-to-
29 one relationship with the plurality of optical fiber bundles; a plurality of cameras in a
30 one-to-one relationship with the plurality of optical fiber bundles, each respective optical
31 fiber bundle, of the plurality of optical fiber bundles, having a respective lens, of the

1 plurality of lenses, located at a respective distal end, and a camera, of the plurality of
2 cameras, located at a respective proximal end, the plurality of optical fiber bundles being
3 coupled together at a common distal end, and otherwise being uncoupled from one
4 another, a bending radius of the endoscope defined by a largest respective bending radius
5 of each of the plurality of optical fiber bundles; and a controller configured to: receive
6 respective images from each of the plurality of cameras, receiving, at the controller, the
7 respective images from each of the plurality of cameras; combining, at the controller, the
8 respective images into a single higher resolution image; and combining the respective
9 images into a depth-map of objects in front of the plurality of lenses.

10 **[0017]** The method can further comprise: removing, at the controller, dead pixels from
11 the respective images prior to combining the respective images into one or more of the
12 single higher resolution image and the depth-map.

13 **[0018]** The method can further comprise: combining the respective images into the
14 depth-map using a light field processing.

15 **[0019]** Two or more of the plurality of lenses have one or more of: different depths of
16 field, different fields of view of objects in front of the plurality of lenses: and different
17 angular view of objects in front of the plurality of lenses.

18 **[0020]** Yet a further aspect of the specification provides a computer-readable medium
19 storing a computer program, wherein execution of the computer program is for: at an
20 endoscope having: a plurality of optical fiber bundles; a plurality of lenses in a one-to-
21 one relationship with the plurality of optical fiber bundles; a plurality of cameras in a
22 one-to-one relationship with the plurality of optical fiber bundles, each respective optical
23 fiber bundle, of the plurality of optical fiber bundles, having a respective lens, of the
24 plurality of lenses, located at a respective distal end, and a camera, of the plurality of
25 cameras, located at a respective proximal end, the plurality of optical fiber bundles being
26 coupled together at a common distal end, and otherwise being uncoupled from one
27 another, a bending radius of the endoscope defined by a largest respective bending radius
28 of each of the plurality of optical fiber bundles; and a controller configured to: receive
29 respective images from each of the plurality of cameras, receiving, at the controller, the
30 respective images from each of the plurality of cameras; combining, at the controller, the
31 respective images into a single higher resolution image; and combining the respective

1 images into a depth-map of objects in front of the plurality of lenses. The computer-
2 readable medium can comprise a non-transitory computer-readable medium.

3

4

5

BRIEF DESCRIPTIONS OF THE DRAWINGS

[0021] For a better understanding of the various implementations described herein and to show more clearly how they may be carried into effect, reference will now be made, by way of example only, to the accompanying drawings in which:

[0022] Figure 1 shows an example operating room setup for a minimally invasive access port-based medical procedure, according to non-limiting implementations.

[0023] Figure 2 is a block diagram illustrating components of a medical navigation system that may be used to implement a surgical plan for a minimally invasive surgical procedure, according to non-limiting implementations.

[0024] Figure 3 depicts a block diagram illustrating components of a planning system used to plan a medical procedure that may then be implemented using the navigation system of Figure 2, according to non-limiting implementations.

[0025] Figure 4 depicts an example implementation port based brain surgery using a video scope, according to non-limiting implementations.

[0026] Figure 5 depicts insertion of an access port into a human brain, for providing access to interior brain tissue during a medical procedure, according to non-limiting implementations.

[0027] Figure 6 depicts a schematic diagram of a system that includes a flexible high resolution endoscope, according to non-limiting implementations.

[0028] Figure 7 depicts a block diagram of a flowchart of a method for combining images using, for example, the flexible high resolution endoscope of Figure 6, according to non-limiting implementations.

[0029] Figure 8 depicts the system of Figure 6 in use, according to non-limiting implementations.

[0030] Figure 9 depicts an optical element of the flexible high resolution endoscope of Figure 6, according to non-limiting implementations.

[0031] Figure 10 depicts an alternative optical element that can be used with the flexible high resolution endoscope of Figure 6, according to non-limiting implementations.

[0032] Figure 11 depicts the optical element of Figure 10 in an alternative use scenario, according to non-limiting implementations.

1 [0033] Figure 12 depicts the optical element of Figure 10 in a further alternative use
2 scenario, according to non- limiting implementations.

3 [0034] Figure 13 depicts a schematic diagram of a system that includes an alternative
4 flexible high resolution endoscope, according to non- limiting implementations.

5

6

DETAILED DESCRIPTION

[0035] Various implementations and aspects of the specification will be described with reference to details discussed below. The following description and drawings are illustrative of the specification and are not to be construed as limiting the specification. Numerous specific details are described to provide a thorough understanding of various implementations of the present specification. However, in certain instances, well-known or conventional details are not described in order to provide a concise discussion of implementations of the present specification.

[0036] The systems and methods described herein may be useful in the field of neurosurgery, including oncological care, neurodegenerative disease, stroke, brain trauma and orthopedic surgery; however persons of skill will appreciate the ability to extend these concepts to other conditions or fields of medicine. It should be noted that the surgical process is applicable to surgical procedures for brain, spine, knee and any other suitable region of the body.

[0037] Various apparatuses and processes will be described below to provide examples of implementations of the system disclosed herein. No implementation described below limits any claimed implementation and any claimed implementations may cover processes or apparatuses that differ from those described below. The claimed implementations are not limited to apparatuses or processes having all of the features of any one apparatus or process described below or to features common to multiple or all of the apparatuses or processes described below. It is possible that an apparatus or process described below is not an implementation of any claimed subject matter.

[0038] Furthermore, numerous specific details are set forth in order to provide a thorough understanding of the implementations described herein. However, it will be understood by those skilled in the relevant arts that the implementations described herein may be practiced without these specific details. In other instances, well-known methods, procedures and components have not been described in detail so as not to obscure the implementations described herein.

[0039] In this specification, elements may be described as “configured to” perform one or more functions or “configured for” such functions. In general, an element that is configured to perform or configured for performing a function is enabled to perform the

1 function, or is suitable for performing the function, or is adapted to perform the function,
2 or is operable to perform the function, or is otherwise capable of performing the function.

3 **[0040]** It is understood that for the purpose of this specification, language of “at least
4 one of X, Y, and Z” and “one or more of X, Y and Z” may be construed as X only, Y
5 only, Z only, or any combination of two or more items X, Y, and Z (e.g., XYZ, XY, YZ,
6 ZZ, and the like). Similar logic may be applied for two or more items in any occurrence
7 of “at least one ...” and “one or more...” language.

8 **[0041]** Referring to Figure 1, a non-limiting example navigation system 100 is shown
9 to support minimally invasive access port-based surgery. In Figure 1, a neurosurgeon
10 101 conducts a minimally invasive port-based surgery on a patient 102 in an operating
11 room (OR) environment. The navigation system 100 includes an equipment tower,
12 tracking system, displays and tracked instruments to assist the surgeon 101 during the
13 procedure. An operator 103 may also be present to operate, control and provide
14 assistance for the navigation system 100.

15 **[0042]** Referring to Figure 2, a block diagram is shown illustrating components of an
16 example medical navigation system 200, according to non-limiting implementations. The
17 medical navigation system 200 illustrates a context in which a surgical plan including
18 equipment (e.g., tool and material) tracking, such as that described herein, may be
19 implemented. The medical navigation system 200 includes, but is not limited to, one or
20 more monitors 205, 211 for displaying a video image, an equipment tower 201, and a
21 mechanical arm 202, which supports an optical scope 204. The equipment tower 201
22 may be mounted on a frame (e.g., a rack or cart) and may contain a computer or
23 controller (examples provided with reference to Figures 3 and 6 below), planning
24 software, navigation software, a power supply and software to manage the mechanical
25 arm 202, and tracked instruments. In one example non-limiting implementation, the
26 equipment tower 201 may comprise a single tower configuration with dual display
27 monitors 211, 205, however other configurations may also exist (e.g., dual tower, single
28 display, etc.). Furthermore, the equipment tower 201 may also be configured with a
29 universal power supply (UPS) to provide for emergency power, in addition to a regular
30 AC adapter power supply.

1 [0043] A patient's anatomy may be held in place by a holder. For example, in a
2 neurosurgical procedure the patient's head may be held in place by a head holder 217,
3 and an access port 206 and an introducer 210 may be inserted into the patient's head.
4 The introducer 210 may be tracked using a tracking camera 213, which provides position
5 information for the navigation system 200. The tracking camera 213 may also be used to
6 track tools and/or materials used in the surgery, as described in more detail below. In one
7 example non-limiting implementation, the tracking camera 213 may comprise a 3D
8 (three-dimensional) optical tracking stereo camera, similar to one made by Northern
9 Digital Imaging (NDI), configured to locate reflective sphere tracking markers 212 in 3D
10 space. In another example, the tracking camera 213 may comprise a magnetic camera,
11 such as a field transmitter, where receiver coils are used to locate objects in 3D space, as
12 is also known in the art. Location data of the mechanical arm 202 and access port 206
13 may be determined by the tracking camera 213 by detection of tracking markers 212
14 placed on these tools, for example the introducer 210 and associated pointing tools.
15 Tracking markers may also be placed on surgical tools or materials to be tracked. The
16 secondary display 205 may provide output of the tracking camera 213. In one example
17 non-limiting implementation, the output may be shown in axial, sagittal and coronal
18 views as part of a multi-view display.

19 [0044] As noted above with reference to Figure 2, the introducer 210 may include
20 tracking markers 212 for tracking. The tracking markers 212 may comprise reflective
21 spheres in the case of an optical tracking system and/or pick-up coils in the case of an
22 electromagnetic tracking system. The tracking markers 212 may be detected by the
23 tracking camera 213 and their respective positions are inferred by the tracking software.

24 [0045] As shown in Figure 2, a guide clamp 218 (or more generally a guide) for
25 holding the access port 206 may be provided. The guide clamp 218 may optionally
26 engage and disengage with the access port 206 without needing to remove the access port
27 206 from the patient. In some examples, the access port 206 may be moveable relative to
28 the guide clamp 218, while in the guide clamp 218. For example, the access port 206 may
29 be able to slide up and down (e.g., along the longitudinal axis of the access port 206)
30 relative to the guide clamp 218 while the guide clamp 218 is in a closed position. A
31 locking mechanism may be attached to or integrated with the guide clamp 218, and may

1 optionally be actuatable with one hand, as described further below. Furthermore, an
2 articulated arm 219 may be provided to hold the guide clamp 218. The articulated arm
3 219 may have up to six degrees of freedom to position the guide clamp 218. The
4 articulated arm 219 may be lockable to fix its position and orientation, once a desired
5 position is achieved. The articulated arm 219 may be attached or attachable to a point
6 based on the patient head holder 217, or another suitable point (e.g., on another patient
7 support, such as on the surgical bed), to ensure that when locked in place, the guide
8 clamp 218 does not move relative to the patient's head.

9 **[0046]** Referring to Figure 3, a block diagram is shown illustrating a control and
10 processing unit 300 that may be used in the navigation system 200 of Figure 2 (e.g., as
11 part of the equipment tower). In one example non-limiting implementation, control and
12 processing unit 300 may include one or more processors 302, a memory 304, a system
13 bus 306, one or more input/output interfaces 308, a communications interface 310, and
14 storage device 312. In particular, one or more processors 302 may comprise one or more
15 hardware processors and/or one or more microprocessors. Control and processing unit
16 300 may be interfaced with other external devices, such as tracking system 321, data
17 storage device 342, and external user input and output devices 344, which may include,
18 but is not limited to, one or more of a display, keyboard, mouse, foot pedal, and
19 microphone and speaker. Data storage device 342 may comprise any suitable data
20 storage device, including, but not limited to a local and/or remote computing device (e.g.
21 a computer, hard drive, digital media device, and/or server) having a database stored
22 thereon. In the example shown in Figure 3, data storage device 342 includes, but is not
23 limited to, identification data 350 for identifying one or more medical instruments 360
24 and configuration data 352 that associates customized configuration parameters with one
25 or more medical instruments 360. Data storage device 342 may also include, but is not
26 limited to, preoperative image data 354 and/or medical procedure planning data 356.

27 Although data storage device 342 is shown as a single device in Figure 3, in other
28 implementations, data storage device 342 may be provided as multiple storage devices.

29 **[0047]** Medical instruments 360 may be identifiable using control and processing unit
30 300. Medical instruments 360 may be connected to and controlled by control and
31 processing unit 300, and/or medical instruments 360 may be operated and/or otherwise

1 employed independent of control and processing unit 300. Tracking system 321 may be
2 employed to track one or more of medical instruments 360 and spatially register the one
3 or more tracked medical instruments 360 to an intraoperative reference frame. In another
4 example, a sheath may be placed over a medical instrument 360 and the sheath may be
5 connected to and controlled by control and processing unit 300.

6 **[0048]** Control and processing unit 300 may also interface with a number of configurable
7 devices, and may intraoperatively reconfigure one or more of such devices based on
8 configuration parameters obtained from configuration data 352. Examples of devices
9 320, as shown in Figure 3, include, but are not limited, one or more external imaging
10 devices 322, one or more illumination devices 324, a robotic arm, one or more projection
11 devices 328, and one or more displays 305, 311.

12 **[0049]** Aspects of the specification may be implemented via processor(s) 302 and/or
13 memory 304. For example, the functionalities described herein may be partially
14 implemented via hardware logic in processor 302 and partially using the instructions
15 stored in memory 304, as one or more processing modules 370 and/or processing
16 engines. Example processing modules include, but are not limited to, user interface
17 engine 372, tracking module 374, motor controller 376, image processing engine 378,
18 image registration engine 380, procedure planning engine 382, navigation engine 384,
19 and context analysis module 386. While the example processing modules are shown
20 separately in Figure 3, in one example non-limiting implementation the processing
21 modules 370 may be stored in the memory 304 and the processing modules may be
22 collectively referred to as processing modules 370.

23 **[0050]** It is to be understood that the system is not intended to be limited to the
24 components shown in Figure 3. One or more components of the control and processing
25 unit 300 may be provided as an external component or device. In one example non-
26 limiting implementation, navigation engine 384 may be provided as an external
27 navigation system that is integrated with control and processing unit 300.

28 **[0051]** Some implementations may be implemented using processor 302 without
29 additional instructions stored in memory 304. Some implementations may be
30 implemented using the instructions stored in memory 304 for execution by one or more

1 general purpose microprocessors. Thus, the specification is not limited to a specific
2 configuration of hardware and/or software.

3 **[0052]** While some implementations may be implemented in fully functioning computers
4 and computer systems, various implementations are capable of being distributed as a
5 computing product in a variety of forms and are capable of being applied regardless of
6 the particular type of machine or computer readable media used to actually effect the
7 distribution.

8 **[0053]** At least some aspects disclosed may be embodied, at least in part, in software.
9 That is, the techniques may be carried out in a computer system or other data processing
10 system in response to its processor, such as a microprocessor, executing sequences of
11 instructions contained in a memory, such as ROM, volatile RAM, non-volatile memory,
12 cache and/or a remote storage device.

13 **[0054]** A computer readable storage medium, and/or a non-transitory computer readable
14 storage medium, may be used to store software and data which, when executed by a data
15 processing system, causes the system to perform various methods. The executable
16 software and data may be stored in various places including for example ROM, volatile
17 RAM, non-volatile memory and/or cache. Portions of this software and/or data may be
18 stored in any one of these storage devices.

19 **[0055]** Examples of computer-readable storage media include, but are not limited to,
20 recordable and non-recordable type media such as volatile and non-volatile memory
21 devices, read only memory (ROM), random access memory (RAM), flash memory
22 devices, floppy and other removable disks, magnetic disk storage media, optical storage
23 media (e.g., compact discs (CDs), digital versatile disks (DVDs), etc.), among others.
24 The instructions may be embodied in digital and analog communication links for
25 electrical, optical, acoustical and/or other forms of propagated signals, such as carrier
26 waves, infrared signals, digital signals, and the like. The storage medium may comprise
27 the internet cloud, storage media therein, and/or a computer readable storage medium
28 and/or a non-transitory computer readable storage medium, including, but not limited to,
29 a disc.

30 **[0056]** At least some of the methods described herein are capable of being distributed in
31 a computer program product comprising a computer readable medium that bears

1 computer usable instructions for execution by one or more processors, to perform aspects
2 of the methods described. The medium may be provided in various forms such as, but
3 not limited to, one or more diskettes, compact disks, tapes, chips, USB (Universal Serial
4 Bus) keys, external hard drives, wire-line transmissions, satellite transmissions, internet
5 transmissions or downloads, magnetic and electronic storage media, digital and analog
6 signals, and the like. The computer useable instructions may also be in various forms,
7 including compiled and non-compiled code.

8 **[0057]** According to one aspect of the present application, one purpose of the navigation
9 system 200, which may include control and processing unit 300, is to provide tools to a
10 surgeon and/or a neurosurgeon that will lead to the most informed, least damaging
11 neurosurgical operations. In addition to removal of brain tumors and intracranial
12 hemorrhages (ICH), the navigation system 200 may also be applied to a brain biopsy, a
13 functional/deep-brain stimulation, a catheter/shunt placement procedure, open
14 craniotomies, endonasal/skull-based/ENT, spine procedures, and other parts of the body
15 such as breast biopsies, liver biopsies, etc. While several examples have been provided,
16 aspects of the present specification may be applied to other suitable medical procedures.

17 **[0058]** Attention is next directed to Figure 4 which depicts a non-limiting example of a
18 port-based brain surgery procedure using a video scope. In Figure 4, operator 404, for
19 example a surgeon, may align video scope 402 to peer down port 406. Video scope 402
20 may be attached to an adjustable mechanical arm 410. Port 406 may have a tracking tool
21 408 attached to it where tracking tool 408 is tracked by a tracking camera of a navigation
22 system.

23 **[0059]** Even though the video scope 402 may comprise an endoscope and/or a
24 microscope, these devices introduce optical and ergonomic limitations when the surgical
25 procedure is conducted over a confined space and conducted over a prolonged period
26 such as the case with minimally invasive brain surgery.

27 **[0060]** Figure 5 illustrates the insertion of an access port 12 into a human brain 10, in
28 order to provide access to interior brain tissue during a medical procedure. In Figure 5,
29 access port 12 is inserted into a human brain 10, providing access to interior brain tissue.
30 Access port 12 may include, but is not limited to, instruments such as catheters, surgical
31 probes, and/or cylindrical ports such as the NICO BrainPath. Surgical tools and

1 instruments may then be inserted within a lumen of the access port 12 in order to perform
2 surgical, diagnostic or therapeutic procedures, such as resecting tumors as necessary.

3 However, the present specification applies equally well to catheters, DBS needles, a
4 biopsy procedure, and also to biopsies and/or catheters in other medical procedures
5 performed on other parts of the body.

6 **[0061]** In the example of a port-based surgery, a straight and/or linear access port 12 is
7 typically guided down a sulci path of the brain. Surgical instruments and/or surgical tools
8 would then be inserted down the access port 12.

9 **[0062]** Attention is next directed to Figure 6, which depicts a schematic diagram of a
10 system 600 that includes an example of a flexible high resolution endoscope 601 that
11 could be used with access port 12. It is appreciated that elements of system 600 are not
12 drawn to scale, but are depicted schematically to show functionality. Endoscope 601
13 comprises: a plurality of optical fiber bundles 603; a plurality of lenses 605 in a one-to-
14 one relationship with plurality of optical fiber bundles 603; and, a plurality of cameras
15 607 in a one-to-one relationship with the plurality of optical fiber bundles 603, each
16 respective optical fiber bundle 603, of the plurality of optical fiber bundles 603, having a
17 respective lens 605, of the plurality of lenses 605, located at a respective distal end 609,
18 and a camera 607, of the plurality of cameras 607, located at a respective proximal end
19 611, plurality of optical fiber bundles 603 being coupled together at a common distal end
20 609, and otherwise being uncoupled from one another, a bending radius of endoscope
21 601 defined by a largest respective bending radius of each of the plurality of optical fiber
22 bundles 603. As depicted, plurality of lenses 605 are each formed in a common optical
23 element 613 located at common distal end 609, which also couples together plurality of
24 optical fiber bundles 603 at common distal end 609. It is appreciated that respective distal
25 ends 609 of each optical fibre bundle 603 are coincident with common distal end 609,
26 such each of distal ends 609 and common distal end 609 are similarly numbered.

27 **[0063]** As depicted, system 600 further comprises a controller 615, coupled to each of
28 cameras 607, and a display device 626, as described in more detail below.

29 **[0064]** In general, endoscope 601 is configured to acquire a plurality of images of a
30 tissue sample 620, which can include, but is not limited to, a tissue sample accessible via
31 access port 12. In particular, respective distal ends 609 of the plurality of optical fiber

1 bundles 603, and respective lenses 605 located at respective distal ends 609, can be
2 spaced apart from one another to provide different views of objects (such as tissue sample
3 620) in front of the respective distal ends 609. In some of these implementations
4 endoscope 601 can thereby form a plenoptic camera.

5 **[0065]** While only one of each of plurality of optical fiber bundles 603, plurality of
6 lenses 605, and plurality of cameras 607 is indicated in Figure 6, as depicted, endoscope
7 601 comprises four optical fiber bundles 603, four respective lenses 605 and four
8 respective cameras 607. However, endoscope 601 can comprise as few as two of each of
9 optical fiber bundles 603, lenses 605 and cameras 607, and can comprise more than four
10 of each of optical fiber bundles 603, lenses 605 and cameras 607. However, at a
11 minimum, endoscope 601 comprises the plurality of optical fiber bundles comprises a
12 first optical fiber bundle 603 and a second optical fiber bundle 603, each having the
13 respective lens 605 located at the respective distal end 609, and the respective camera
14 607 located at the respective proximal end 611, which can thereby form a three-
15 dimensional camera.

16 **[0066]** Each optical fiber bundle 603 can comprise an optical fiber having a respective
17 diameter of are less than or equal to about 2mm (however, optical fiber bundles 603 need
18 not have all the same diameter). In particular, each optical fiber bundle 603 can have a
19 diameter that can convey images from respective lenses 605 to respective cameras 607
20 with resolutions similar to cameras 607. For example, 2mm optical fiber bundles can
21 convey images of resolutions of about 18 kilopixels, and hence cameras 607 can produce
22 digital images have resolutions of about 18 kilopixels.

23 **[0067]** Furthermore, as each optical fiber bundle 603 is free to bend independent from
24 every other optical fiber bundle 603, other than at common distal end 609, the bending
25 radius of endoscope 601 is determined and/or defined by the individual bending radii of
26 each optical fiber bundle 603 rather than a total bending radii if optical fiber bundles 603
27 were coupled together along their entire length. Put another way, a bending radius of
28 endoscope 601 is defined by a largest respective bending radius of each of the plurality of
29 optical fiber bundles 603. As such, optical fiber bundles 603 of any suitable diameter are
30 within the scope of present implementations; for example, a specified bending radius of
31 endoscope 601 can be used to select individual optical fibers that will meet this

1 specification, rather than selecting optical fibers that, when coupled together, will meet
2 this specification.

3 **[0068]** In other words, as is understood from Figure 6, plurality of optical fiber bundles
4 603 are coupled together at common distal end 609 (e.g. by way of common optical
5 element 613), and are otherwise uncoupled from one another. Indeed, each of plurality of
6 optical fiber bundles 603 can bend from common distal end 609 independent of the other
7 optical fiber bundles 603. As such plurality of optical fiber bundles 603 are not attached
8 to each other than at common distal end 609.

9 **[0069]** Furthermore, each optical fiber bundle 603 can have a length that is
10 commensurate with insertion through an access port (including, but not limited to, access
11 port 12), as well as port-based surgery, such that common distal end 609 can be inserted
12 through an access port, and optical fiber bundles 603 join respective lenses 605 to
13 respective cameras 607 such that cameras 607 do not block surgical access to access port
14 12 (e.g. cameras 607 do not block access of a surgeon (and the like) and/or surgical tools
15 (and the like) to access port 12). For example each optical fiber bundle 603 can be greater
16 than about a half meter long. Furthermore, optical fiber bundles 603 need not all be the
17 same length, and some optical fiber bundles 603 can be longer or shorter than other
18 optical fiber bundles 603.

19 **[0070]** As depicted, each lens 605 is formed in common optical element 613 located at
20 common distal end 609. Common optical element 613 can comprise one or more of
21 optical glass and optical plastic, at least at a tissue facing side of common optical element
22 613. Each lens 605 can be formed in common optical element 613 using, for example,
23 laser processing (including, but not limited to, femtosecond laser processing, and the like)
24 to form profiles in the index of refraction in the glass and/or plastic of common optical
25 element 613 which correspond to each lens 605. However, lenses 605 can also be tiled
26 together using one or more of a mechanical assembly, adhesives, and the like.

27 **[0071]** Two or more of plurality of lenses 605 can have one or more of: different depths
28 of field, different fields of view of objects in front of the plurality of lenses 605; and
29 different angular view of objects in front of the plurality of lenses 605. Hence, when
30 endoscope 601 is imaging tissue sample 620, tissue sample 620 can be imaged using at

1 least two different depths of field and/or at least two different fields of view and/or at
2 least two different angular views.

3 **[0072]** Each camera 607 can include, but is not limited to one or more of a charge-
4 coupled device (CCD) camera, a digital camera, an optical camera, and the like, and is
5 generally configured to acquire digital images, and in particular digital images received
6 from a respective lens 605 via a respective optical fiber bundle 603. While not depicted,
7 each camera 607 can further include one or more respective lenses for focusing light from
8 a respective optical fiber 603 onto a respective imaging element (such as a CCD). While
9 not depicted, endoscope 601 can include one or more devices for coupling optical fiber
10 bundles 603 to a respective camera 607. Furthermore, each camera 607 can have a
11 resolution of about 18 kilopixels.

12 **[0073]** Controller 615 can comprise any suitable combination of computing devices,
13 processors, memory devices and the like. In particular, controller 615 can comprise one
14 or more of a data acquisition unit, configured to acquire data and/or images at least from
15 cameras 607, and an image processing unit, configured to process data and/or images
16 from cameras 607 for rendering at display device 626. Hence, controller 615 is
17 interconnected with cameras 607 and display device 626. In some implementations,
18 controller 615 can comprise control and processing unit 300 depicted in Figure 3, and/or
19 controller 615 can be in communication with control and processing unit 300 depicted in
20 Figure 3 and/or controller 615 can be under control of communication with control and
21 processing unit 300 depicted in Figure 3.

22 **[0074]** In some implementations, however, controller 615 can be a component of
23 endoscope 601 such that endoscope 601 comprises controller 615. In these
24 implementations, endoscope 601 can be provided as a unit with controller 615 which can
25 be interfaced with control and processing unit 300 depicted in Figure 3, and the like.

26 **[0075]** Display device 626 can comprise any suitable display device including, but not
27 limited to, cathode ray tubes, flat panel displays, and the like. For example, display
28 device 626 can comprise one or more of monitors 205, 211, as depicted in Figure 2,
29 and/or displays 305, 311 depicted in Figure 3.

30 **[0076]** Attention is now directed to Figure 7 which depicts a flowchart of a method 700
31 for combining images from cameras, according to non-limiting implementations. In order

1 to assist in the explanation of method 700, it will be assumed that method 700 is
2 performed using system 600, and specifically by controller 615. Indeed, method 700 is
3 one way in which system 600 and/or controller 615 can be configured. Furthermore, the
4 following discussion of method 700 will lead to a further understanding of controller 615,
5 and system 600 and its various components. However, it is to be understood that system
6 600 and/ controller 615 and/or method 700 can be varied, and need not work exactly as
7 discussed herein in conjunction with each other, and that such variations are within the
8 scope of present implementations.

9 [0077] Regardless, it is to be emphasized, that method 700 need not be performed in the
10 exact sequence as shown, unless otherwise indicated; and likewise various blocks may be
11 performed in parallel rather than in sequence; hence the elements of method 700 are
12 referred to herein as “blocks” rather than “steps”. It is also to be understood, however,
13 that method 700 can be implemented on variations of system 600 as well.

14 [0078] At block 701, controller 615 receives respective images from each of plurality of
15 cameras 607.

16 [0079] At an optional block 703 (indicated by block 703 being shown in broken lines),
17 controller 615 removes dead pixels from the respective images. In some implementations,
18 block 703 is not performed. Furthermore, in other implementations, when no dead pixels
19 are in the respective images, block 703 is not performed.

20 [0080] At block 705, controller 615 can combine the respective images into a single
21 higher resolution image.

22 [0081] At block 707, controller 615 can combine the respective images into a depth-map
23 of objects in front of the plurality of lenses 605 using, for example, light field processing
24 techniques, and the like.

25 [0082] In some implementations, controller 615 can implement both blocks 705, 707, for
26 example in parallel with each other and/or one after the other. In other implementations,
27 controller 615 can implement one of blocks 705, 707.

28 [0083] Furthermore, in some implementations, controller 615 can implement blocks 703
29 in conjunction with one or more of blocks 705, 707.

30 [0084] Method 700 will now be described with respect to Figure 8, which is substantially
31 similar to Figure 6, with like elements having like numbers, however in Figure 8,

1 respective distal ends 609 and respective proximal ends 611 are enlarged, and the entire
2 length of each optical fiber bundle 603 is not depicted.

3 **[0085]** In Figure 8, light 801, 802, 803, 804 representing different respective views of
4 tissue sample 620 is collected by respective lenses 601 and conveyed to respective
5 cameras 607 by respective optical fiber bundles 603. Cameras 607 convert light 801, 802,
6 803, 804 into respective digital images 811, 812, 813, 814 of tissue sample 620, which
7 are received at controller 615 (e.g. at block 701 of method 700).

8 **[0086]** Controller 615 processes digital images 811, 812, 813, 814 to optionally remove
9 dead pixels in each of digital images 811, 812, 813, 814 (e.g. at block 703 of method
10 700), and combine digital images 811, 812, 813, 814 image into one or more of single
11 higher resolution image 820 of tissue sample 620 (e.g. at block 705 of method 700), and a
12 depth-map 830 of tissue sample 620 (e.g. at block 707 of method 700). Controller 615
13 can be configured to produce higher resolution image 820 and/or depth-map 830 from
14 digital images 811, 812, 813, 814 using light field processing, as known to persons of
15 skill in the art. Controller 615 can then provide higher resolution image 820 and/or depth-
16 map 830 to display device 626 for rendering thereupon. Controller can optionally provide
17 one or more of digital images 811, 812, 813, 814 to display device 626 for rendering
18 thereupon (not depicted).

19 **[0087]** In other words, dead pixels of digital images 811, 812, 813, 814 and pixels of
20 digital images 811, 812, 813, 814 can be combined and/or interlaced and/or used to
21 produce interpolated pixels to produce image 820 which has a higher resolution of each
22 of digital images 811, 812, 813, 814 taken alone. Hence, if each of digital images 811,
23 812, 813, 814 has a resolution of about 18 kilopixels, image 820 can have a resolution
24 can at least about double 18 kilopixels. Thus, endoscope 601 can be configured to images
25 having resolutions similar to those produced by existing high resolution endoscopes, but
26 without the attendant problems with bending radius suffered by those existing high
27 resolution endoscopes.

28 **[0088]** In addition, using light field processing of the separate digital images 811, 812,
29 813, 814 from cameras 607, a depth-map of tissue sample 620 (or any other object)
30 imaged by lenses 605 can be reconstructed, which can allow structures with differing
31 depth to be more easily detected and/or see.

1 [0089] Furthermore, when endoscope 601 is configured for omnifocusing (having all
2 objects imaged by lenses 605 in focus), selective post-acquisition focusing, and depth of
3 field control can be possible, both in post-acquisition and real-time. This post-processing
4 can also allow for removal of dead pixels which can be caused by broken fibres within
5 fiber bundles without significant loss of detail. In other words, block 703 can be
6 performed in conjunction with either of blocks 705, 707.

7 [0090] Furthermore, in some implementations, two or more of digital images 811, 812,
8 813, 814 can be combined into a stereo image of tissue sample 620. Indeed, a plurality of
9 pairs of digital images 811, 812, 813, 814 can be combined to produce a plurality of
10 stereo images of tissue sample 620, for example from different angles and/or different
11 fields of view and/or different depths of field.

12 [0091] In yet further implementations, where lenses 605 have different depths of field,
13 but a similar field of view, digital images 811, 812, 813, 814 can be combined into a
14 plenoptic image of tissue sample 620 such that a depth of field of the plenoptic image can
15 be selected by a user interacting with controller 615, display device 626 and an input
16 device (not depicted).

17 [0092] Indeed, in these implementations, lenses 605 can be configured for omnifocusing,
18 where all objects (e.g. including, but not limited to tissue sample 620) imaged by lenses
19 605 are in focus; while each individual lens 605 may not have all objects in focus,
20 collectively lenses 605 can image all objects in focus such that, collectively, all images
21 produced by cameras 607 include all objects imaged by lenses 605 in focus, at least in
22 one of the images.

23 [0093] Attention is next directed to Figure 9 which depicts common optical element 613.
24 Common optical element 613 is generally configured to both provide lenses 605 and
25 couple together the plurality of optical fiber bundles 603 at common distal end 609.

26 [0094] Hence, common optical element 613 comprises lenses 605 and, as depicted,
27 respective slots 901 for receiving a respective optical fiber bundle 603 on a proximal
28 side, each slot 901 in a body of common optical element 613, and each slot 901
29 terminating at a respective lens 605 at distal end 609.

30 [0095] Hence, each slot 901 has a diameter that is similar to a diameter of a respective
31 optical fiber bundle 603 such that each slot 901 can receive a respective optical fiber

1 bundle 603 and seat a distal end of each respective optical fiber bundle 603 at a
2 respective lens 605.

3 **[0096]** While not depicted, common optical element 613 can further comprise a
4 mechanism for fixing each respective optical fiber bundle 603 within a respective slot
5 901; alternatively, adhesives (including, but not limited to optical adhesives) can be used
6 to fix a respective optical fiber bundle 603 within a respective slot 901.

7 **[0097]** Attention is next directed to Figure 10 which depicts an alternative common
8 optical element 613a, which is substantially similar to optical element 613, with like
9 elements having like numbers, however with an "a" appended thereto. Hence, optical
10 element 613a comprises a plurality of lenses 605a at a distal end 609a. However, in
11 contrast to optical element 613, optical element 613a comprises eight lenses 605a, and
12 one slot 901a configured to receive a plurality of optical fiber bundles. However, optical
13 element 613a can comprise fewer than eight lenses 605a and more than eight lenses 605a.

14 **[0098]** Attention is next directed to Figure 11 which depicts slot 901a of optical element
15 613a receiving a plurality of optical fiber bundles 603a, in a one-to-one relationship with
16 plurality of lenses 605a, optical fiber bundles 603a being coupled together a common
17 distal end 609a, and otherwise being uncoupled from one another. While only a portion
18 of optical fiber bundles 603a is depicted, it is assumed that each optical fiber bundle 603a
19 is coupled to a respective camera at a proximal end, similar to implementations depicted
20 in Figure 6.

21 **[0099]** In particular, coupling together of optical fiber bundles 603a at common distal
22 end 609a results in a total diameter of coupled optical fiber bundles 603a that is about a
23 same diameter as slot 901a. While not depicted, distal ends of optical fiber bundles 603a
24 are aligned with a respective lens 605a, as in system 600. For example, a geometry of
25 distal ends of optical fiber bundles 603a can be selected so that when distal ends of
26 optical fiber bundles 603a are coupled together, they form a geometric pattern, and lenses
27 605a can be arranged into a similar pattern. Hence, when distal ends of optical fiber
28 bundles 603a are inserted into slot 901a, one or more of distal ends of optical fiber
29 bundles 603a and common optical element 613a can be rotated until alignment with
30 lenses 605a occurs. Such alignment can be determined by one or more of processing and
31 viewing images from cameras to which each optical fiber bundle 603a is coupled.

1 **[00100]** Alternatively, distal ends of optical fiber bundles 603a can have a cross-
2 section of a given geometric shape, for example a geometric shape having at least one flat
3 side, and a respective cross-section slot 901a can have a similar shape; hence, when distal
4 ends of optical fiber bundles 603a are inserted into slot 901a the flat sides align which
5 can cause the distal ends of optical fiber bundles 603a to align with lenses 605a.

6 **[00101]** Alternatively, a mechanical assembly can be used to couple together distal
7 ends of optical fiber bundles 603a and further space distal ends of optical fiber bundles
8 603a in a pattern similar to lenses 605a; in these implementations, slot 901a can be
9 adapted to receive the distal ends of optical fiber bundles 603a and the mechanical
10 assembly.

11 **[00102]** Attention is next directed to Figure 12 which depicts common optical
12 element 613a being used with an optical fiber bundle 603b having a similar diameter to
13 that of slot 901a, and can include a plurality of optical fiber bundles coupled together at
14 common distal end 609a, as well as along their length. Hence, optical fiber bundle 603b
15 is configured to convey images from lenses 605a to one or more cameras at a common
16 proximal end. Indeed, individual optical fiber bundles of optical fiber bundle 603b need
17 not be aligned with lenses 605a as a proximal end of optical fiber bundle 603b can have a
18 diameter that can receive light from all of lenses 605a. The bending radius of optical
19 fiber bundle 603b is larger than a bending radius of endoscope 601, however such
20 difference in bending radius does not preclude use of common optical element 613a with
21 more typical endoscopes.

22 **[00103]** Attention is next directed to Figure 13, which depicts an alternative system
23 1300 that includes an example of a flexible high resolution endoscope 1301 that could be
24 used with access port 12 to image tissue sample 620. System 1300 is substantially similar
25 to system 600, with like elements having like numbers, but in a "1300" series rather than
26 a "600" series. However, in contrast to endoscope 601, optical fiber bundles of endoscope
27 1301 are coupled together at both a common distal end and a common proximal end, and
28 are otherwise uncoupled, and cameras used with endoscope 1301 are not necessarily in a
29 one-to-one relationship with the optical fiber bundles.

30 **[00104]** Hence, endoscope 1301 comprises: a plurality of optical fiber bundles
31 1303; a plurality of lenses 1305 in a one-to-one relationship with plurality of optical fiber

1 bundles 1303; and, one or more cameras 1307. Each respective optical fiber bundle 1303,
2 of the plurality of optical fiber bundles 1303, has a respective lens 1305, of the plurality
3 of lenses 1305, located at a respective distal end 1309. One or more cameras 1307 are
4 located at a common proximal end 1311 of the plurality of optical fiber bundles 1303.
5 Plurality of optical fiber bundles 1303 are coupled together at a common distal end 1309
6 and at common proximal end 1311, and are otherwise uncoupled from one another. As
7 depicted, plurality of lenses 1305 are each formed in a common optical element 1313
8 similar to common optical element 613. As depicted, system 1300 further comprises a
9 controller 1315, coupled to each of one or more cameras 1307, and a display device 1326.

10 **[00105]** While endoscope 1301, as depicted, includes three cameras 1307, in other
11 implementations endoscope 1301 could include as few as one camera 1307 and more
12 than three cameras 1307, including more than four cameras 1307. It is assumed, however
13 that cameras 1307 of endoscope 1301 are collectively configured to receive light from all
14 of optical fiber bundles 1303, and that each of one or more cameras 1307 can be arranged
15 to receive images from one or more of plurality of optical fiber bundles 1303

16 **[00106]** Hence, in these implementations, respective alignment of distal and
17 proximal ends of optical fiber bundles 1303 with lenses 1305 and one or more cameras
18 1307 is less important than in system 600, as each of one or more cameras 1307 can be
19 arranged to receive images from one or more of plurality of optical fiber bundles 1303.
20 Controller 1315 can hence be configured to separate and/or combine images from each of
21 one or more cameras 1307 into images corresponding to fields of view of each of lenses
22 1305.

23 **[00107]** Indeed while, as depicted, each of distal ends of plurality of optical fiber
24 bundles 1303 is aligned with a respective lens 1305, in other implementations, more than
25 one of plurality of optical fiber bundles 1303 can be arranged to receive light from one or
26 more of lenses 1305, such that plurality of optical fiber bundles 1303 functions optically
27 as a larger optical fiber bundle similar to that depicted in Figure 12. Indeed, in some
28 implementations, common optical element 1313 can be replaced with common optical
29 element 613a having one larger slot 901a instead of individual slots.

30 **[00108]** However, as each of plurality of optical fiber bundles 1303 are free to
31 bend individually, other than at ends 1309, 1311, a bending radius of endoscope 1301 is

1 determined by the bending radii of individual optical fiber bundles 1303 rather than all of
2 optical fiber bundles 1303 bending together.

3 **[00109]** Hence, provided herein is a flexible endoscope that comprises of multiple
4 optical fibre bundles which can each have about 18 kilopixels resolution, each coupled to
5 a multi-lens array at a distal end and multiple cameras at a proximal end. Each lens on the
6 array can convey a separate image to the distal end of each optical fibre bundle and
7 cameras coupled to the proximal end of the optical fibre bundles acquire separate
8 pixelated images. These lower resolution images, acquired by each of the cameras, can
9 merged and/or combined, and reconstructed using principles of light field imaging and
10 processing, to produce a super-resolution image This can allow for much higher
11 resolution imaging than with conventional endoscopes, which can allow for better
12 diagnosis and treatment.

13 **[00110]** Furthermore, using light field processing of the separate images from the
14 cameras, a depth-map of objects imaged by the lenses can be reconstructed, which can
15 allow structures with differing depth to be more easily detected and/or seen. By taking
16 advantage of the underlying optics of the method, omnifocusing (having all object in the
17 scene in-focus), selective post-acquisition focusing, and depth of field control is possible
18 post-acquisition and real-time. This post-processing can allow for removal of “dead”
19 pixels which can be caused by broken fibres within fiber bundles without significant loss
20 of detail

21 **[00111]** Using separate fibre bundles can also resolve flexibility issues associated
22 with having one large fibre bundle, since each smaller fiber bundle can move
23 independently from one another and not seize when bent.

24 **[00112]** While devices and methods described herein have been described with
25 respect to surgical and/or medical applications, devices and methods described herein can
26 be used other fields, such as in engineering and defense, in in particular in scenarios
27 where high-resolution three-dimensional imaging of a space and/or objects occurs
28 through a small, (and even convoluted) access port.

29 **[00113]** The specific embodiments described above have been shown by way of
30 example, and it should be understood that these embodiments may be susceptible to
31 various modifications and alternative forms. It should be further understood that the

1 claims are not intended to be limited to the particular forms disclosed, but rather to cover
2 all modifications, equivalents, and alternatives falling within the spirit and scope of this
3 disclosure.

4

5

1 **What is claimed is:**

2 1. An endoscope comprising:

3 a plurality of optical fiber bundles;

4 a plurality of lenses in a one-to-one relationship with the plurality of optical fiber
5 bundles;

6 a plurality of cameras in a one-to-one relationship with the plurality of optical fiber
7 bundles,

8 each respective optical fiber bundle, of the plurality of optical fiber bundles, having
9 a respective lens, of the plurality of lenses, located at a respective distal end, and a
10 camera, of the plurality of cameras, located at a respective proximal end,

11 the plurality of optical fiber bundles being coupled together at a common distal end,
12 and otherwise being uncoupled from one another, a bending radius of the endoscope
13 defined by a largest respective bending radius of each of the plurality of optical fiber
14 bundles; and

15 a common optical element, wherein the plurality of lenses are each formed in the
16 common optical element, the common optical element located at the common distal
17 end, the common optical element being one or more of: removable from the common
18 distal end of the plurality of optical fiber bundles; and disposable.

19 2. The endoscope of claim 1, wherein the plurality of optical fiber bundles comprises a
20 first optical fiber bundle and a second optical fiber bundle, each having the respective
21 lens located at the respective distal end, and the respective camera located at the
22 respective proximal end, thereby forming a three-dimensional camera.

23 3. The endoscope of claim 1, wherein respective distal ends of the plurality of optical fiber
24 bundles, and respective lenses located at the respective distal ends, are spaced apart from
25 one another to provide different views of objects in front of the respective distal ends,
26 thereby forming a plenoptic camera.

27 4. The endoscope of claim 1, wherein two or more of the plurality of lenses have one or
28 more of: different depths of field, different fields of view of objects in front of the

1 plurality of lenses: and different angular view of objects in front of the plurality of
2 lenses.

3 5. The endoscope of claim 1, further comprising a controller configured to: receive
4 respective images from each of the plurality of cameras; and combine the respective
5 images into a single higher resolution image.

6 6. The endoscope of claim 1, further comprising a controller configured to: receive
7 respective images from each of the plurality of cameras; remove dead pixels from the
8 respective images; and combine the respective images into a single higher resolution
9 image.

10 7. The endoscope of claim 1, further comprising a controller configured to: receive
11 respective images from each of the plurality of cameras; and combine the respective
12 images into a depth-map of objects in front of the plurality of lenses.

13 8. The endoscope of claim 1, further comprising a controller configured to: receive
14 respective images from each of the plurality of cameras; and combine the respective
15 images into a depth-map of objects in front of the plurality of lenses using light field
16 processing.

17 9. The endoscope of claim 1, wherein each respective diameter of the plurality of
18 optical fiber bundles is less than or equal to about 2mm.

19 10. The endoscope of claim 1, wherein the common optical element comprises: a body
20 having a proximal side and distal side, the plurality of lenses formed at the distal side; and
21 respective slots for receiving a respective optical fiber bundle on the proximal side, each
22 of the respective slots terminating at a respective lens, of the plurality of lenses, at the distal
23 side.

24

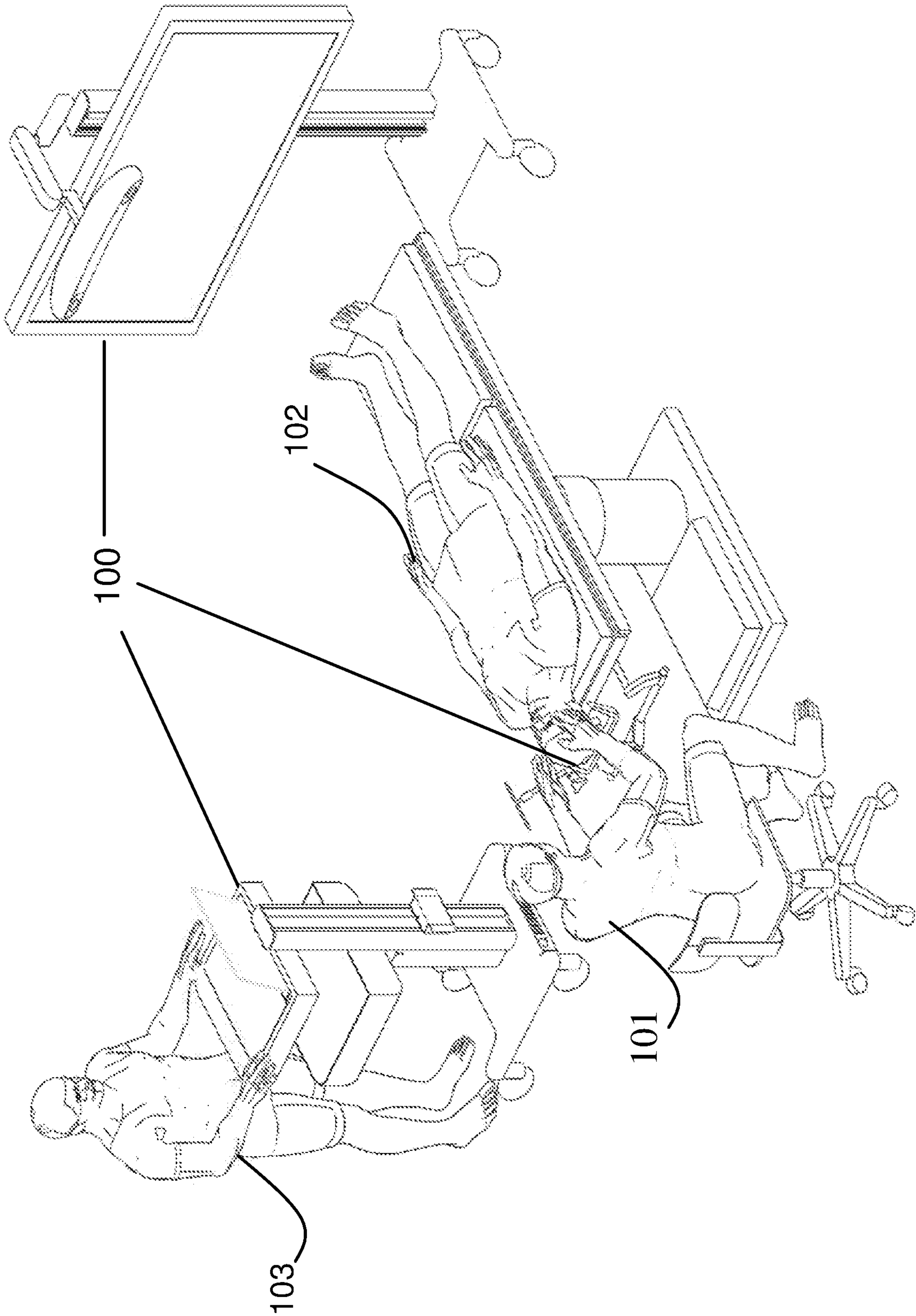


Figure 1

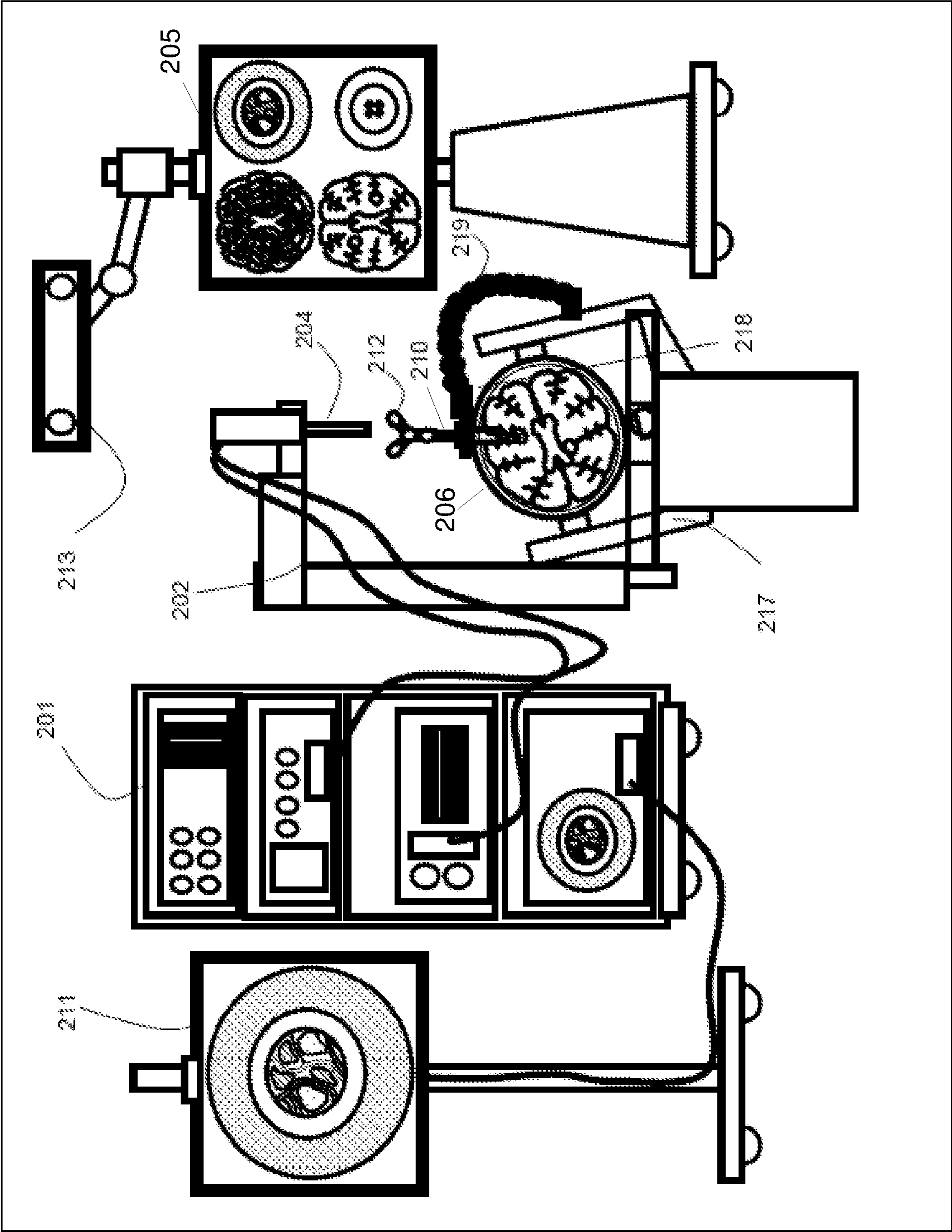
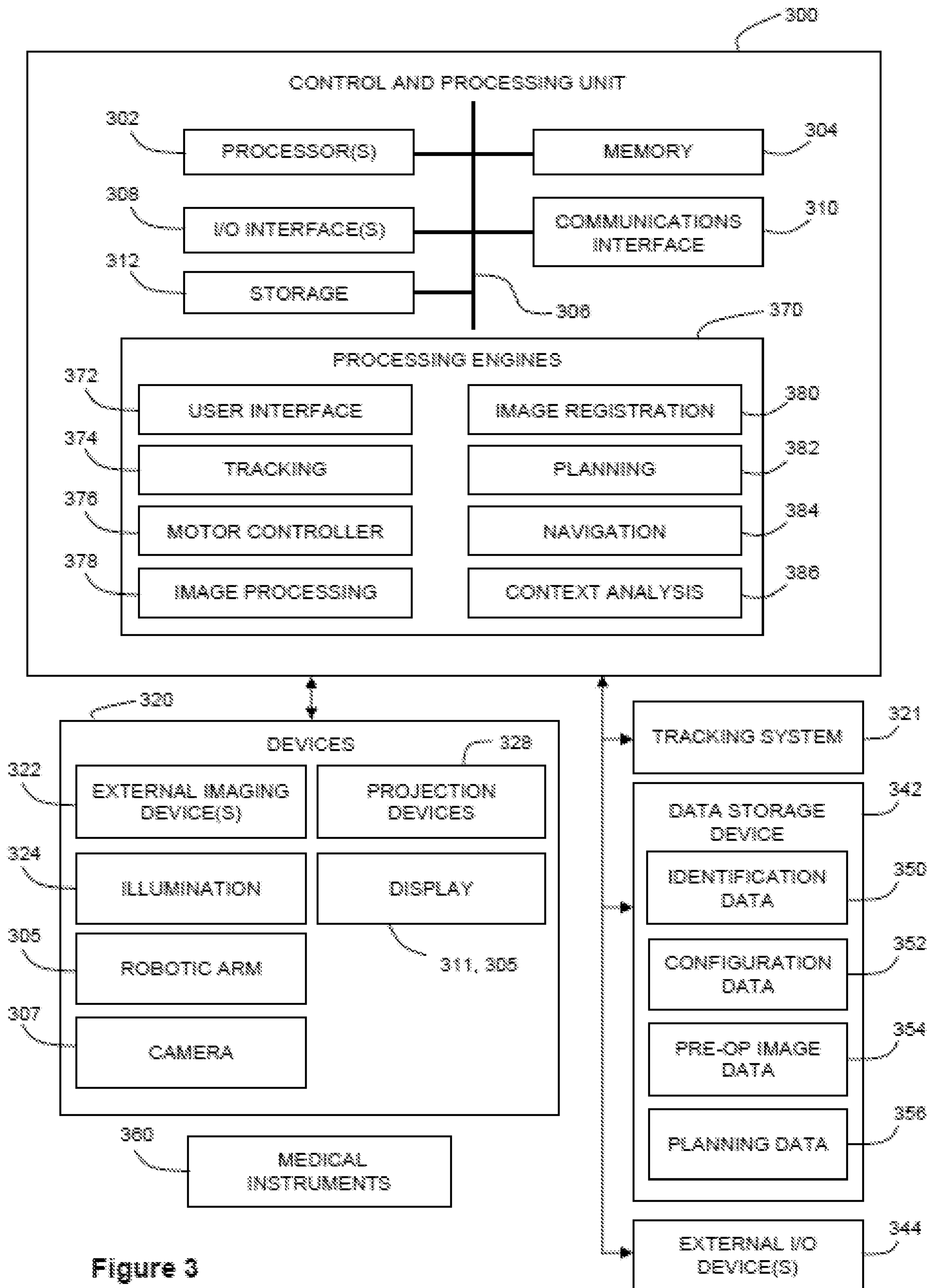


Figure 2

**Figure 3**

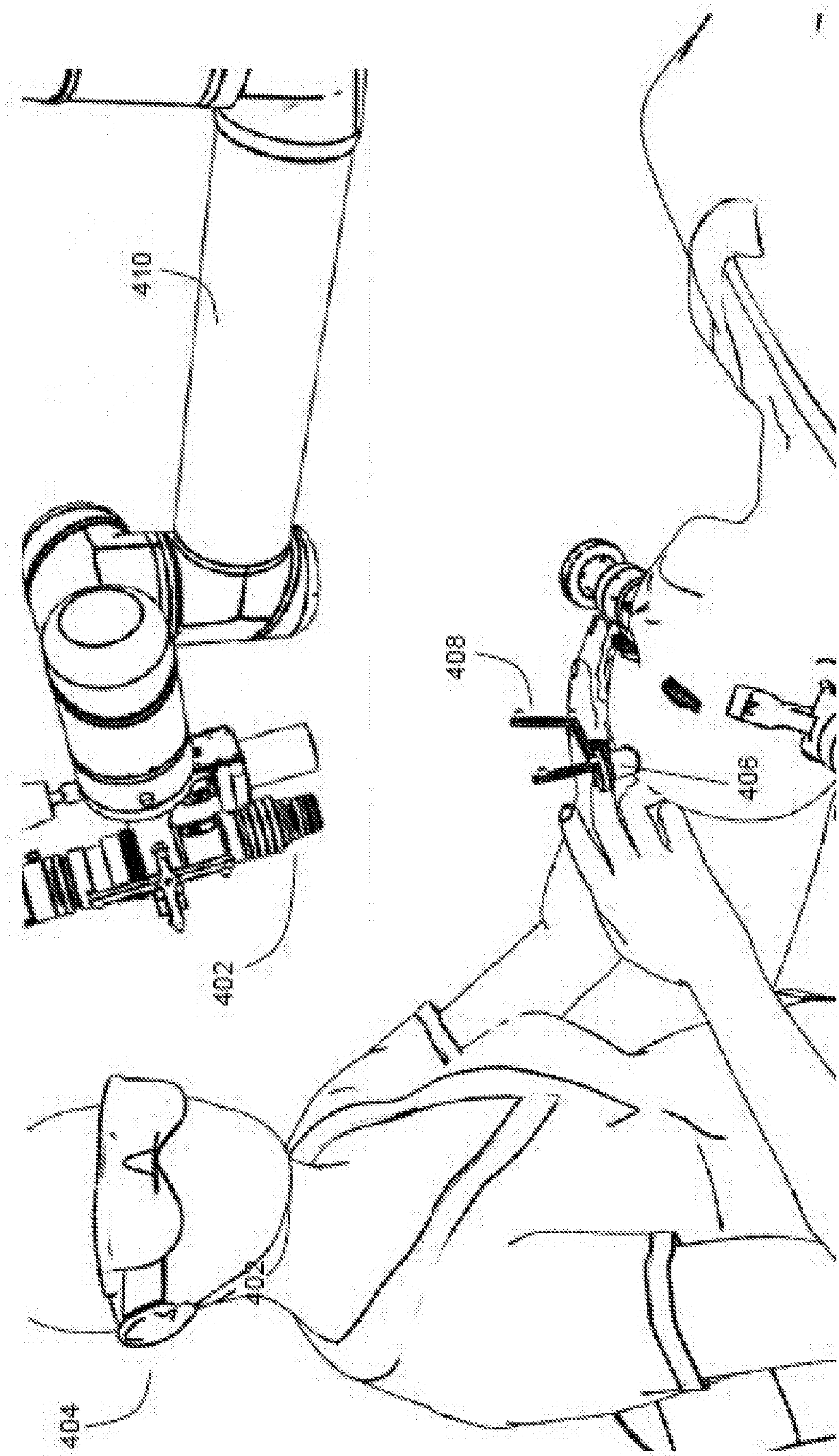


Figure 4

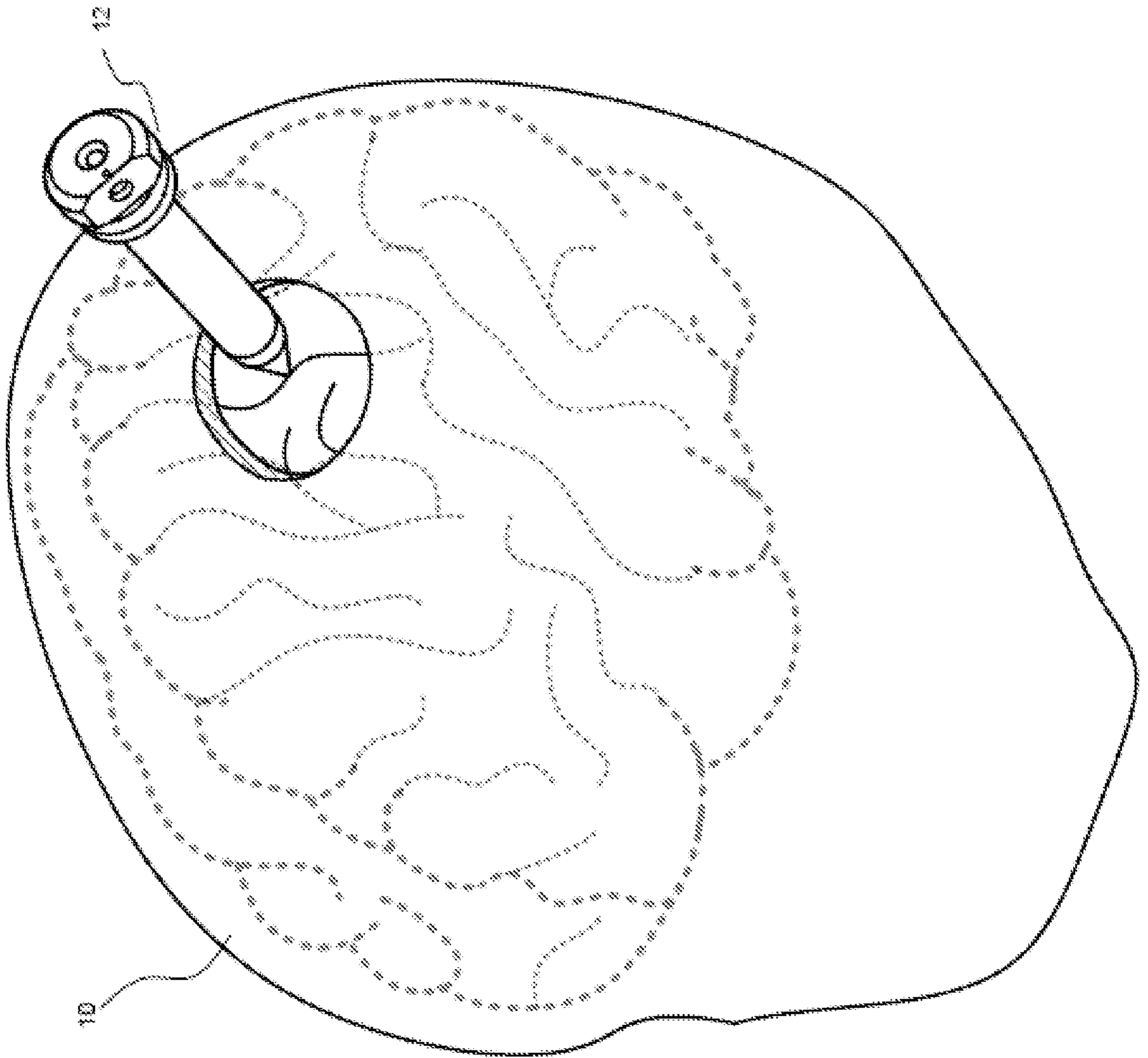


Figure 5

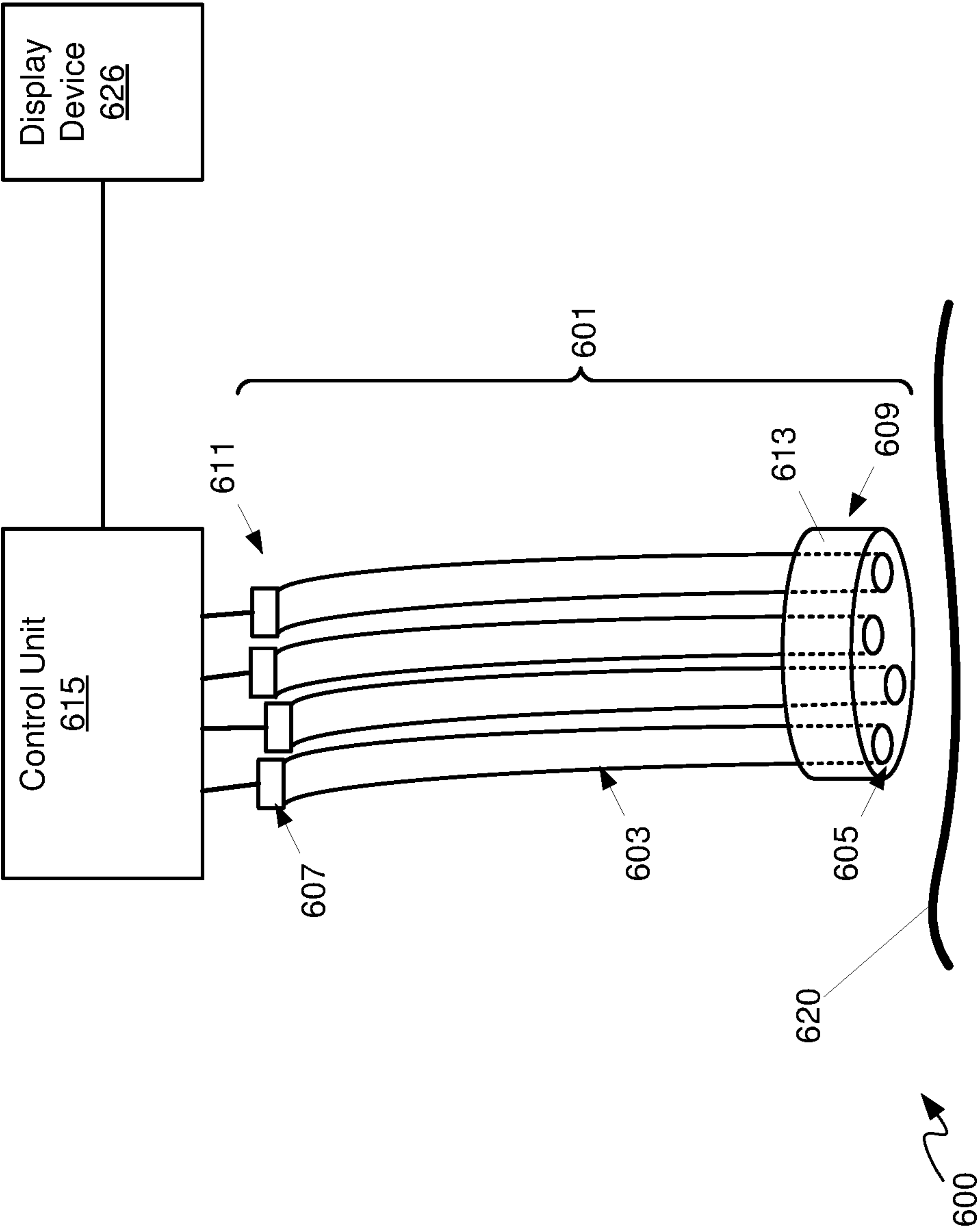


Figure 6

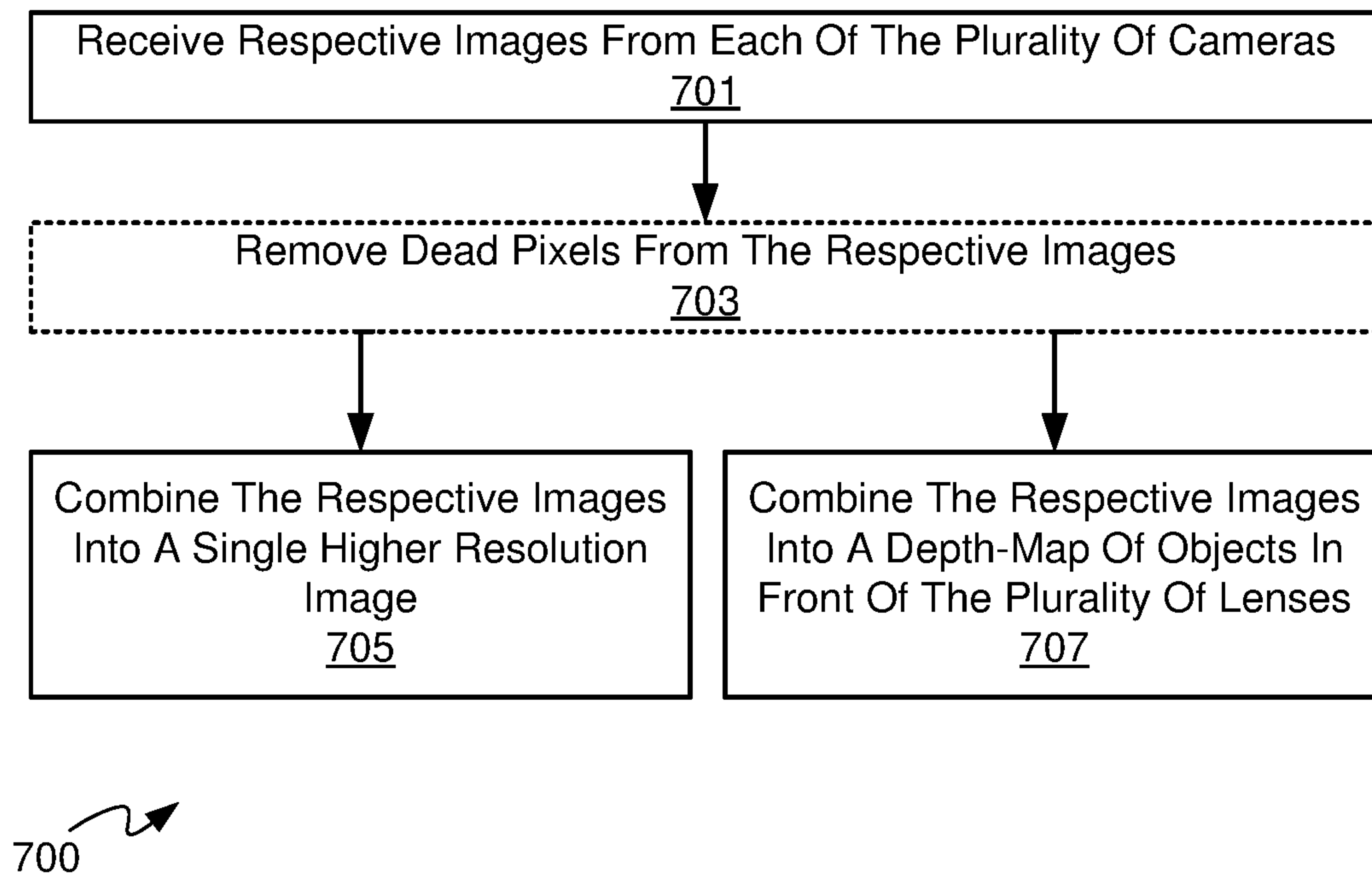


Fig. 7

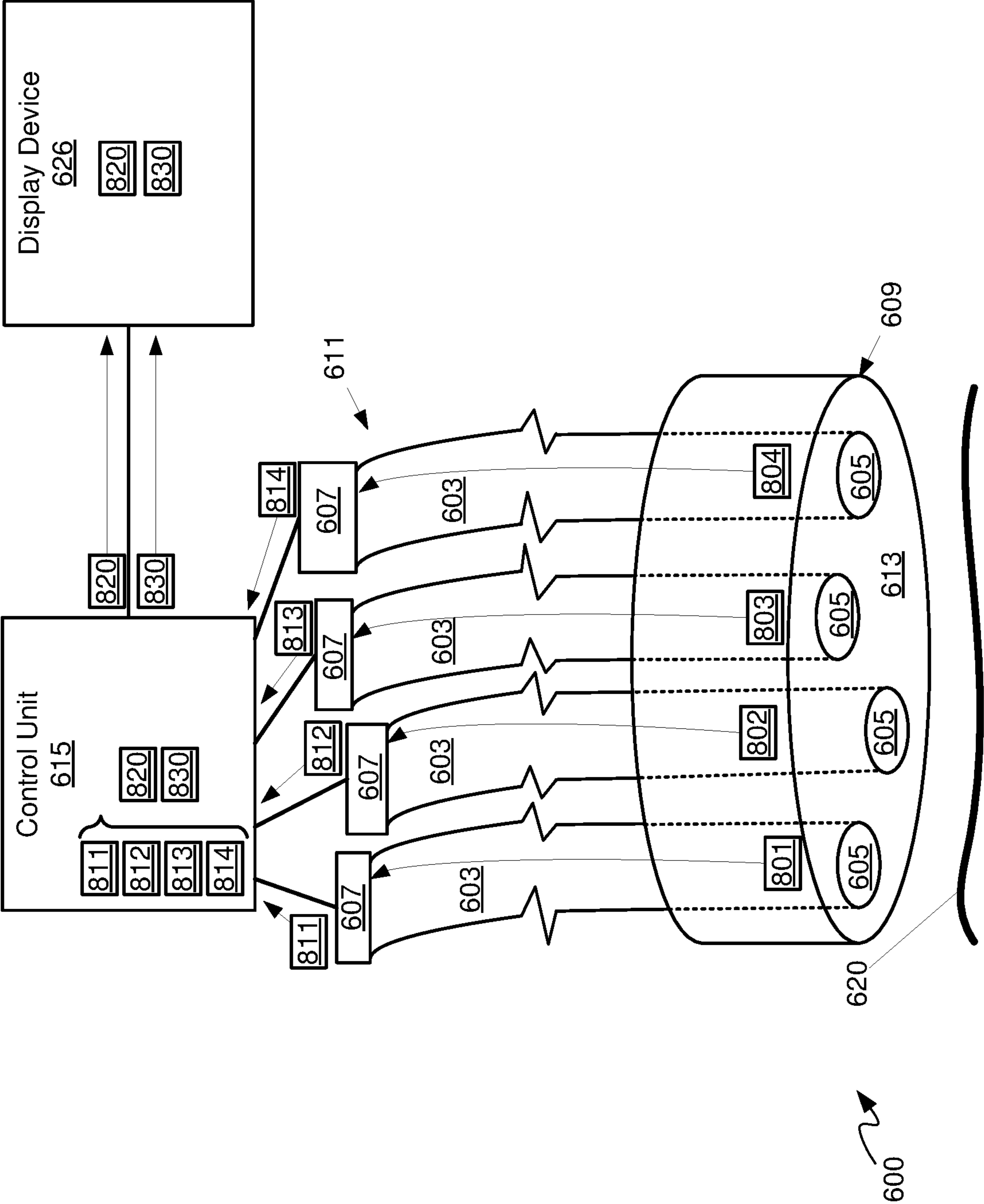


Figure 8

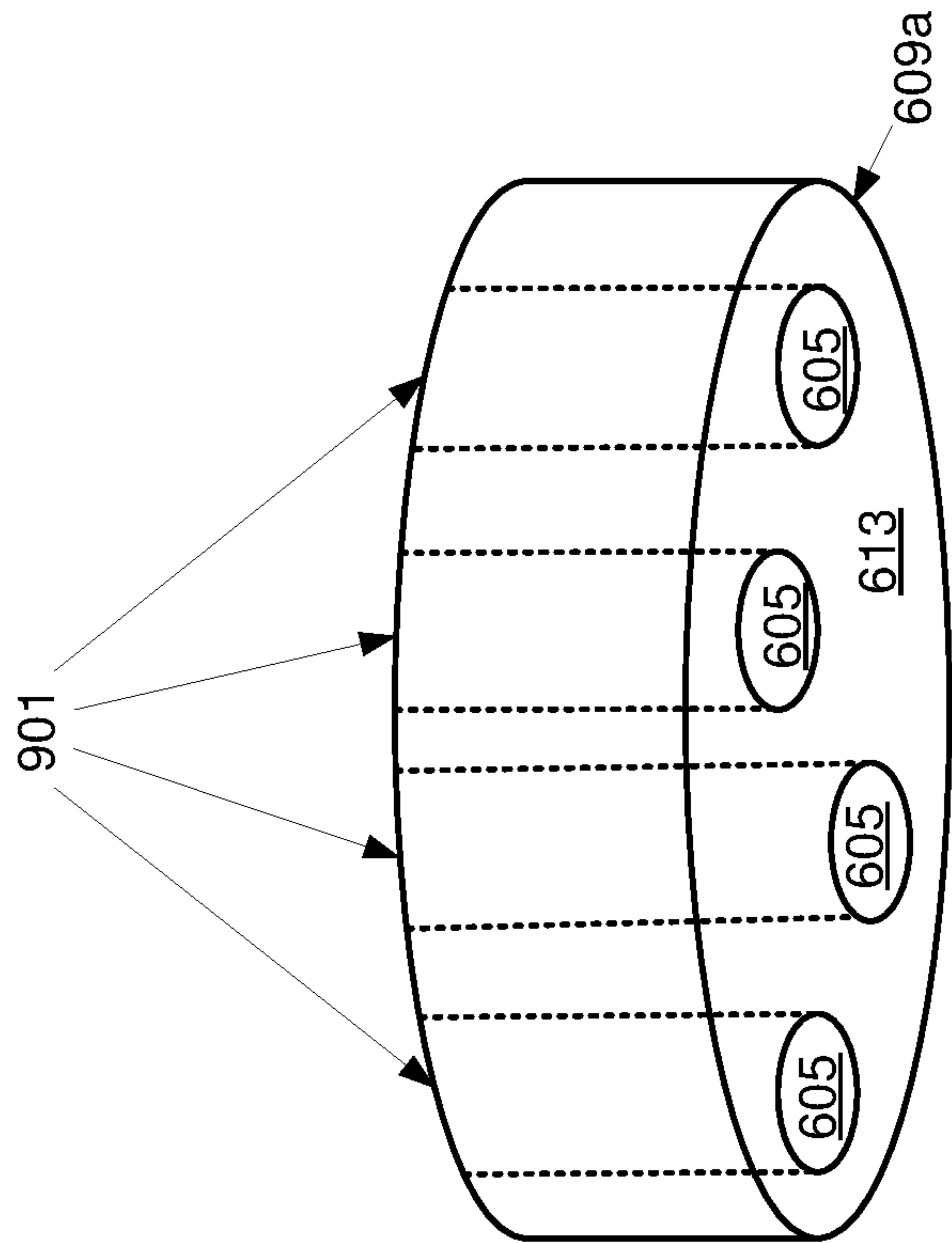


Figure 9

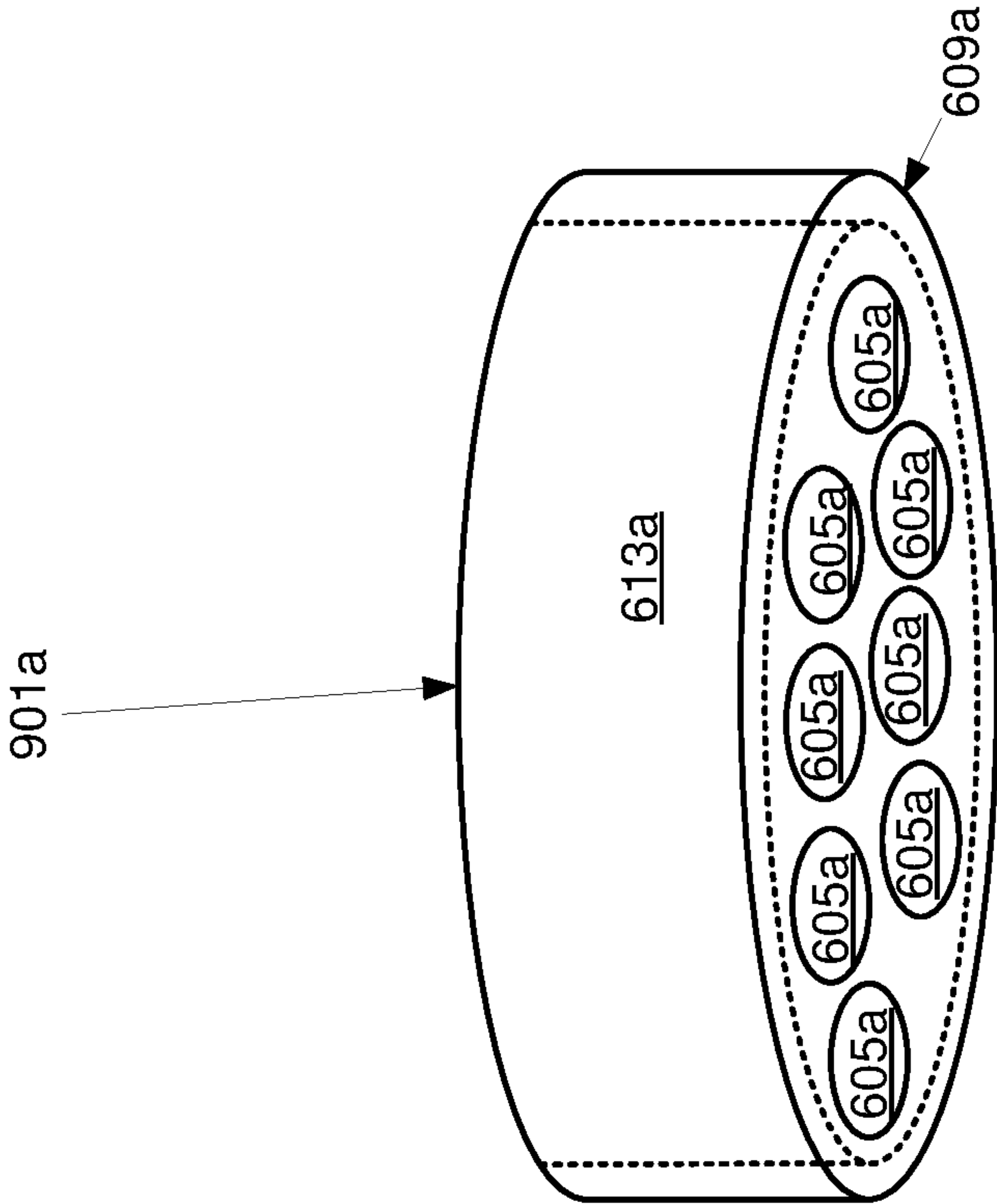


Figure 10

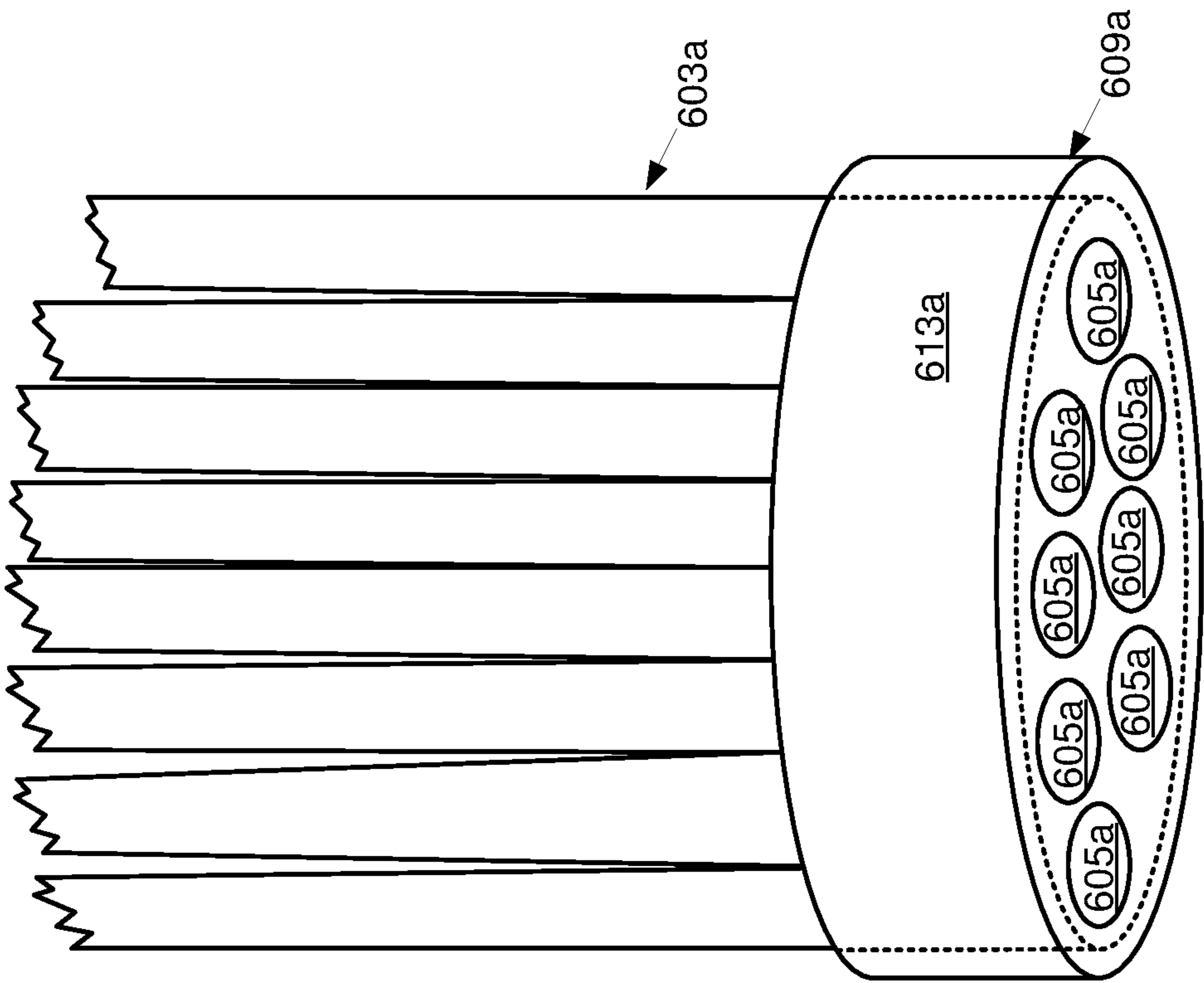


Figure 11

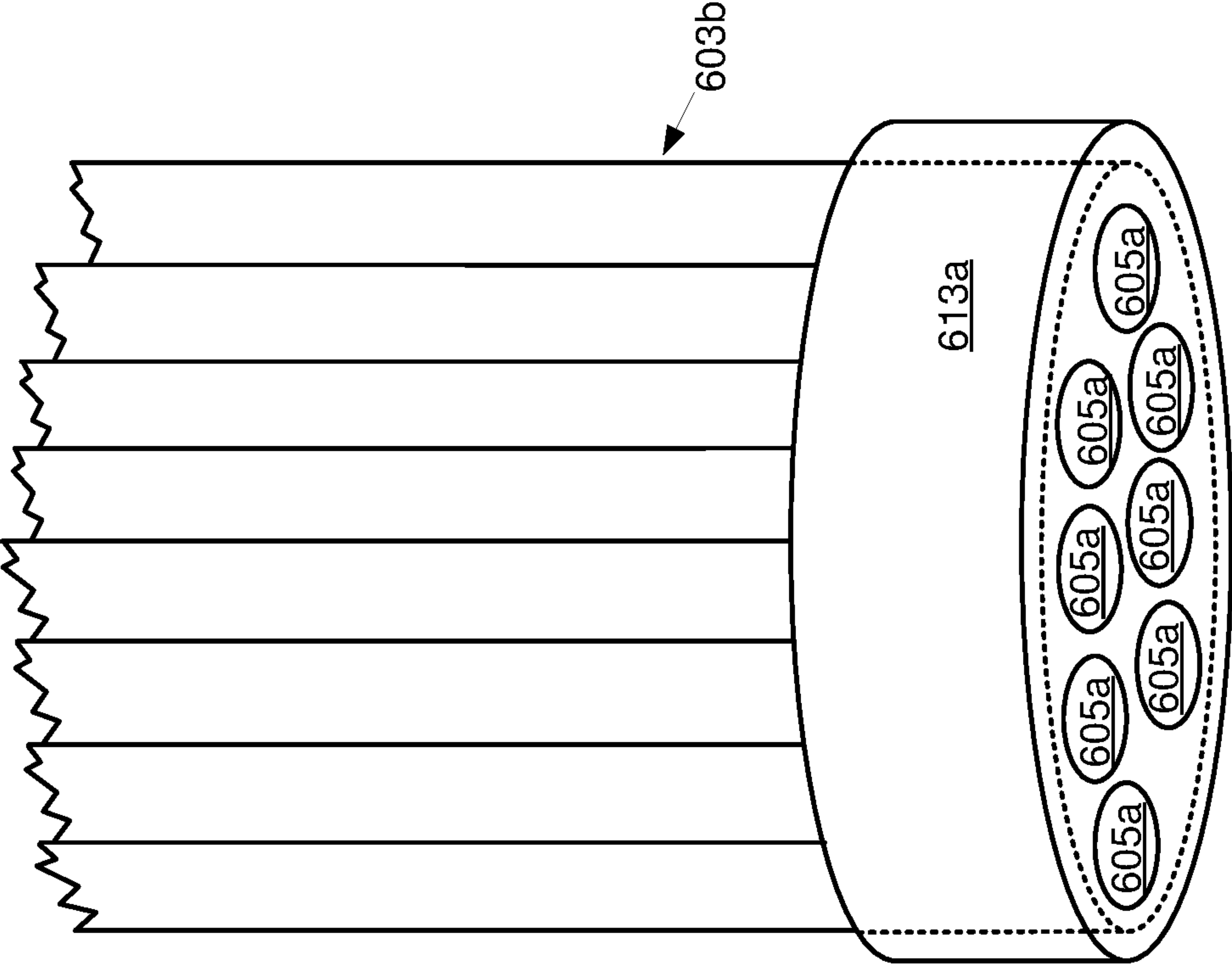


Figure 12

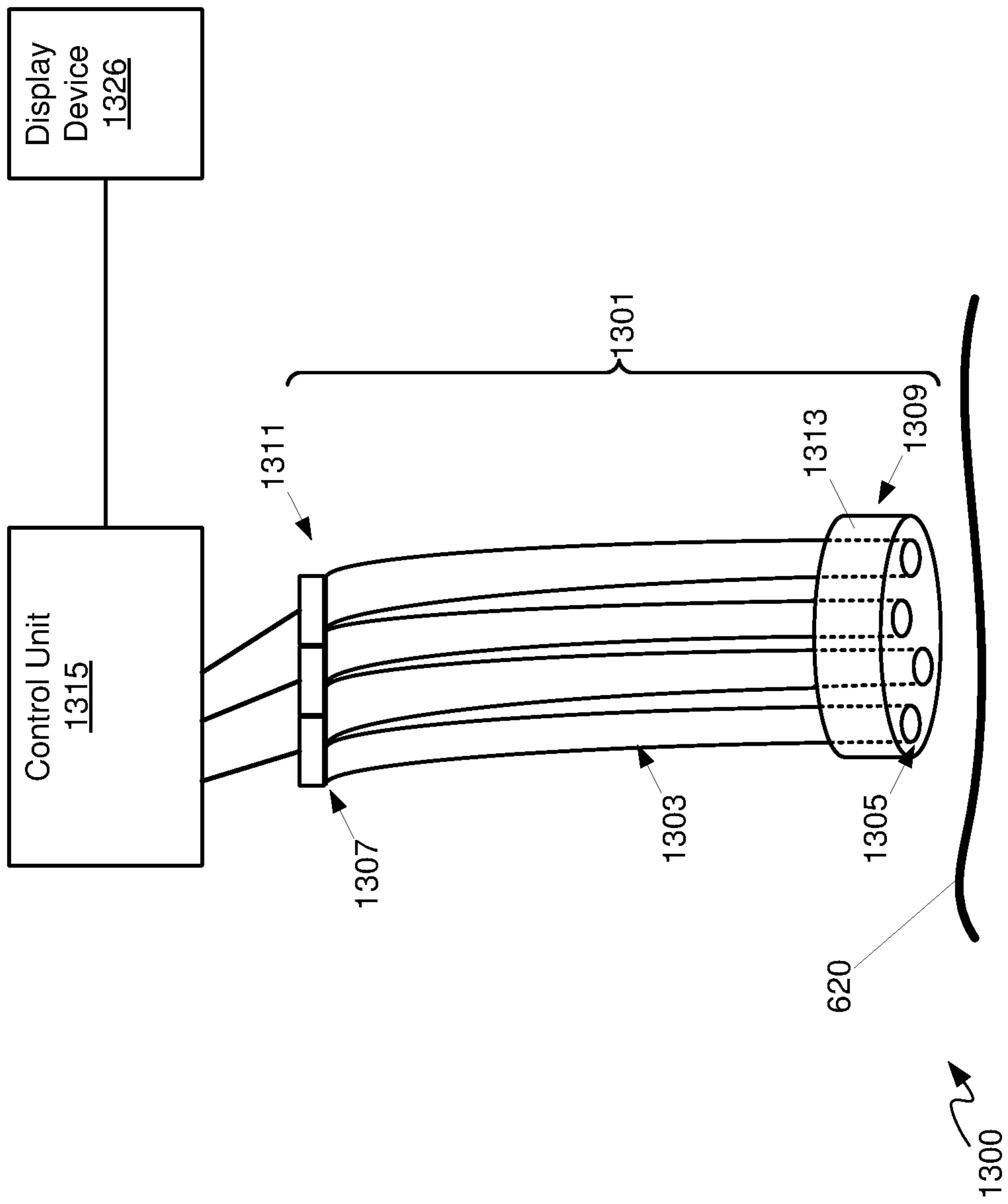


Figure 13

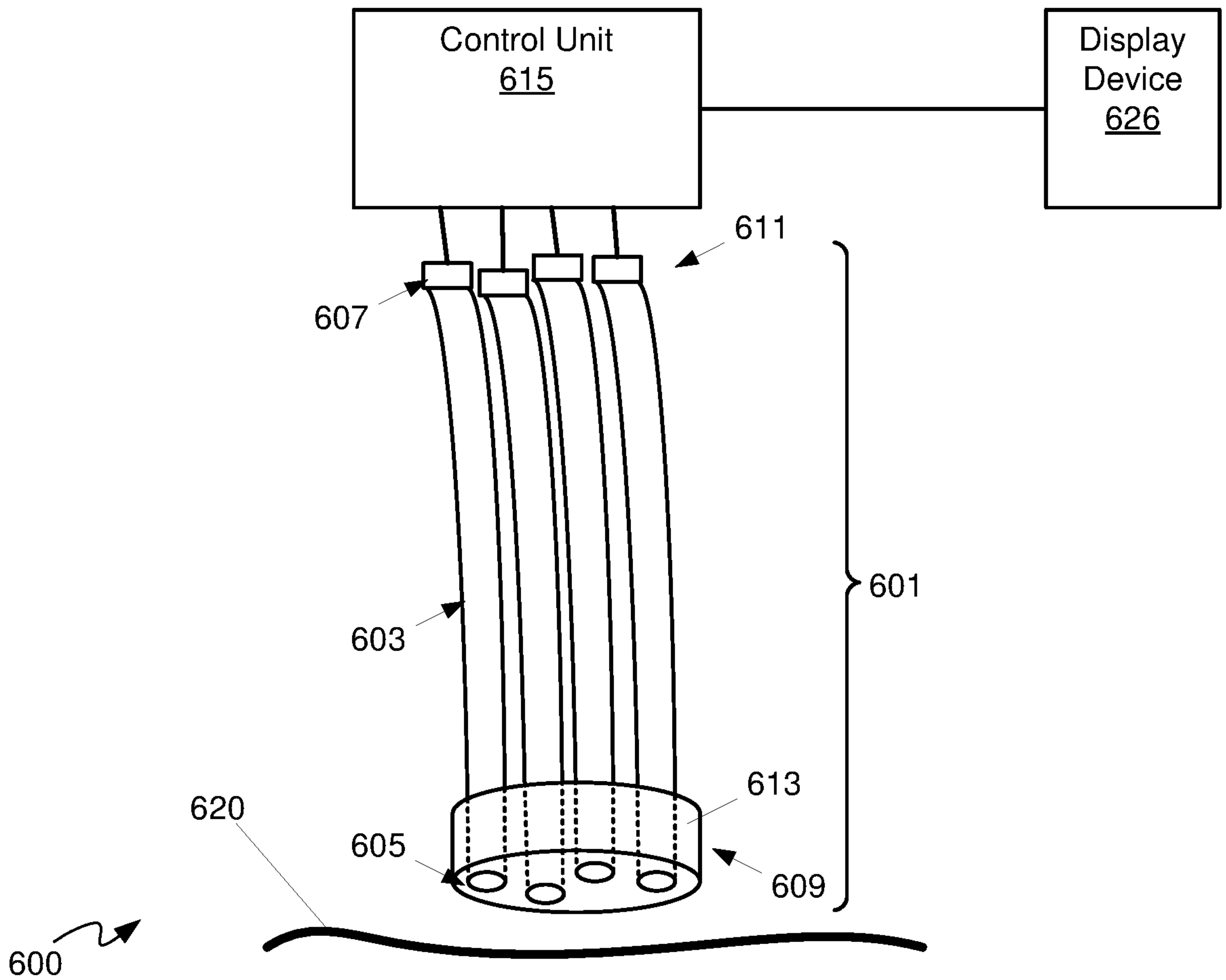


Figure 6