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(54) Title: SYSTEM AND METHOD FOR AUTOMATED ARTIFICIAL VISION GUIDED DISPENSING VISCOUS FLUIDS
FOR CAULKING AND SEALING OPERATIONS

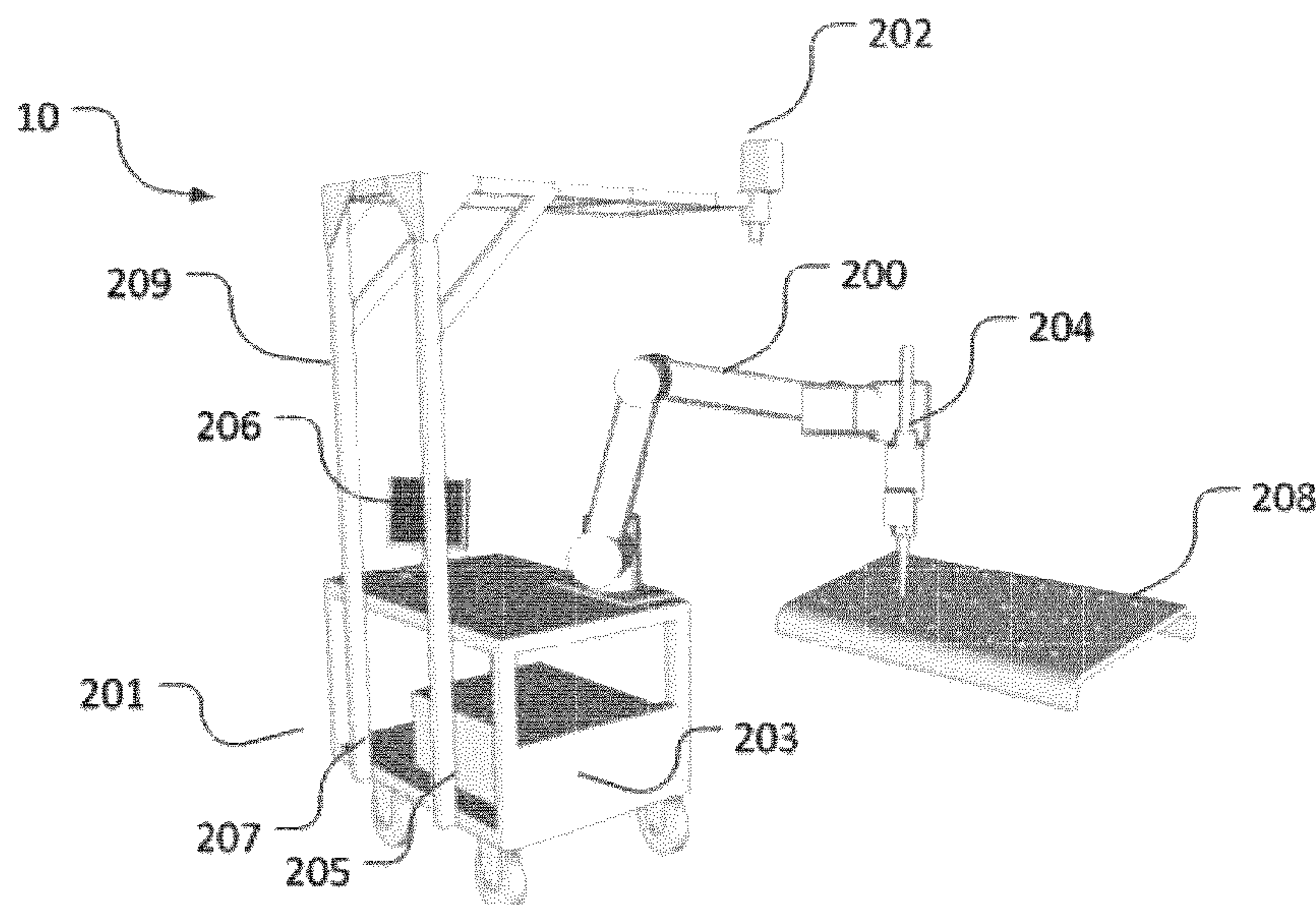


Figure 2

(57) Abrégé/Abstract:

The present disclosure provides a method and system by which a precise amount of a viscous fluid sealing compound can be dispensed at required locations through computer vision-based observation of the fluid deposited, its rate and amount of deposition

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and location; and that the dispensed fluid may be accurately shaped through robotic or other special purpose mechanism motion. The invention enables instant quality inspection of the dispensing process in terms of the locations, amounts and shapes of newly created seals.

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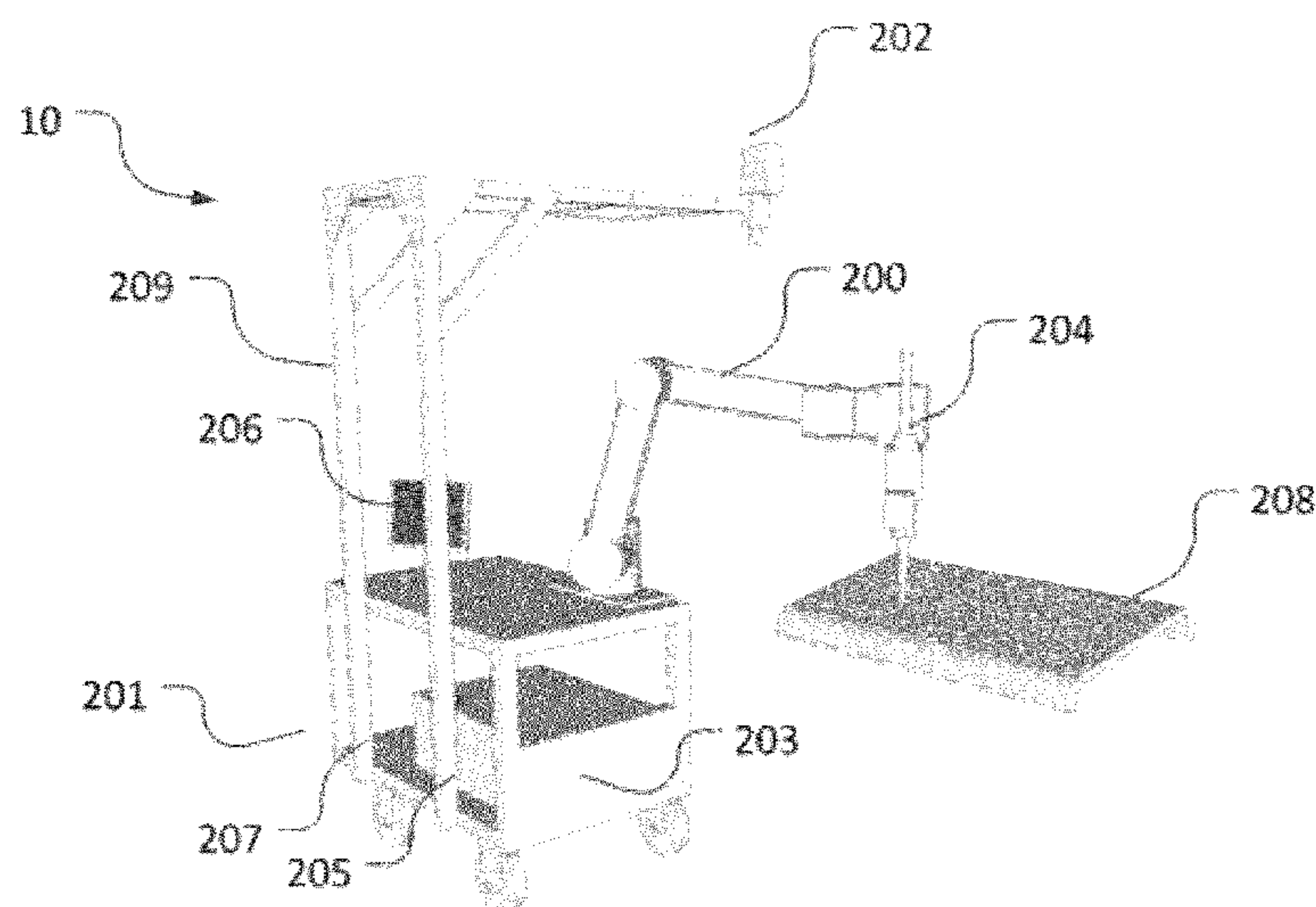


Figure 2

(57) Abstract: The present disclosure provides a method and system by which a precise amount of a viscous fluid sealing compound can be dispensed at required locations through computer vision-based observation of the fluid deposited, its rate and amount of deposition and location; and that the dispensed fluid may be accurately shaped through robotic or other special purpose mechanism motion. The invention enables instant quality inspection of the dispensing process in terms of the locations, amounts and shapes of newly created seals.

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SYSTEM AND METHOD FOR AUTOMATED ARTIFICIAL VISION GUIDED DISPENSING VISCOUS FLUIDS FOR CAULKING AND SEALING OPERATIONS

5

FIELD

This disclosure relates to a method and system for the automated artificial vision-guided dispensing of viscous fluids for performing caulking and sealing operations for sealing around various features such as fasteners or
10 along joints.

BACKGROUND

Large manufactured objects fastened from multiple parts must be frequently fully sealed, for example aircraft wing's interior is used to hold fuel
15 and sealing prevents leakage. In order to accomplish this task the head of each fastener is covered with sealing compound, which is applied as a viscous fluid that hardens. Similarly, seams between parts must also have sealing compound applied at the joins to prevent fuel seepage (so-called fillet seals). The application of such viscous sealing fluid must be done in a precise manner
20 for several reasons including ensuring that a sufficient amount of sealant has been deposited around and/or along a sealed feature to create a reliable seal and to control the shape of the resulting seal to prevent contamination of the contained liquid or providing spaces on the hardened sealing compound in which contaminants can be build up. Furthermore the seal must be sufficiently
25 homogeneous and cohesive that fragments of the dried sealant material do not detach from the seal after deposition. Currently, most aircraft wing sealing is performed manually as this is a complex task that cannot be easily replaced

with robots. Several robotic prototypes have been developed and patents awarded.

United States Patent No. 6,908,642 issued to Hubert discloses a gantry mounted robot equipped with an applicator that can seal spars of a wing section mounted on a rotary positioner. The robot's trajectory is pre-programmed and stored in a controller and can have its path adjusted by comparing images from a camera with images stored in the controller.

United States Patent No. 8,651,046 issued to Davanaces discloses an apparatus for dispensing sealant that incorporates a clamp for stopping sealant flow.

United States Patent No. 9,095,872 issued to Topf discloses an apparatus for dispensing sealant equipped with a variety of sensors for sensing for example temperature and pressure and includes a controller that controls movement of sealant from a storage unit to a dispensing device.

United States Patent Publication No. 2015/0086706 A1 by Guzowski discloses a sealing system with two robots, the first robot is tasked for performing the sealing and the second robot is tasked with resupplying the first robot with fresh sealant cartridges from storage.

United States Patent Publication No. US2015/0314890 discloses method and apparatus for performing an operation on a work surface of a structure and includes a motion platform and an overhead support system with the motion platform being configured to be positioned above the work surface of the structure to perform desired operations on the surface.

SUMMARY

The present disclosure provides a system and method by which a precise amount of a viscous fluid sealing compound can be dispensed at required locations through computer vision-based observation of the fluid deposited, its rate and amount of deposition and location; and that the dispensed fluid may be accurately shaped through robotic or other special purpose mechanism motion. The present system and method enables instant or real-time quality inspection of the dispensing process in terms of the locations, amounts dispensed and shapes of newly created seals.

In an embodiment there is provided a real-time computer implemented method for automated part sealing, comprising:

acquiring real-time visual images of one or more parts to be sealed;

detecting at least one feature associated with a part to be sealed;

computing a position and orientation of the at least one feature relative to

a dispensing device mounted to a robotic arm;

moving the robotic arm to position the dispensing system in a preselected location and orientation with respect to the at least one feature; and

controlling an amount of sealant being dispensed based on real-time processing of the visual images of the sealant being dispensed which are acquired during dispensing of the sealant to produce a seal.

The present disclosure provides a vision guided dispensing system for sealing one or more parts, comprising:

a housing having a dispensing device mounted to said housing, said dispensing device having a dispensing nozzle;

a vision sensor mounted on said housing; and

a vision processor interfaced with said dispensing device and said vision sensor, said vision processor being programmed with instructions for real-time processing of images of the one or more parts being sealed and said dispensing nozzle and to determine a position said dispensing nozzle needs to be positioned with respect to said feature prior to dispensing sealant, said vision processor being programmed to acquire images of said dispensing nozzle while a sealant is being dispensed by said dispensing device, said vision processor being programmed with instructions to determine, from said real-time processed images, whether or not sufficient sealant has been dispensed and to control the dispensing device when to initiate, and stop dispensing of sealant.

The quality of the seal may be assessed by acquiring and analyzing images before and after the seal is applied, and determining whether the seal is placed at a preferred location with respect to the feature and has a desired shape and size.

The vision sensor may include one or more 2D cameras.

Alternatively, the vision sensor may include one or more 2D camera and one or more rangefinders.

The vision sensor may be mounted to observe a tip of the dispenser nozzle, feature being sealed or both of them and a surface of the part close to the nozzle which is being sealed.

The vision sensor may include one or more stereo cameras.

The vision sensor may include one or more 3D cameras.

The vision sensor may include one or more 2D cameras and one or more structured light projectors.

The present disclosure also provides a sealing system for automated artificial vision-guided dispensing of viscous fluids for caulking and sealing operations around various features on a part, comprising:

5 a mobile platform for gross positioning of said system relative to said part containing said features;

a dispensing device for applying sealant to said feature;

a positioning device mounted on said mobile platform to which said dispensing device is attached for positioning the dispensing device relative to said feature;

10 a sensing device for determining the position of the mobile platform relative to said part;

a second sensing device for determining the position of said feature on said part with respect to the dispensing device and also determining the required amount of sealant to be dispensed based on visual images of the sealant being dispensed; and

15

a controller for controlling said positioning device and said dispensing device based on feedback from said second sensing device.

A further understanding of the functional and advantageous aspects of the disclosure can be realized by reference to the following detailed description and drawings.

20

BRIEF DESCRIPTION OF THE DRAWINGS

Embodiments will now be described, by way of example only, with reference to the drawings, in which:

Figure 1 shows a picture of the aircraft assembly technicians performing the caulking and sealing operation manually.

Figure 2 shows a robotic sealing system mounted on a mobile platform (a push cart is shown).

5 **Figure 3A** shows an embodiment of the dispensing system disclosed herein mounted on a robotic end-effector.

Figure 3B shows an alternative embodiment of the dispensing system

Figure 4 shows a sealant dispensing device, which forms a part of the present dispensing system.

10 **Figure 5** shows a flow diagram showing the steps involved in the dispensing operations using the method and system disclosed herein.

Figure 6 shows a flow diagram showing the steps involved in the offline and online calibration processes used in the method and system forming part of the present invention

15 **Figure 7** pictorially shows how the location of a fastener is computed.

Figure 8 pictorially shows how 2D inspection of a dome is performed

Figure 9 shows how 3D inspection of a dome is performed.

Figure 10 shows an alternative design of the present dispensing system from Figure 3 with a single camera and two laser projectors.

20 **Figure 11** shows an alternative embodiment of the present dispensing device with continuous mixing of two part compounds.

Figure 12 shows an alternative embodiment of the dispensing system from Figure 3 that uses three (3) linear motors

25 **Figure 13** shows an alternative embodiment of the dispensing system from **Figure 3** with flexible tubing.

Figure 14 shows an extension of the present embodiment of the sealing system with a pattern projector.

Figure 15 shows an alternative embodiment of the dispenser shown in Figure 3 with a rotating needle to remove any air bubbles from the sealant

5 **Figure 16** shows a collaborative workcell with a robot and worker working alongside

Figure 17 shows a swirl pattern executed at the end of dome sealing.

Figure 18 shows a sealing of fillet joints using the system disclosed herein.

10 **Figure 19** shows worksites reachable from one location.

Figure 20 shows an alternative embodiment of the robotic arm mounted on a mobile gantry.

Figure 21 shows an alternative embodiment of a robotic arm suspended from a mobile gantry system.

15 **Figure 22** shows an alternative embodiment of a robotic arm suspended from a fixed gantry system.

DETAILED DESCRIPTION

Various embodiments and aspects of the disclosure will be described
20 with reference to details discussed below. The following description and drawings are illustrative of the disclosure and are not to be construed as limiting the disclosure. The drawings are not necessarily to scale. Numerous specific details are described to provide a thorough understanding of various embodiments of the present disclosure. However, in certain instances, well-

known or conventional details are not described in order to provide a concise discussion of embodiments of the present disclosure.

As used herein, the terms, “comprises” and “comprising” are to be construed as being inclusive and open ended, and not exclusive. Specifically, when used in this specification including claims, the terms, “comprises” and “comprising” and variations thereof mean the specified features, steps or components are included. These terms are not to be interpreted to exclude the presence of other features, steps or components.

As used herein, the term “exemplary” means “serving as an example, instance, or illustration,” and should not be construed as preferred or advantageous over other configurations disclosed herein.

As used herein, the terms “about” and “approximately”, when used in conjunction with ranges of dimensions of particles, compositions of mixtures or other physical properties or characteristics, are meant to cover slight variations that may exist in the upper and lower limits of the ranges of dimensions so as to not exclude embodiments where on average most of the dimensions are satisfied but where statistically dimensions may exist outside this region. It is not the intention to exclude embodiments such as these from the present disclosure.

Fasteners are often sealed by creating a dome shaped deposition of the sealing compound. This is typical for rivets, as for such low profile fasteners, the dome shape provides the minimum amount of compound, while ensuring required thickness. Other fasteners, such as hi-loks and bolts, are taller and a truncated conical shape or cone provides the minimum amount of sealant, while ensuring required thickness. In the description below the term dome sealing

should be understood to include other shapes of deposited sealing compound including conical.

While the present computer controlled sealing method and system is illustrated and described below with specific reference to aircraft wings, it will be appreciated that the system and method disclosed herein may be used for other manufacturing endeavours.

Referring to **Figure 1**, there is shown a current manual sealing process. Worker **100** is applying a bead of seal on joints and worker **101** is applying a sealant dome on fasteners respectively, both on the wing section **102** using hand held dispensing devices **103** and **104** respectively. As can be appreciated this prior art technique is very labor intensive and prone to producing seals which may not be the most robust, as the workers tire during a shift.

An embodiment of the present computer implemented sealing system **10** is shown in **Figure 2**. A positioning device which is a robotic manipulator or robotic arm **200** (hereinafter robotic arm) is mounted on a mobile platform **201** with wheels as shown in **Figure 2**, or a wheeled gantry setup shown in **Figures 20** and **21** or a fixed platform along which the robotic arm **200** can move shown **Figure 22**. The platforms of **Figures 20** to **22** will be described hereinafter. The robotic arm **200** may be a 6-DOF serial link robotic arm as shown in the **Figure 2** or a robotic arm with a different topology (e.g. parallel link robotic arm) or with a different number of degrees of freedom as long as it can position a tool in three (3) translational and three (3) rotational degrees of freedom at the tip of robotic arm **200**.

The mobile platform **201** may be a manually operated push cart as shown in the **Figure 2**, a motorized platform or a semi or fully autonomous

vehicle. Its purpose is to provide gross positioning of said system relative to the part containing the features that are to be sealed. It may also be a platform which runs along a motorized linear stage as in **Figures 20, 21 or 22**. An overhead camera **202** is mounted on a frame **209** attached to the platform **201** and observes a part **208** to be sealed. The camera **202** is interfaced with a vision processor **203**. Overhead camera **202** may be considered a global vision sensor. Attached to robotic arm **200** is a dispensing system **204** for dispensing sealant on the joints or any other item to be sealed. A robot controller **205** is interfaced with the vision processor **203**, the robotic arm **200** and the dispensing system **204**. A touch-screen monitor **206** with the user interface is interfaced with the vision processor **203** is used by an operator to observe the system status and to command actions. An uninterruptible power supply or a battery **207** is mounted on the platform **201** to provide power to the system while moving between work sites.

The expression “vision system” refers to cameras **202, 302**, rangefinder **301** interconnected with vision processor **203**.

Both the vision processor **203** and the robotic arm controller **205** may be known microprocessors or computers which are configured to communicate with each other, the vision processor **203** being programmed with instructions or algorithms to analyze the real-time images from sensors **202** and **302**, and any other additional sensors that may be included in various embodiments, and based on the analysis of these images, is further programmed with instructions or algorithms to instruct the robotic arm controller **205** to position the robotic arm **200** in pre-selected locations with the at least one feature to be sealed. Once the robotic arm **200** is positioned in the pre-selected location, the vision

processor **203** (and/or the robotic arm controller) are programmed to activate the dispensing system **204** to dispense the sealant, and based on images acquired real-time during dispensing of the sealant, cease dispensing the sealant once it is determined that sufficient sealant has been dispensed.

5 Alternatively, it will be appreciated by those skilled in the art that a single processor interfaced with both the cameras/optical sensors and the robotic arm may be used. This microprocessor or computer would be programmed with all the algorithms required for analyzing the images from the sensors and all the algorithms needed to control robotic arm **200**.

10 The dispensing system **204** is shown in detail in **Figure 3A** and is comprised of a dispensing device **300**, a structured light rangefinder **301** and an observation camera **302** with lights **303**. The rangefinder **301** projects a plane of light **304** on the section **305** of part **208** forming a light pattern **306** that is observed by a second camera (not shown) in the rangefinder **301** enabling
15 computation in vision processor **203** of the three-dimensional distance to the light pattern on the part. In the embodiment shown in **Figure 3a** the plane of light **304** is roughly paralleled to the longitudinal axis of the nozzle **307** and is placed in front of the nozzle **307**. This has some advantages as the range is measured ahead of the nozzle **307** when creating a fillet seam; however, there
20 is a disadvantage caused by the fact that the distance is measured with a certain parallax and not at the location where nozzle **307** is closest to the part. Re-orienting the plane of light **304** or rotating the rangefinder **301** will bring the plane of light **304** closer to the nozzle **307** thus reducing the parallax. The observation camera **302** observes the tip of the nozzle **307** of the dispensing

device **300** and a portion of the part **208** to be sealed which is shown at **305** in **Figure 3a** and **3b**.

The camera **302** is used to perform two tasks: 1) monitor and control the amount of dispensed sealant from the nozzle **307** as described below, and 2) to
5 detect features to be sealed and provide input to the robotic controller **205** to instruct the robotic arm **200** to position the nozzle **307** at the preferred location for dispensing. Using one camera **302** for both tasks has an advantage as less hardware is required; however, this camera **302** has a reduced field of view due to the presence of the nozzle **307**. In order to detect the next feature it might be
10 necessary to move the dispensing system **204** to a location with unobstructed view, thus increasing the operation time.

An exterior three dimensional marker system **308a**, **308b**, **308c** and **308d** may be attached to the dispensing system **204** to provide an alternative means of locating the dispensing system **204** with respect to the part via means
15 of an external camera system.

In some instances it would be advantageous to augment an existing robotic workcell with a dispensing capability. This would take the form of the dispensing system **204** shown in **Figure 3a** and also the vision processor **203** which is shown in **Figure 2**, but not shown **Figure 3a**. The vision processor
20 **203** may also be built into the dispensing system **204** to form a single intelligent add-on unit. More particularly, the combination of the dispensing system **204** with the vision processor **203** forms a vision guided dispensing system, or smart dispensing system, which may be retrofitted to existing robotic arms. The vision processor **203** is programmed with algorithms for analyzing
25 the amount of sealant dispensed as well as the final shape of the produced

seal. The dispensing system **204** may contain a metering device which tracks and records the amount of sealant dispensed, and this recorded amount of sealant dispensed in conjunction with the shape of the seal gives a comprehensive record of each produced seal.

5 The dispensing system **204** may be coupled with the robotic arm **200** tip either directly through a bolted interface at **311** or a force moment sensor **309** may be attached between them. The force sensor **309** enables detecting contact forces between the nozzle **307** and sealed parts. Advance/retract buttons **310** activate manual advancement or retracting of the plunger **405**
10 (forming part of dispensing device **300** shown in **Figure 4**) and lights indicating status may be integrated with the dispensing system **204**. Alternatively, the force sensor can be integrated into the structure of the dispensing device **300**. An alternative method of determining contact is by measuring torque increases in the robot arm **200** joints. This can be achieved through measuring torque at
15 the output of each manipulator joint in the robotic arm **200** with explicit torque transducers, or by measuring the current of the motor in each of the robot arm **200** joints.

 An alternative embodiment of the dispensing system **204**, which eliminates the need for additional robotic arm motions, is shown at **204'** in
20 **Figure 3b**. Dispensing system **204'** is similar to system **204** but includes an additional third camera **312** with a light **313** that is positioned to observe features in front of the nozzle **307** and without occlusions. This arrangement has an advantage over the dispensing system **204** in **Figure 3a** as it is not required to move the dispensing system to capture an unobstructed image of
25 the next feature leading to faster system operation.

The dispensing device **300** with a motor driven lead-screw assembly is shown in cross-section in **Figure 4**. Dispensing device **300** includes a cartridge **400** which is inserted into a cartridge holder **401** and a nozzle **307** is then attached to cartridge **400**. The cartridge **400** is locked in place with a cap **410** with a twist-lock system. The cap **410** is attached to a motor **403**, which drives a lead-screw **404** with an attached plunger **405** that enters the cartridge **400**. As the plunger **405** moves down the sealant liquid is pushed out through the nozzle **307**. A casing **406** of the motor **403** is attached to cap **410** and arrests rotational motion through an attached pin **407**. The pin **407** triggers sensors at the top **408** and bottom **409** of plunger motion travel. The motor **403** with the lead-screw **404** is attached to the cap **410**. The motor **403** may be a stepper motor driving the lead screw **404** directly or a servo motor coupled to the lead screw **404** through a gear box.

The nozzle **307** may be straight or bent to enable easy access to apply the sealant in difficult to access locations; and have a circular, oval or rectangular tip opening. The tip diameter may be expanded by attaching a cup **411** to the dispensing end of nozzle **307** to shape the sealant for deposition on the sealed part if required.

DOMES SEALING

A work flow diagram showing the steps involved in the dispensing operations for application of domes of sealant on fasteners using the method and system forming part of the present invention is shown in **Figure 5** with each step further described in detail below. Additional explanations for more complex steps are provided in sections below. The operation below is discussed with

respect to dispensing system **204** but it will be appreciated that dispensing system **204'** will function in essentially the same way.

1. The operator starts the computer implemented sealing system **10** and loads data files pertaining to the part of interest that will have fluid dispensed on it.
2. The operator opens the cartridge holder **401** mounted in the dispensing system **204** and replaces a cartridge **400** of the viscous fluid to be dispensed.
3. The operator attaches nozzle **307** to viscous fluid cartridge **400** and closes the cartridge holder **401** with a twist-lock system **410**.
4. The operator may perform calibration using a calibration target and prime the nozzle **307** manually or the operator may initiate an automatic process and the system performs these operations automatically. Detailed descriptions are provided below.
5. The operator pushes the cart **201** to near the worksite while the vision system uses overhead camera **202** to look for the first worksite of the sealed part. The vision system alerts the operator when the platform **201** is near enough to ideal location to begin work. Details are provided below.
6. The operator confirms location using the touch-screen **206** and initiates sealing operation.
7. The robot controller **205** commands the robotic arm **200** to move the dispensing system **204** near to the first fastener.
8. The vision system in conjunction with overhead camera **202** scans the surface with rangefinder **301** and determines distance to the part **208** along the projected line **306** as seen in **Figure 3a**. Details are provided below.

9. The robot controller **205** commands the robotic arm **200** to rotate approximately about optical axis of rangefinder **301** and/or translates it.

10. The vision system scans surface of part **208** a second time and determines distance to the part **208** along the projected line **306**. Details are
5 provided below.

11. The vision system determines a plane of best fit and based on this information the robot controller **205** commands the robotic arm **200** to adjust the dispensing system longitudinal axis to be locally normal to the surface of part **208**. This computation may rely on calculating the cross product of the step 9
10 and 11, which is the surface normal of the plane that the fastener is located on.

12. The vision system uses dispensing system camera **302** to find location of fastener with respect to the camera **302**. Details are provided below.

13. The vision system uses the rangefinder **301** to find the depth of the fastener with respect to the nozzle **307**. The vision system uses camera **302** to
15 capture a reference image of the fastener to be sealed. Details are provided below.

14. The vision system uses combined rangefinder **301** and camera **302** data to find the location of the fastener in three (3) translational dimensions with respect to the dispensing system **204**.

20 15. The robot controller **205** commands the robotic arm **200** to move the dispensing system **204** over the fastener. The robotic arm force control is activated to limit the force in case of unwanted contact with the sealed part **102**.

16. The vision system commands the dispensing device **300** to dispense a suitable amount of fluid by actuating the motor driven lead-screw **404**. Details
25 are provided below.

17. The vision system commands the dispensing device **300** to stop motion and retract the plunger **405** when a sufficiently large amount of fluid is detected. This detection can be accomplished via measurement of the fluid blob diameter.

5 18. The robot controller **205** commands the robotic arm **200** to move the tip **411** of the nozzle **307** in such a way that the viscous fluid is laid into its desired final shape prior to fluid hardening. Typically a swirl (a 3D helix-like motion) is executed to ensure that remaining sealant is deposited on the dome without contaminating the part, see **Figure 17**).

10 19. The robot controller **205** commands the robotic arm **200** to move dispensing system **204** back to position mentioned in step 13 and performs an inspection by recording a comparison 2D or 3D image. Detailed description is provided below.

15 20. The robot controller **205** commands the robotic arm **200** to move the dispensing system **204** to a low hover position over the next fastener location based on pre-planned data files and positions of the recently detected fasteners.

21. Steps 12 through 20 are repeated.

20 22. If necessary based on data files (e.g. next fastener is not co-planar with previous fastener) the system will repeat steps 8 to 11 for fastener localization before repeating steps 12 through 20 for a subsequent set of fasteners

23. When limit switch **409** in the dispensing device **300** detects a finished or empty cartridge **400** the dispensing process is paused and the robotic arm **200** moves the dispensing system **204** away from the part **208**. The operator is

flagged for a cartridge change and repeats steps 2 to 4 prior to pressing resume.

24. When a worksite is finished, the operator is flagged by the system and instructed to move to the next stored worksite for the part of interest repeating
5 steps 2 to 22 until entire part **208** has fluid dispensed on it in desired locations.

25. The sealing system **10** is moved away from worksite and shut-down.

With respect to item 4 above, a detailed description of the nozzle **307** calibration and priming is shown in **Figure 6**. Manual off-line calibration is performed using a special calibration target **600** shown in **Figure 6** and
10 consisting of separate sections for placing the tip **411** (**Figure 4**) of nozzle **307** at a known location on the calibration target **600**, patterns **604** (in this particular embodiment, the patterns **604** are a series of parallel lines), and a calibration target **605 to be viewed by** the camera **302**. The operator inserts the nozzle
307 onto the post **603** (step **601**), rotates the calibration target **600** so as to
15 align the line projected by the rangefinder **301** with the series of lines on the target **604** (step **606**), and activates the vision system to capture an image of the calibration target **605**. In an alternate embodiment, instead of the human operator inserting the nozzle **307**, the robot arm **200** positions the dispensing system **204** nozzle onto the post with the benefit of the force-control function in
20 the robot controller **205**. The image is processed to compute external camera calibration parameters and relates the geometry of the nozzle tip **411**, with the rangefinder **301** and camera **302** (step **607**). This calibration need only be performed once as long as the camera pose does not change with respect to the frame of the dispensing system **204**.

The dispensing system **204** (or **204'**) may be configured to ensure that the nozzle **307** is always in the same relative position with respect to the sensors and robotic arm **200** after replacing a cartridge **400** or a nozzle **307**. If this is not the case then an in-situ (online) calibration may be performed when
5 a new cartridge **400** or nozzle **307** is installed. The operator may use a touch-screen or another input device to command the manipulator to move the nozzle **307** to center over a visual target within reach of the manipulator such as a checkerboard, a grid of circles or even a circle from the dispense position (steps **608** and **609**). The X, Y and Z offset between the new nozzle location
10 and original dispense position is recorded as the calibration and applied to the rest of fasteners (steps **610** and **611**).

The calibration procedure can be automated by using the dispensing system camera **302** to align the nozzle **307** with the visual target. The depth is calibrated by a) maneuvering the tip **411** of the nozzle **307** to touch the target
15 and record the depth value using the rangefinder **301**; b) command the robotic arm **200** to a predefined height with respect to the vision target; c) visual servo X and Y position of nozzle **307** using camera **302** until the nozzle **307** aligns with a feature in the calibration target (**605**) within desired accuracy. Visual servoing is accomplished by taking the relative pose of the nozzle tip **411** with
20 regard to the calibration target **605** and using a control loop in the robotic arm controller **205** to adjust the position of the nozzle tip **411** in a plane parallel to and above the vision target **605**.

Once the dispensing system **204** is calibrated, the operator manually advances the plunger **405** to fill up the nozzle **307** with sealant by manually

activating a button **310** on the dispensing system **204** or using a touch-screen **206** command.

The priming procedure can be automated by using the camera **302** in the dispensing system **204** to monitor the flow coming out from nozzle **307**. During
5 the automated procedure, the size of the nozzle **307** in the image is computed by the detecting its projection in the image and estimating the size, using for example, blob detection and measurement technique. The dispensing device **300** is commanded to advance the plunger **405**, which causes the sealant to flow. Once the vision system detects an increase in the projected blob size by
10 a pre-defined threshold value, this indicates that sealant is coming out from the nozzle **307** and the nozzle **307** is primed. The vision system commands the dispensing device to stop advancing the plunger **405** and to retract it by a predefined amount to release the pressure inside the cartridge **400** and to prevent leakage. The computer implemented sealing system **10** may proceed
15 automatically to the next step or the operator may be notified to inspect the nozzle **307** before proceeding to the next step.

With respect to item 6 above, the vision system alerts operator when the mobile platform **201** (**Figure 2**) is near enough to the ideal location to begin work. The operator confirms location and initiates the fluid dispensing
20 operation using the touch-screen **206**.

- 1) A GUI overlays the part model at canonical pose onto the live image stream of the camera **302**.
- 2) The operator manually moves the platform **201** to align the model with the image in the GUI.

- 3) Once the model and image are approximate aligned, the operator presses a GUI button to execute pose refinement function.
- 4) A model based 3D pose estimation algorithm solves part pose with respect to the camera to a high accuracy. The algorithm is based on the nonlinear optimization that minimizes the error of projected model contours with the ones extracted from live image. The algorithm is efficient as the operator has already roughly positioned the cart to the correct pose and only a small pose parameter space need to be explored to solve the problem.
- 5) The refined result is overlaid on the live image and the operator is required to confirm the location.

With respect to item 8 above, the vision system scans surface with the rangefinder **301** and determines line of best fit using the following steps.

- 1) Extract a predefined number of points that are located on the flat surface in front of a fastener.
- 2) Fit a line to the points by using, for example, the Random sample consensus (RANSAC) algorithm or another algorithm with similar functionality.
- 3) Output the direction of the line as a 3 by 1 vector.

With respect to item 10 above the vision system scans the surface of workpiece **208** with the rangefinder **301** for a second time and determines a second line of the best fit.

With respect to item 12 above the vision system uses the dispensing system camera **302 (Figure 3a)** or **312 (Figure 3b)** to find location of fastener

with respect to the camera. If the camera **302** is a 2D camera then the following algorithm may be used, see **Figure 7A**.

- 1) The type of the fastener and its approximate location in the image is known from the CAD model of the part and the approximate location of the part with respect to the mobile platform **201**.
 - 2) The vision system uses a dynamic thresholding algorithm such as the Otsu algorithm to create a binary image, this algorithm or comparable algorithms are programmed into the vision processor **203**
 - 3) A blob detection algorithm is utilized to locate the fastener in the binary image.
 - 4) Output a ray **701** (3 by 1 vector) defined by the projection center of the camera **302** and the centroid of the blob representing the fastener **700** in the image and finding its intersection with plane of the part.
- This provides the 3D location of the fastener center.

With respect to item 14 above the vision system processor **203** uses combined rangefinder **301** and camera **302** data to find the location of the fastener in three (3) dimensions with respect to the dispensing system. **Figure 7A** shows a side view of this geometry: camera **302** observes the nozzle **307** and a fastener **700** on the part **305**. An image from the camera **302** is shown in **Figure 7B**, and includes the nozzle **307**, the fastener **700** to be sealed and a fastener **703** that has already been sealed. The 3D location of the fastener **700** to be sealed with respect to the dispensing system camera **302** thus can be solved by finding the intersection of the ray **701** passing through a center of the fastener **700** with an image plane of the camera **302** and using a standoff distance obtained from the rangefinder **301**.

Alternatively, the dispensing system **204** can be placed at a required stand-off distance by using the force sensor **309** (**Figure 3a**) and the camera **302** and without the need for rangefinder **301**. The dispensing system **204** needs to be placed above the fastener **700** to be sealed using above described vision processing. The robotic arm **200** is commanded to lower the dispensing system **204** until contact between the nozzle **307** and part the surface of part **208** on which the sealing procedures are being conducted is detected by the force sensor **309**. The data from the force sensor **309** can be used to align the nozzle **307** perpendicularly to the surface of part **208** being sealed. From this position the robotic arm **200** is commanded to raise the dispensing system **204** by the required stand-off distance.

With respect to item 17 above the vision system processor **203** commands the dispensing system **204** to stop motion and retract plunger when a sufficiently large amount of fluid is detected. This detection can be accomplished via measurement of fluid blob diameter. **Figure 7C** shows the nozzle **307** in a position at a predefined distance above the fastener **700** before the sealant is dispensed. The actual fastener is obscured by the nozzle **307**. **Figure 7D** shows the image from the same position after the dispensing device has been actuated and the sealant **704** is being dispensed. The flowing sealant forms an approximately circular shape on the surface of the part. The images 7C and 7D can be processed by using this algorithm

- 1) Threshold the image using the Otsu or a similar algorithm and create a binary image,
- 2) extract contour of the dispense nozzle/sealant from the binary image,

- 3) correct the contour for the projective distortion, assuming planar surface of the part and using known orientation and standoff distance of the camera, by re-projecting it onto plane parallel to the part surface,
- 4) compute the average radius from the points on the corrected contour to
5 the center of nozzle,
- 5) once the average radius grows equal or larger to a pre-defined threshold, command the dispensing system **204** to stop motion and retract plunger **405**, and
- 6) push down the nozzle **307** (i.e., reduce the gap between the nozzle **307**
10 and plane) to a pre-defined value during 5) or until contact is detected with the force sensor **309**. This ensures proper adherence of the sealant to the surface and size of the dome.

With respect to item 20 above, hereunder is a detailed description of the inspection process which occurs after deposition of the dome seal to determine
15 its quality. The 2D inspection is illustrated in **Figures 8A to 8C** and relies on capturing an image of an uncovered fastener **700** (**Figure 8A**) and a sealed fastener **703** (**Figure 8B**) from the same hover location (vantage point). As the repeatability of robots is very high (for example, 0.1 mms is a typical
repeatability for industrial robots) the comparison image (**Figure 8C**) can be
20 created by directly overlaying images from **Figures 8A** and **8B** and constructing a composite image in **Figure 8C**. The offset **800** between the center of the fastener **700** and fluid blob **703** is computed by the vision processor **203** and stored in an inspection database. Also computed is the maximum and
minimum radii of the fluid blob from the fastener center, smoothness of contour
25 and circularity of contour for tail detection. Tails are extraneous sealant left as

a trailing thread from the dome as the nozzle separates from the just deposited seal. The characteristics of the deposited seal, offset **800** such as minimum radius, maximum radius, average radius, standard deviation and smoothness of contour and circularity of contour can be displaced on the touch-screen monitor

5 **206** as shown in the display screen **801**.

If the robotic arm repeatability is not sufficient for alignment of the images shown in **Figure 8A** and **8B**, then the alignment may be further improved by using an external 3D tracking system that will estimate pose of the dispensing system and allow the robot controller **205** to adjust the pose with a

10 higher accuracy. Targets **308a**, **308b**, **308c** and **308d** can be used for accurate estimation of this pose.

Similarly, the 3D inspection relies on capturing two 3D images from the positions before and after dispensing. If a 3D camera is used, then these images can be captured directly from the same location before and after

15 sealing. In the preferred embodiment the rangefinder provides 3D data along the projected pattern. Therefore to create a 3D image the robotic arm moves the rangefinder **301** in the dispensing system above the fastener **700** (or dome **703** when the sealing is complete) and the system records simultaneously the range data and robotic arm tip position. This approach allows for creating 3D

20 images, which may be then represented as 3D pointclouds or surfaces and used to compute the relative position of the fastener and dome seal, amount of the sealant deposited, smoothness of the surface, thickness of the sealant and to detect extraneous sealant (tail), insufficient coverage or air bubbles.

Figure 9 shows side views of a sealed part with a fastener before

25 sealing shown at **700** and after sealing shown at **703**. The rangefinder **301**

captures 3D shapes, which the can be combined together as shown at **900** in **Figure 9**. It is possible then to calculate the volume of the deposited sealant by subtracting volume of the unsealed fastener at **700** from the volume of the sealed fastener **703**, maximum and minimum radii of the fluid blob from the fastener center, smoothness of contour, and detect a tail or other defects of the sealant dome.

The shape of the seal is not limited to only domes. By using a combination of a different nozzle with appropriate aperture and employing an alternate motion trajectory the dispensing system, alternatively shaped seals such as cones can be deposited.

FILLET SEALING

Figure 18 shows vision guided laying of fillet seals. Previously stored part location data is used to command the dispensing system **204** to an approximate location and the rangefinder **301** data or camera **312** images are used to locate the joint (such as Tee or lap) **1800** position, orientation and a starting point. Range data from the rangefinder **301** is processed by the vision processor **203** in real time to estimate the location of the joint **1800**. This information is provided to the robot controller **205** to adjust the trajectory. Alternatively, if contact between the nozzle **307** and the part is required the force sensor **309** data can be used to adjust the motion of robotic arm **200**. The camera **302** acquires images of the nozzle tip and deposited sealant **1801**. The images are processed enabling real-time control of the sealant flow from the dispensing device **300** to achieve suitable width, shape and quality of the sealant bead allowing for in-situ inspection of the seal. The control may rely on

computing the width of the deposited sealant and sending commands to the dispensing device to increase or reduce the advancement of the plunger.

Alternatively, the width control may be achieved by increasing or decreasing speed of the dispensing tip of nozzle **307** with respect to the sealed part by commanding the robotic arm **200**. The camera **302** may be a 2D camera as in a preferred embodiment, a 3D camera or another structured light rangefinder operating under same principle as rangefinder **301**. Alternatively, the control may be performed in 3D by using a second rangefinder, similar to rangefinder **301**, but placed behind the nozzle **307** and observing a finished fillet seal. The first rangefinder **301** will capture a 3D pointcloud representing the sealed parts, whereas the second one will capture a 3D pointcloud representing the surface of the actual fillet seal. These two pointclouds can be aligned in 3D using known spatial placement of the rangefinders and timestamps on the acquired 3D data. The volume between these two pointclouds represents the deposited sealant compound. Analyzing the shape, size and specific dimensions of this volume will enable the assessment of the quality of the fillet seal in a similar way to inspecting the dome seals. This might include placement of the sealant with respect to the edge, width, height and volume of the seal, and shape of the cross-section.

Figure 19 shows the reach **191** of the robotic arm **200** from one location of the mobile platform **201**. Many industrial structures **208** needing to be sealed, such as but not limited to, aircraft wing panels, are long and exceed the reach of the robot manipulator **200** in the setup shown in **Figure 19**, such that the mobile platform **201** must be moved to successive locations along the part **208**.

Referring again to **Figure 2**, moving the mobile platform **201**, either manually or autonomously, requires interrupting the sealing process, stowing the robotic arm **200**, moving the platform **201** and registering the position of the robotic arm **200** with the part for the sealing process to continue. This slows
5 down the process and may require operator intervention. Referring to **Figure 20**, an alternative embodiment of the mobile system is shown where the robotic arm **200** reach is extended without moving the mobile platform **201'** through the use of a linear motion base stage. This reduces the need to move the platform **201'** as many times as platform **201**, reduces operation time and operator's
10 involvement. In this embodiment the robotic arm **200** is mounted on a translating base **210**, which runs on a linear motion track **212** along the length of a the mobile platform **201'**. The sealing system **10** is delivered to a worksite and registered as before. When the robotic arm **200** nears to its maximum reach, the translating base **210** is translated along the linear motion track **212**,
15 thereby moving the base of the robotic arm **200** along the sealed part **208** thus extending the reach of the robotic arm **200**. The length of the linear motion track **212** may be multiple times of the reach of robotic arm **200**, for example from 2m to as long as the wing length when it is aircraft wings being sealed. This length is selected depending on the length of the sealed part and the
20 required maneuverability

Referring to **Figure 21**, an alternative embodiment of a mobile system for positioning the robotic arm **200** is shown, wherein the robotic arm **200** is suspended from a mobile gantry system **211** above the part **208** being sealed. This approach also extends the lateral reach of the system from one location of
25 the mobile platform as the robotic arm **200** can reach on both sides of its base.

The mobility enables accessing the whole part along the longitudinal axis of part **208**. This can be done manually by pushing the gantry **211** or by having the base of the gantry being motorized for semi-autonomous or autonomous motion with respect to the part.

5 Referring to **Figure 22**, an alternative embodiment of a mobile system for positioning the robotic arm **200** is shown, which includes a gantry **222**. The robotic arm **200** is attached to a mobile base **223** that can move along the rail or beam **221**. This provides access to the whole or a large portion of the part **208** by moving the robotic arm or the part along beam **221**. **Figure 22** shows
10 an embodiment that extends the reach **191** in both lateral and longitudinal dimensions of the part **208** as mobile base **223** moves robotic arm **200** along beam **221**.

The alternate embodiments shown in **Figures 20** and **22** eliminate many or all of the time consuming movements of the manual or motorized mobile base
15 201 motions in Figure 1. This facilitates a much faster overall sealing operation, particularly because the re-registration of the base to the part is not required. The alternate embodiments shown in **Figures 20** and **22** also afford a further alternate embodiment of performing a scan of a large part of or the entire wing section prior to beginning of the sealing operation. The dispensing
20 system **204** and the vision system can be translated along the length of the wing to determine the location of the features to be sealed with respect to the sealing head for given manipulator and mobile platform locations. Such a scan can enable faster localization of the fasteners once the actual sealing operation is executed. When fillet sealing operations are also performed the following
25 additional actions are performed:

1. After fastener sealing at a worksite is performed the sealant nozzle **307** is swapped for a fillet sealing nozzle by the operator.
2. The operator initiates fillet sealing operation for a worksite by using the touch-screen.
- 5 3. The robotic arm **200** moves dispensing system **204** near to start location of fillet seal.
4. The robotic arm **200** moves nozzle down until contact is detected with workpiece through force sensing **309** or suitable standoff using the vision system detection.
- 10 5. The robotic arm **200** moves nozzle in a direction towards the part joint stopping when sufficient force is reached or the vision system detects that sufficient sideways traversal has occurred.
6. The robot controller **205** initiates the dispensing of fluid along part joint as the robotic arm moves the nozzle **307** along to the joint.
- 15 7. After the robot controller **205** has determined that sufficient distance has been travelled based on stored CAD data or vision system estimation or the force sensor **309** detecting the end of the joint, the robot arm motion and dispenser action are stopped.
8. The robot controller **205** initiates a viscous fluid breaking motion by the
20 robotic arm **200** such as a swirl or retraction to separate dispensed fluid from the dispenser and place the tail on the seal.
9. the Sealing System repeats steps 3 through 8 for all fillet seals reachable at a worksite.
10. The operator moves platform to next fillet sealing worksite and repeats
25 steps 3 through 9.

11. If a sealant cartridge is detected as fully dispensed, the robotic arm **200** motion and dispensing system **204** action are paused until the operator can replace cartridge **400**.

12. After the completion of fillet sealing the operator shuts down system.

5

An alternative embodiment of the dispensing system is shown in **Figure 10** and includes two or more laser line projectors (**10-1** and **10-2**) and camera **302** (which may be either a stereo or a monocular camera) observing intersections of two laser planes with the part. The two laser line projectors **10-1** and **10-2** would be mounted so that the extracted line of best fit from each projector **10-1** and **10-2** would provide an instant surface normal via methods including and but not limited to the cross-product of the line of best fit unit vector. Ideally, the camera would be mounted in such a way so that a single camera could be used for 2D planar fastener detection and also view the two laser projections on the part. The laser projectors **10-1** and **10-2** may be turned on and off to allow acquisition of images without projected light, with laser active or both. Alternatively, one camera would be used to observe the laser lines and another to observe the tip of nozzle **307**.

An alternative embodiment of the dispensing device **300**, shown in **Figure 11**, can be considered for fluids that do not come in pre-mixed cartridges. These fluids typically come in two part chemical compounds that must then be mixed together at the time of dispensing. To this end, this alternative embodiment would control the two pumps (**11-1** and **11-2**) (either through passive means such as valve sizing or active means such as metering) to extract the two part compounds from their respective reservoirs (**11-4** and

25

11-5) and direct their output to a mixing nozzle (**11-3**). The output of the mixing nozzle can be connected to the desired shape of nozzle for shaping the fluid. The pumps can be co-located at the base of the robotic arm, mounted on the robotic arm boom (between shoulder and elbow joint or between elbow and wrist joint), or mounted on the end-effector depending on the size of pumps, volume of fluid to be dispensed, and payload capacity of the robotic arm **200**.

Another alternative embodiment of the dispensing system would be to attach a cam mechanism or orthogonally mounted linear motors (**Figure 12: 12-1, 12-2, 12-3**) to the dispenser unit. These 3 motors can be used to provide a limited range of three orthogonal translational motions which in concert can produce a motion trajectory that forms the fluid shaping swirl pattern. Such a 3-axis motion stage can be used to make fine adjustments instead of using the whole robot arm.

Another alternative embodiment of the dispensing system is shown in **Figure 13** instead of a traditional rigid plastic nozzle a piece of surgical or similar tubing (**13-2**) is used to provide attachment from the dispenser cartridge (**13-1**) to the dispense nozzle/cup (**13-3**) that will be in contact with the fastener. This dispense nozzle/cup is clamped (**13-4**) to a Stewart or delta robot platform (**13-5**) which allows a limited range of motion for performing the fluid shaping swirl or to make fine position adjustments relative to the tip of the manipulator within the robotic sealing system.

A potential addition to the present system is shown in **Figure 14**. A projector **14-1** is mounted on the overhead frame **209** next to the overhead camera **202**. The projector **14-1** can be used to highlight potential problem areas or locations to the operator (incorrect fluid dispensing, malformed

fasteners, etc.) that have been detected during automated inspection of the part **208**. These locations are highlighted by selectively projecting patterns of light **14-2** and **14-3** and indicating to the operator that further attention by human operators or the automated sealing system **10** is required in those areas.

5 Another use of the projector would include projecting an Augmented Reality style pattern (graphics and / or text) on the workpiece that the operator could use for alignment of the cart when it is moved between different worksites. When the system determines that it is time to move worksites the operator would be informed on screen and the projector **14-1** would project an
10 outline drawing of the next work area on to the workpiece. The user could then move the platform until the outline drawing matches with features on the workpiece.

 Another embodiment of the present sealing system **10** would use an external 3D vision system rather than a rangefinder **301** to find the location of
15 the dispensing system **204** with respect to the part **208** being sealed. This vision system would localize the workpiece **208** with respect to the dispensing system **204** in lieu of the overhead camera **202**. This would be achieved by using the external vision system to match features or targets attached to the workpiece and use the targets on the dispensing system **204** to locate the
20 relative pose of the dispensing system **204** with respect to the part **208** being sealed.

 Another embodiment would place the robotic arm **200** on a self-guided robotic vehicle so that the transition between worksites is automatic.

 Another embodiment of the sealing system **10** would be to replace the
25 camera **302** and rangefinder **301** scanner with a 3D camera. Equivalent 3D

image processing algorithms will be used to analyze images from such a 3D camera to compute locations of fasteners.

An addition to the present sealing system **10** design is shown in **Figure 15**. In the embodiment shown in **Figure 15** the nozzle **307** would have a separately actuated rotated needle **15-1** placed at the same height as the nozzle **307**. During fillet sealing operations this rotating needle **15-1** would be activated and the robotic arm **200** would move the dispensing system **204** in such a manner so that needle **15-1** would trail the nozzle **15-1**. The needle **15-1** would act to pop air bubbles in the dispensed fillet sealing fluid by agitating the surface in a manner similar to friction stir welding. Alternatively, in dome seals that are identified as having air bubbles the needle **15-1** can be moved on top of the dome seal and actuated to spin vigorously to remove any air bubbles present. In addition to the needle **15-1**, a secondary silicone (or other pliable material) rounded protrusion could also follow the needle **15-1** (or be used in place of the needle) to smooth out fillets seals in a manner similar to a gloved worker dragging their finger along the finished fillet seal surface.

The sealing system **10** disclosed herein may be used as a part of a collaborative robotic arm and worker workcell as shown in **Figure 16**. The robotic arm **200** equipped with a dispensing system **204** is sealing the part, while the worker **101** is using a hand held dispenser **104**. The worker may be correcting seals missed by the sealing system **10**. The sealing system **10** is designed to safely operate in the presence of the human operator through a combination of limited robotic arm **200** maximum tip velocities, and limits on the maximum loads that the arm can exert on another object as measured by the force-moment sensor **309** and controlled by the robot controller **205**.

Figure 17 shows an example of a swirl trajectory that is executed at the end of each dome seal to deposit the viscous material on the dome and achieve the desired shape without contaminating the panel or part **208** or creating thin sealant trailing threads (tails). In an embodiment the sealing system **10** uses one or more predefined swirls depending on the shape and size of a fastener being sealed. In an alternative approach the swirl trajectory may be computed in real time using data from the vision system and observation of the sealant tail.

Alternative actions that can be performed by the system include:

1. Alternative method of achieving the correct size dome seals (comprising a replacement for steps 16 through 18 of dome sealing steps):
 - a. Dispensing device **300** pre-dispenses a set amount of material into a blob underneath the nozzle **307** hovering above the fastener.
 - b. The robotic arm **200** moves the dispensing system **204** down over fastener until the vision system recognizes a blob of the correct shape or the force sensor **309** determines contact has been made
 - c. Dispensing device **300** retracts plunger **405**.
 - d. The robotic arm **200** executes swirl motion.
2. Inspection of the dispensed fluid as follows (**Figure 9**):
 - a. After finishing fluid dispensing on a fastener the robotic arm **200** returns to initial hover position to take a second photo of the worksite. The vision system produces information on amount of material covered and how centered fluid is on fastener via a difference between photos.

- b. After finishing a worksite the robotic arm **200** moves the dispensing system **204** slowly over recently completed areas to assess dispensed fluid quality with a laser scanner.
- c. Inspection scans can also be used to servo the dispensing system **204** to a superior location for the next fastener based on comparison with CAD data
- 5
3. Determining distance from the fastener to the dispensing system **204** by moving the dispensing device **300** towards the fastener and stopping when contact is made. Contact determination is made through
- 10 measurements of the force moment sensor **309**.

THEREFORE WHAT IS CLAIMED IS:

1. A real-time computer implemented method for automated part sealing, comprising:
 - acquiring real-time visual images of one or more parts to be sealed;
 - detecting at least one feature associated with a part to be sealed;
 - computing a position and orientation of the at least one feature relative to a dispensing device mounted to a robotic arm;
 - moving the robotic arm to position the dispensing system in a preselected location and orientation with respect to the at least one feature; and
 - controlling an amount of sealant being dispensed based on real-time processing of the visual images of the sealant being dispensed which are acquired during dispensing of the sealant to produce a seal.
2. The method according to claim 1 including acquiring a real-time image of the produced seal, and including assessing a quality of the produced seal by analyzing the real-time images before and after the seal is applied.
3. The method according to claim 2 wherein assessing the quality of the seal includes determining whether the seal is placed at a pre-selected location over the feature.
4. The method according to claim 2 wherein assessing the quality of the produced seal includes determining whether the produced seal is of a pre-selected shape.

5. The method according to claim 4 wherein the pre-selected shape of the produced seal is a dome.
6. The method according to claim 4 wherein the pre-selected shape of the produced seal is a cone.
7. The method according to claim 2 wherein assessing a quality of the produced seal includes acquiring and analyzing a 2D image of the produced seal.
8. The method according to claim 2 wherein assessing a quality of the produced seal includes acquiring and analyzing a 3D image of the produced seal.
9. The method according to any one of claims 1 to 8 wherein the step of computing a position and orientation further includes a calibration step.
10. A vision guided dispensing system for sealing one or more parts, comprising:
 - a housing having a dispensing device mounted to said housing, said dispensing device having a dispensing nozzle;
 - a vision sensor mounted on said housing; and
 - a vision processor interfaced with said dispensing device and said vision sensor, said vision processor being programmed with instructions for real-time processing of images of the one or more parts being sealed and said

dispensing nozzle and to determine a position said dispensing nozzle needs to be positioned with respect to said feature prior to dispensing sealant, said vision processor being programmed to acquire images of said dispensing nozzle while a sealant is being dispensed by said dispensing device, said vision processor being programmed with instructions to determine, from said real-time processed images, whether or not sufficient sealant has been dispensed and to control the dispensing device when to initiate, and stop dispensing of sealant.

11. The vision guided dispensing system according to claim 10 wherein said vision sensor includes one or more 2D cameras.

12. The vision guided dispensing system according to claim 10 wherein said vision sensor includes one or more 2D cameras and one or more rangefinders.

13. The vision guided dispensing system according to claim 12 wherein one or more of the said 2D cameras is mounted to observe a tip of the dispensing nozzle and the rangefinder is mounted to observe a surface of the part close to the nozzle which is being sealed.

14. The vision guided dispensing system according to claim 11 wherein one of the said 2D cameras is mounted to observe a tip of the dispensing nozzle and the surface of the part close to the nozzle which is being sealed.

15. The vision guided dispensing system according to any one of claims 10 to 14 wherein said vision sensor includes a stereo camera.

16. The vision guided dispensing system according to any one of claims 10 to 15 wherein said vision sensor includes a 3D camera.

17. The vision guided dispensing system according to any one of claims 10 to 16 wherein said vision sensor includes one or more 2D camera and one or more structured light projectors.

18. The vision guided dispensing system according to any one of claims 10 to 17 including an interface for coupling said dispensing apparatus to a robotic arm.

19. The vision guided dispensing system according to claim 18 wherein said robotic arm is mounted on a mobile platform, and includes a global vision sensor for obtaining global images of a workspace containing the one or more parts to be sealed, and wherein said robotic arm is connected to a controller that is programmed to, based on analysis of the global images of the workspace, instruct the robotic arm to move the dispensing apparatus into close proximity to the one or more parts to be sealed.

20. The vision guided dispensing system according to claim 10 including a contact sensor for detection of contact between said dispensing apparatus and said part.

21. The vision guided dispensing system according to claim 20 including a force sensor mounted between said dispensing apparatus and said robotic arm for detecting contact between said dispensing apparatus and said part.

22.. The vision guided dispensing system according to claim 20 wherein the contact sensor is integrated within the dispensing apparatus.

23. The vision guided dispensing system according to claim 10 wherein the contact between said dispensing apparatus and said part is detected through the measurement of currents in said robotic arm joint motors.

24. The vision guided dispensing system according to any one of claims 10 to 23 wherein the dispensing device contains a cartridge that stores the sealant.

25. The vision guided dispensing system according to any one of claims 10 to 21 wherein the dispensing device further comprises;

an actuator and

a plunger; wherein said plunger is advanced by said actuator in order to force the sealant through the dispensing nozzle.

26. The vision guided dispensing system according to claim 25 wherein said actuator may be any one of an electric motor with a lead screw, linear motor, servo motor, pneumatic actuator and a hydraulic actuator.

27. The vision guided dispensing system according to claim 25 or 26 wherein said vision processor is programmed with instructions such that when said vision processor has detected excess sealant, said vision processor instructs said motor to withdraw said plunger to remove the excess sealant.

28. The vision guided dispensing system according to any one of claims 10 to 27 wherein the dispensing device further comprises at least one pressure sensor mounted on said dispensing nozzle or sealant cartridge for measuring the pressure of the sealant.

29. The vision guided dispensing system according to any one of claims 10 to 28 including wherein said dispensing device includes a meter mechanism for measuring an amount of sealant dispensed.

30. The vision guided dispensing system according to any one of claims 10 to 29 wherein the sealant is supplied to the dispensing device by pumping the sealant from an external storage container.

31. The vision guided dispensing system according to any one of claims 10 to 30 wherein the dispensing device contains a plurality of cartridges that store sealant.

32. The vision guided dispensing system according to claim 29 wherein the sealant from the plurality of cartridges is mixed in situ before it is dispensed.

33. The vision guided dispensing system according to any one of claims 10 to 32 wherein the one or more parts to be sealed includes at least one fastener associated with the one or more parts.

34. The vision guided dispensing system according to any one of claims 10 to 32 wherein the one or more parts to be sealed include at least one fillet edge associated with the one or more parts.

35. A sealing system for automated artificial vision-guided dispensing of viscous fluids for caulking and sealing operations around various features on a part, comprising:

- a mobile platform for gross positioning of said system relative to said part containing said features;

- a dispensing device for applying sealant to said feature;

- a positioning device mounted on said mobile platform to which said dispensing device is attached for positioning the dispensing device relative to said feature;

- a sensing device for determining the position of the mobile platform relative to said part;

- a second sensing device for determining the position of said feature on said part with respect to the dispensing device and also determining the required amount of sealant to be dispensed based on visual images of the sealant being dispensed; and

- a controller for controlling said positioning device and said dispensing device based on feedback from said second sensing device.

36. The system according to claim 35 wherein the mobile platform for gross positioning of the system further comprises

a positioning device having a tip and being mounted on the mobile base; and

an uninterruptible power supply mounted on the mobile platform to provide power to the system;

wherein the positioning device is configured to provide at least three translational and three rotational degrees of freedom at the positioning device tip.

37. The system according to claim 36 wherein the positioning device is a serially linked, robotic arm mounted on said mobile platform.

38. The system according to claim 36 wherein the mobile platform for positioning of the system is a manually operated push cart.

39. The system according to claim 36 wherein the mobile platform for positioning of the system is a motorized platform.

40. The system according to claim 36 wherein the mobile platform is a mobile gantry unit from which the system is suspended above said part containing said features.

41. The system according to claim 36 wherein the mobile base is a gantry resting on a stationary support structure containing a longitudinal beam,

wherein the system is suspended from said longitudinal beam above said part containing said features and is movable along said beam.

42. The system according to claim 36 wherein the mobile platform for positioning of the system is a semi-autonomous vehicle.

43. The system according to claim 36 wherein the mobile platform means for positioning of the system is a fully autonomous vehicle.

44. The system according to any one of claims 36 to 43 wherein the second sensing device comprises:

a vision sensor; and

a vision processor interfaced with said dispensing means and said vision sensor, said vision processor being programmed with instructions to process images of the one or more parts being sealed and said dispensing means to determine a position said dispensing nozzle needs to be positioned in with respect to said features prior to dispensing said sealant.

45. The system according to claim 44 wherein the dispensing means is a dispensing device comprising:

a housing, the vision sensor being mounted to said housing;

a dispensing nozzle;

wherein said vision processor is programmed to acquire images of said dispensing nozzle while a sealant is being dispensed by said dispensing device, and said vision processor is programmed with instructions to

determine, from said acquired images, whether or not sufficient sealant has been dispensed and to control the dispensing device during the dispensing of sealant.

46. The system according to claim 44 wherein the vision sensor includes one or more 2D cameras and one or more rangefinders.

47. The system according to claim 46 wherein the one or more rangefinders project a plane of light on the part to form a light pattern, said 2D cameras observing and acquiring an image of said light pattern to enabling computation of a three-dimensional distance to the light pattern on the part.

48. The system according to claim 47 further comprising:

an external camera system; and

a plurality of three dimensional markers, removably fastened to said dispensing device;

wherein the external camera system acquires images of said three dimensional marker to provide an means of locating the dispensing system with respect to the part containing said features.

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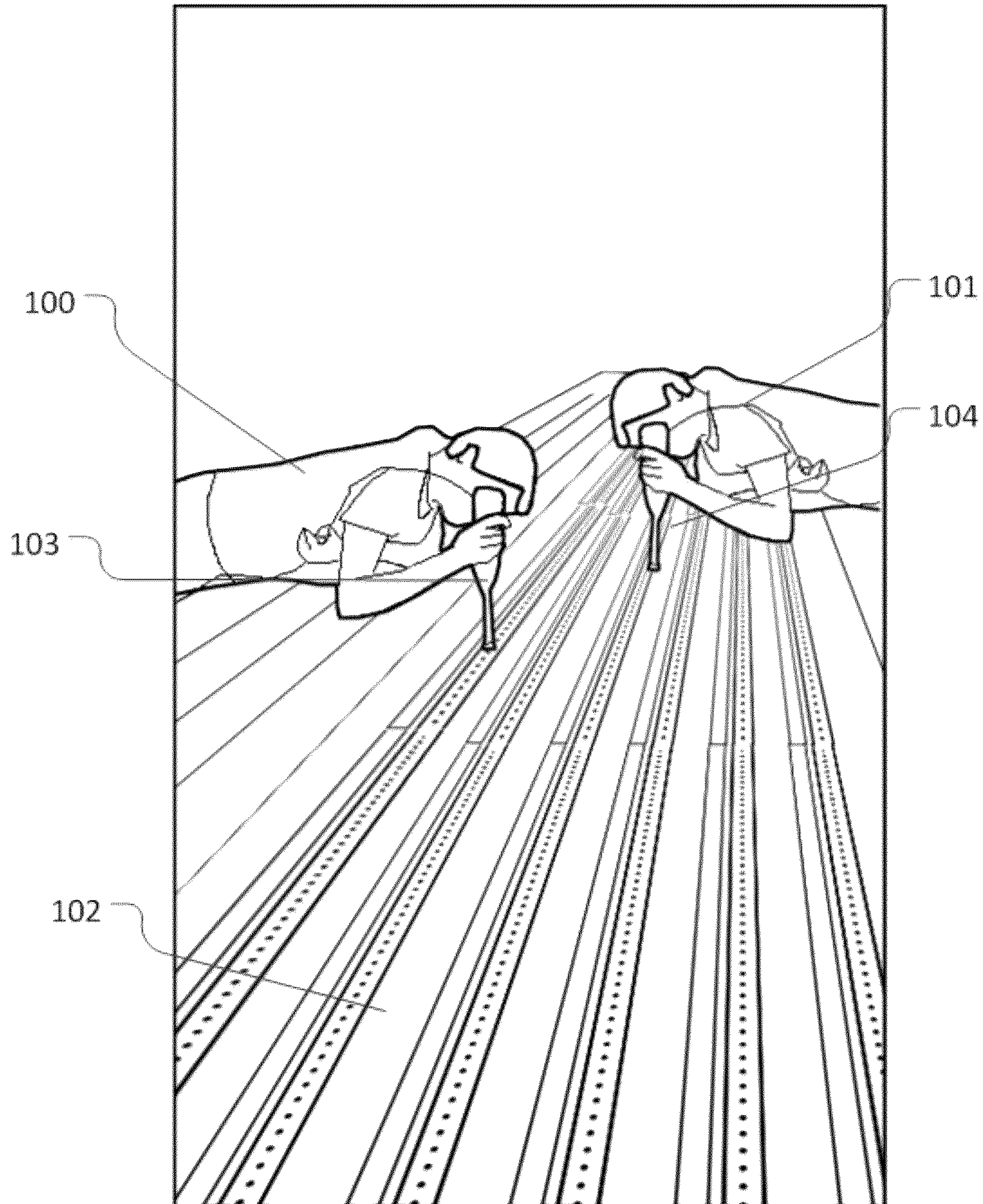


Figure 1

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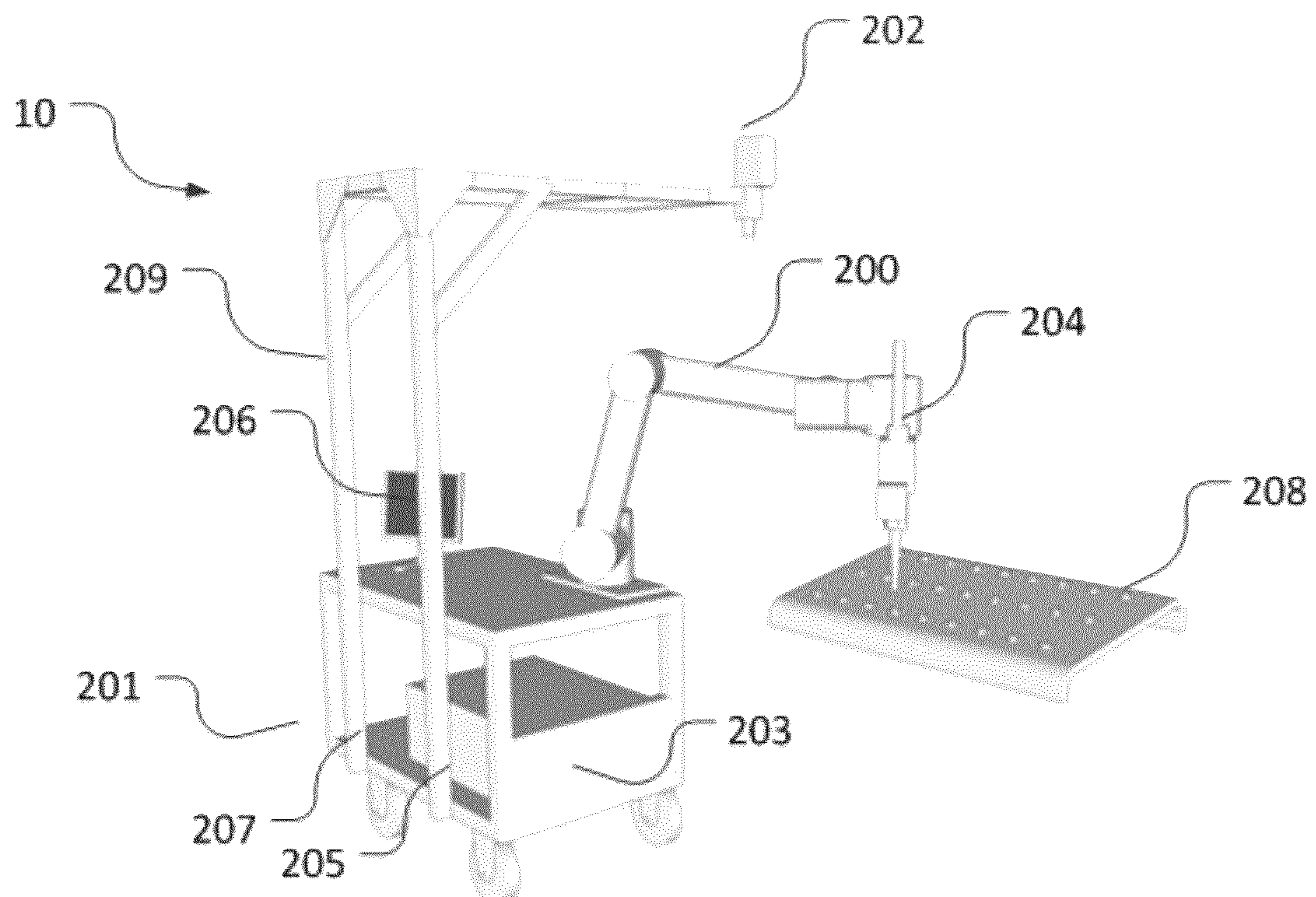


Figure 2

3/23

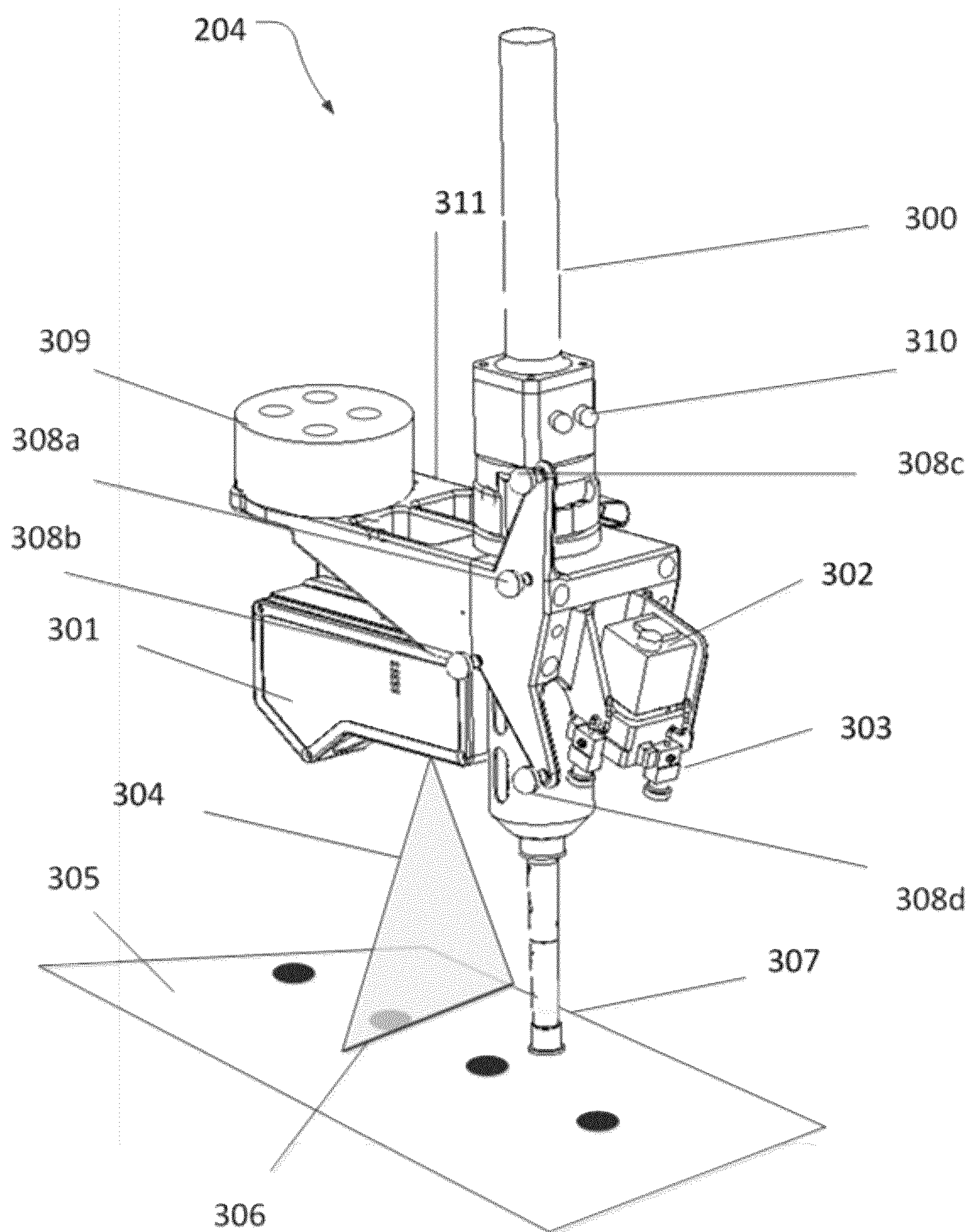


Figure 3a

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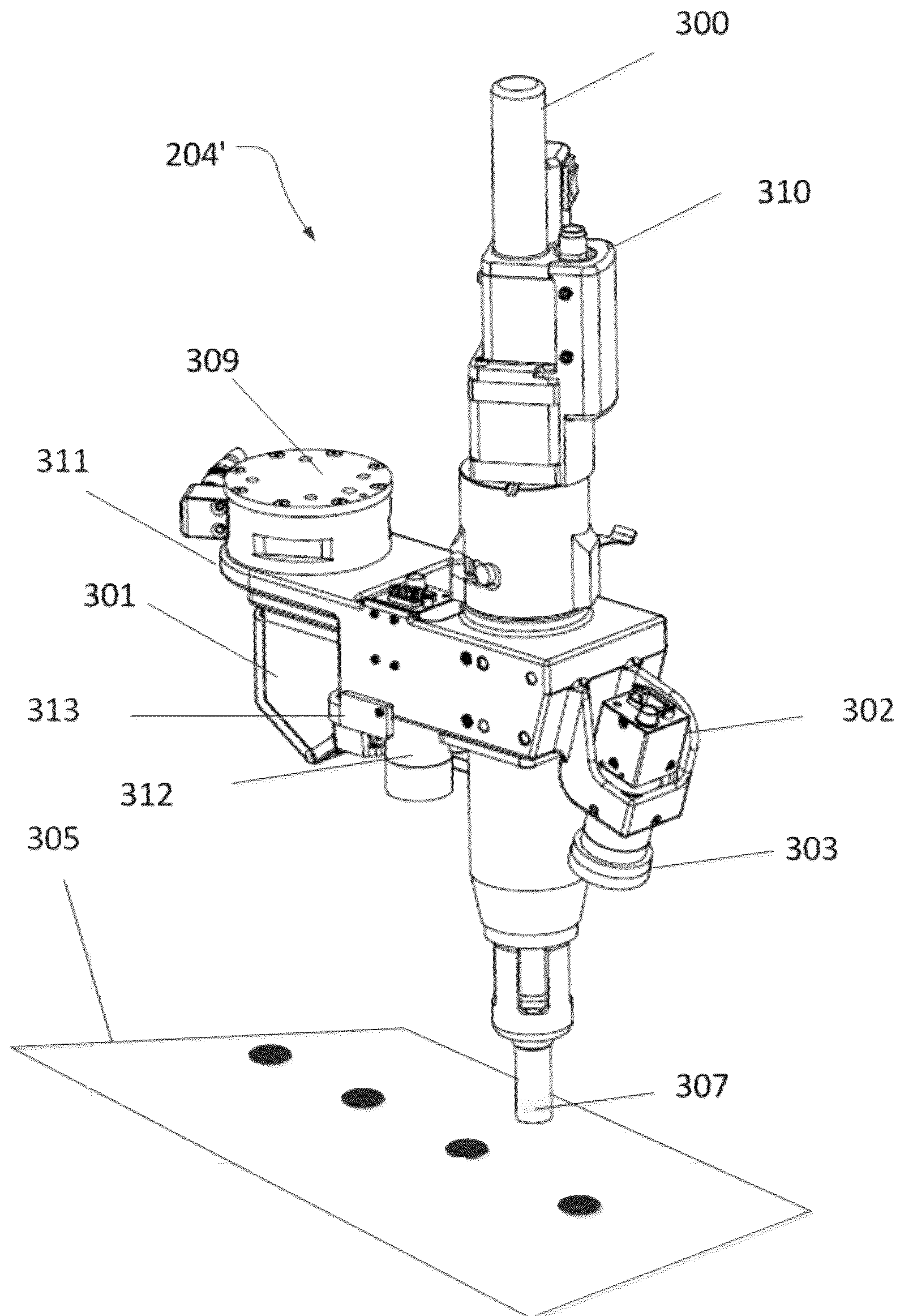


Figure 3b

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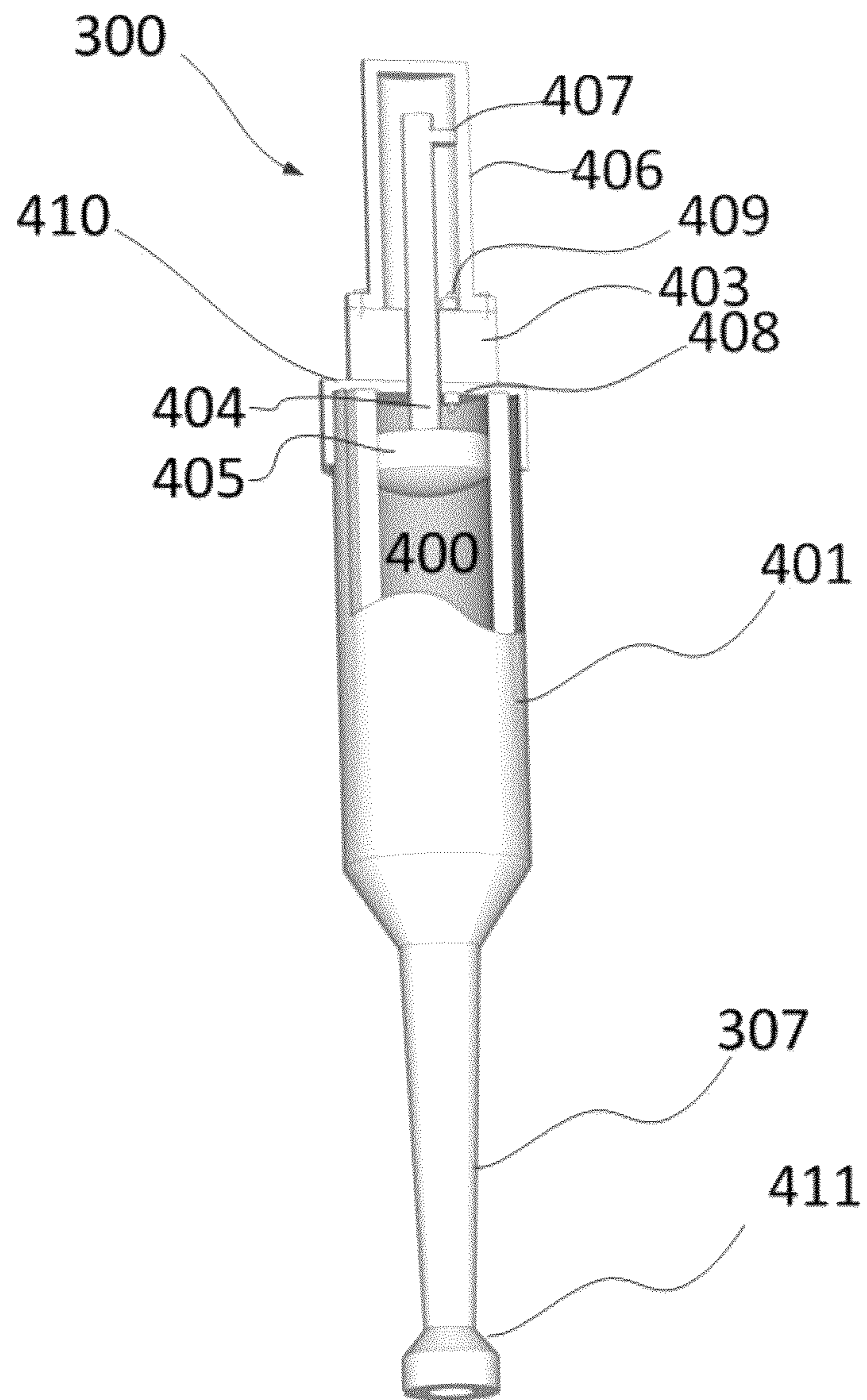


Figure 4

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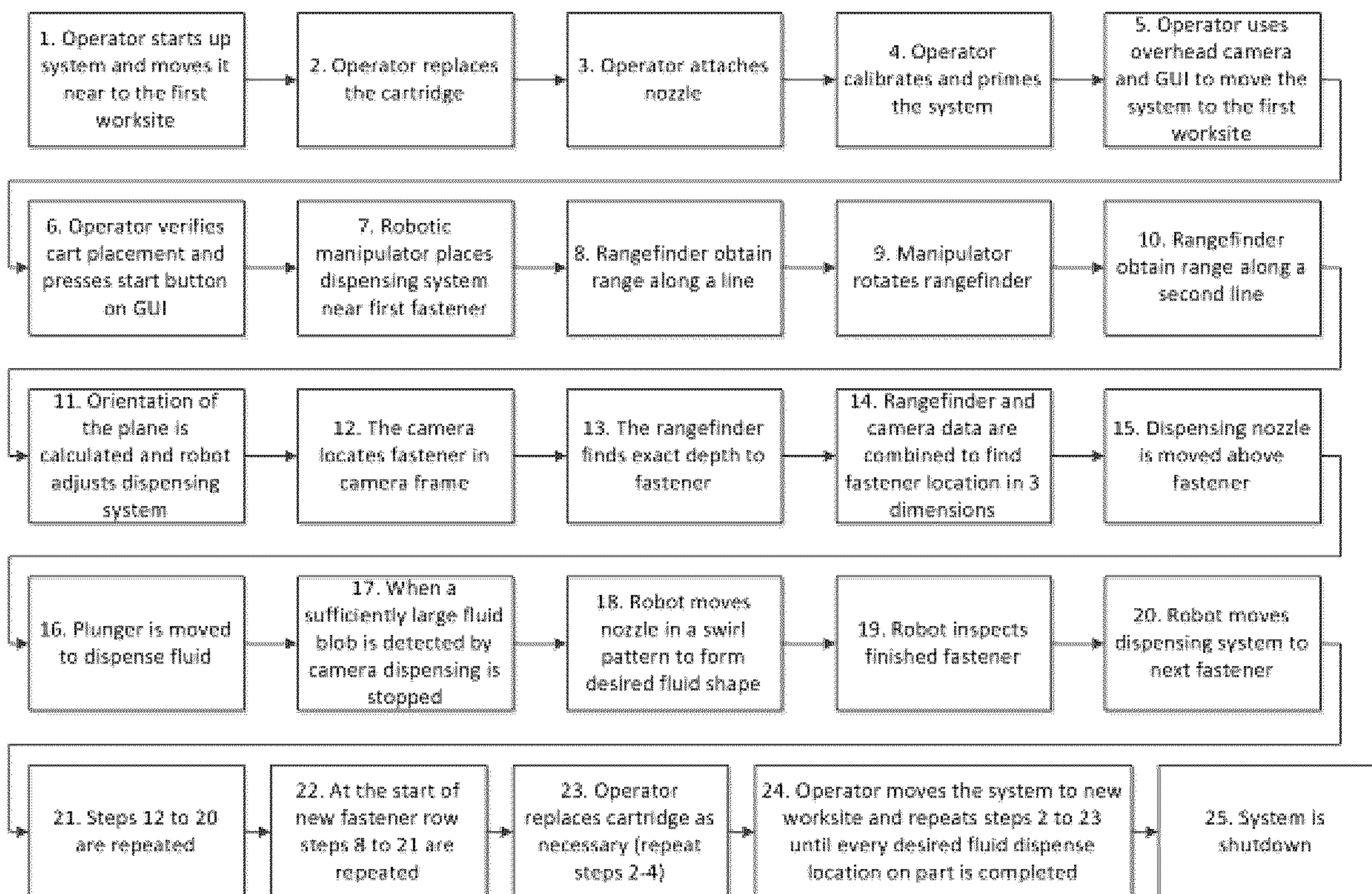


Figure 5

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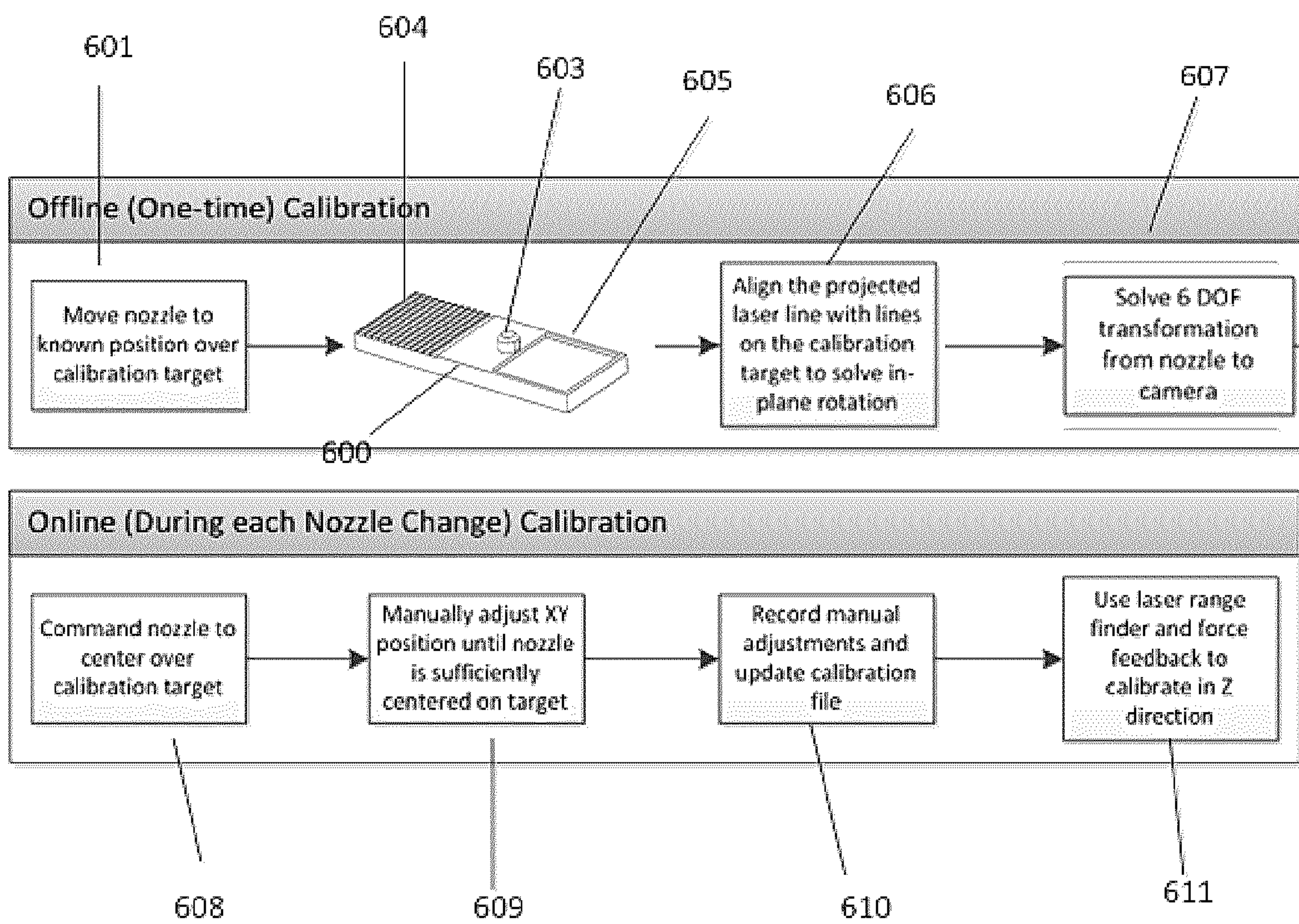


Figure 6

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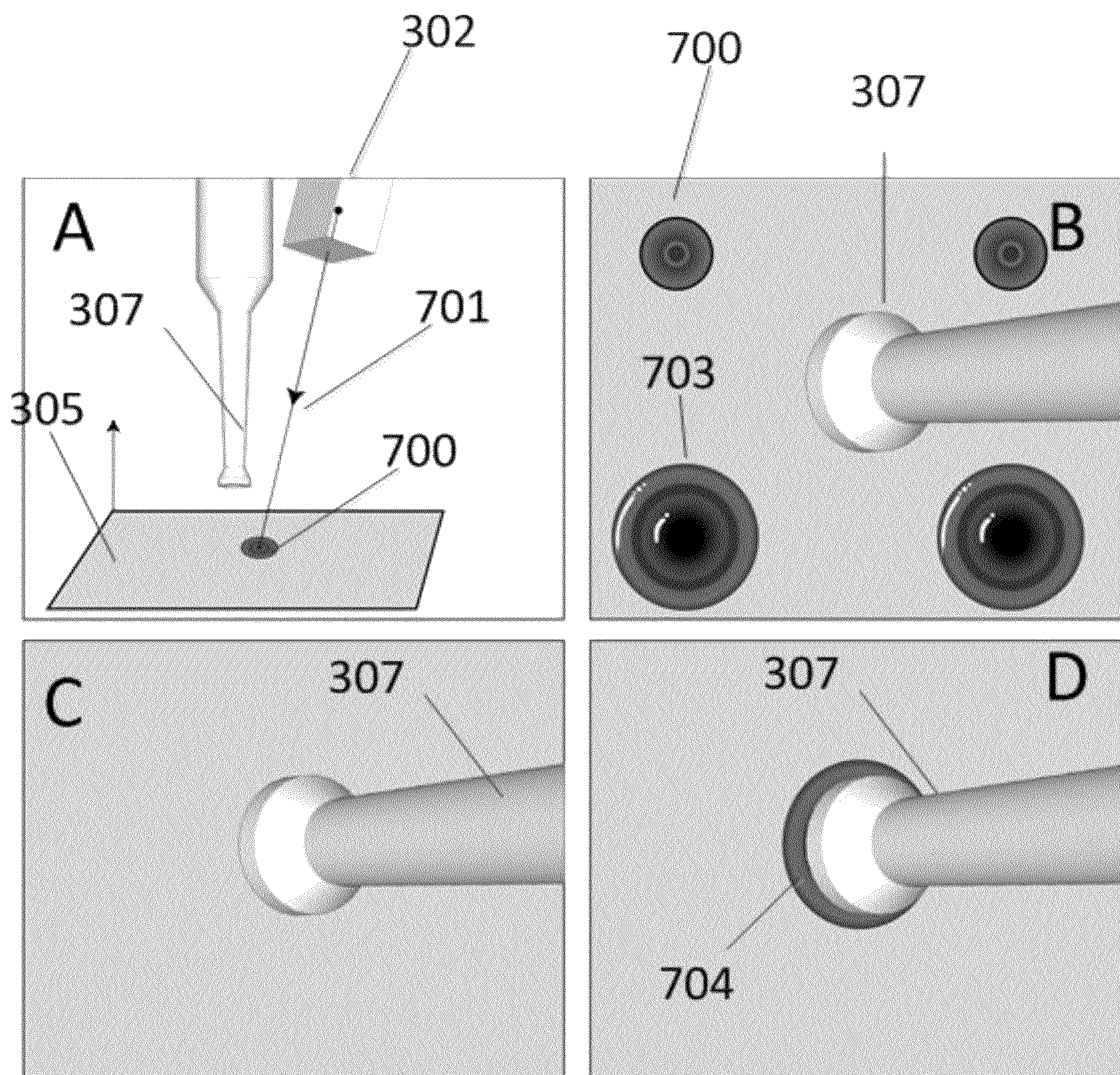


Figure 7

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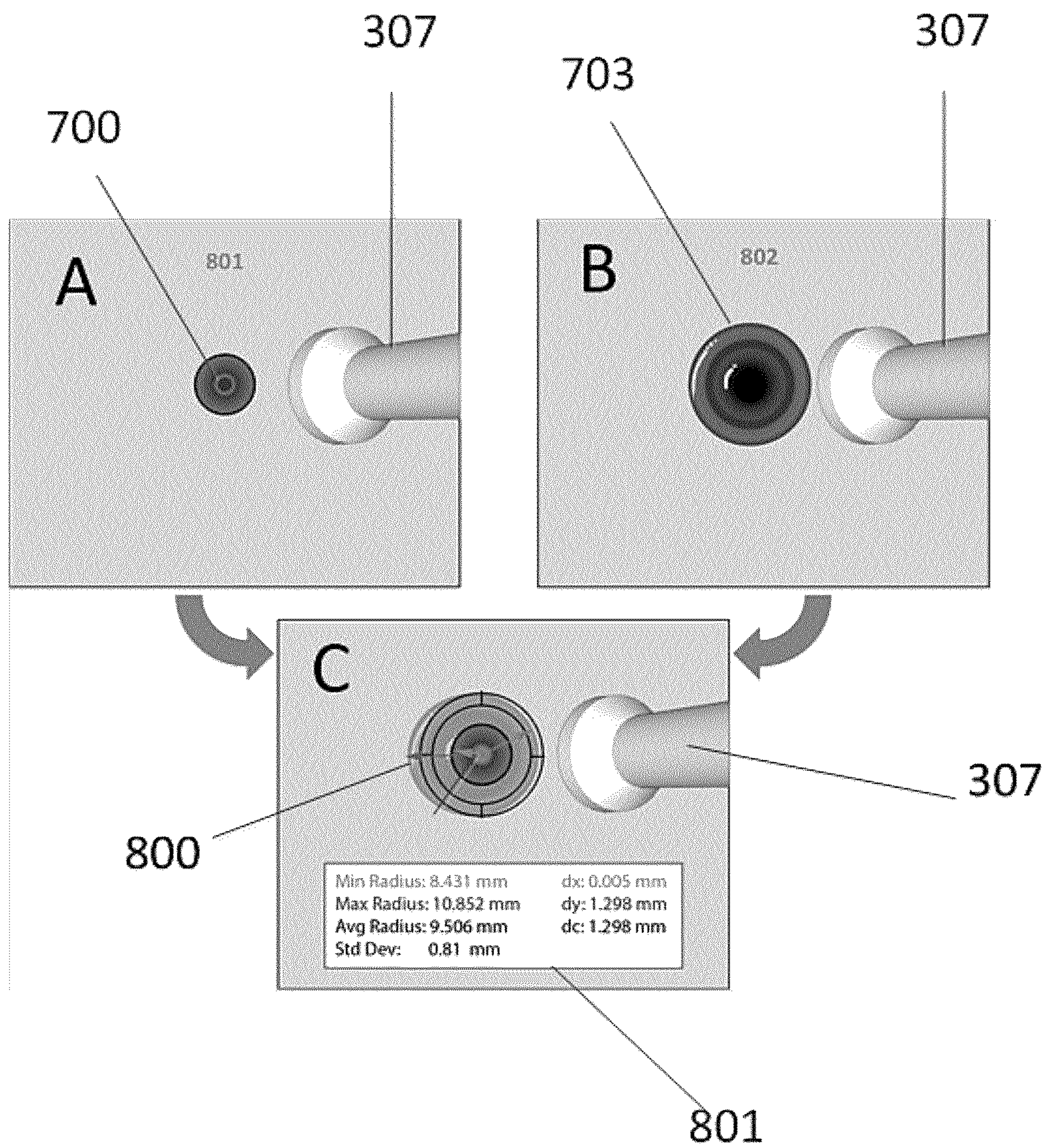


Figure 8

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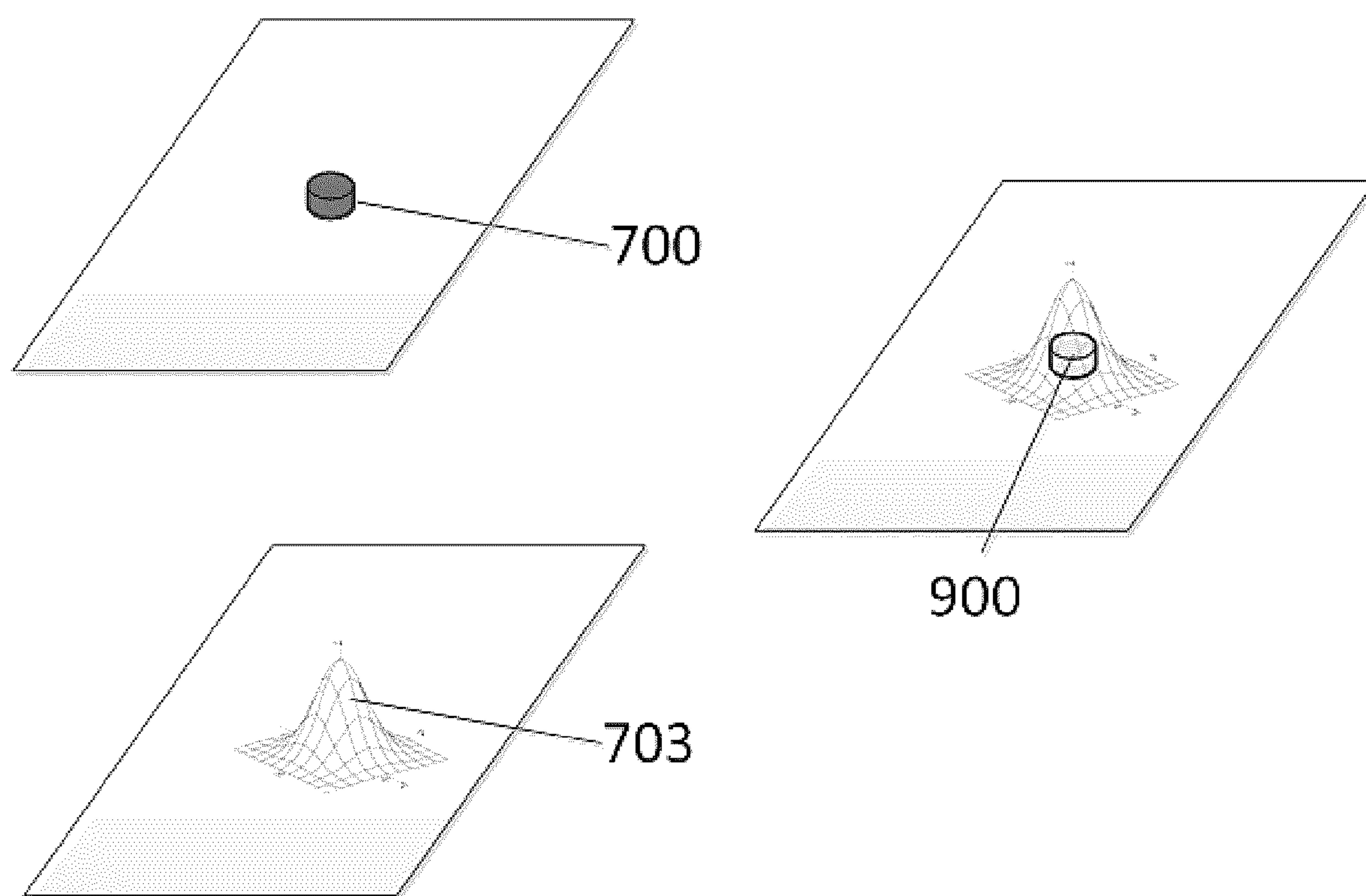


Figure 9

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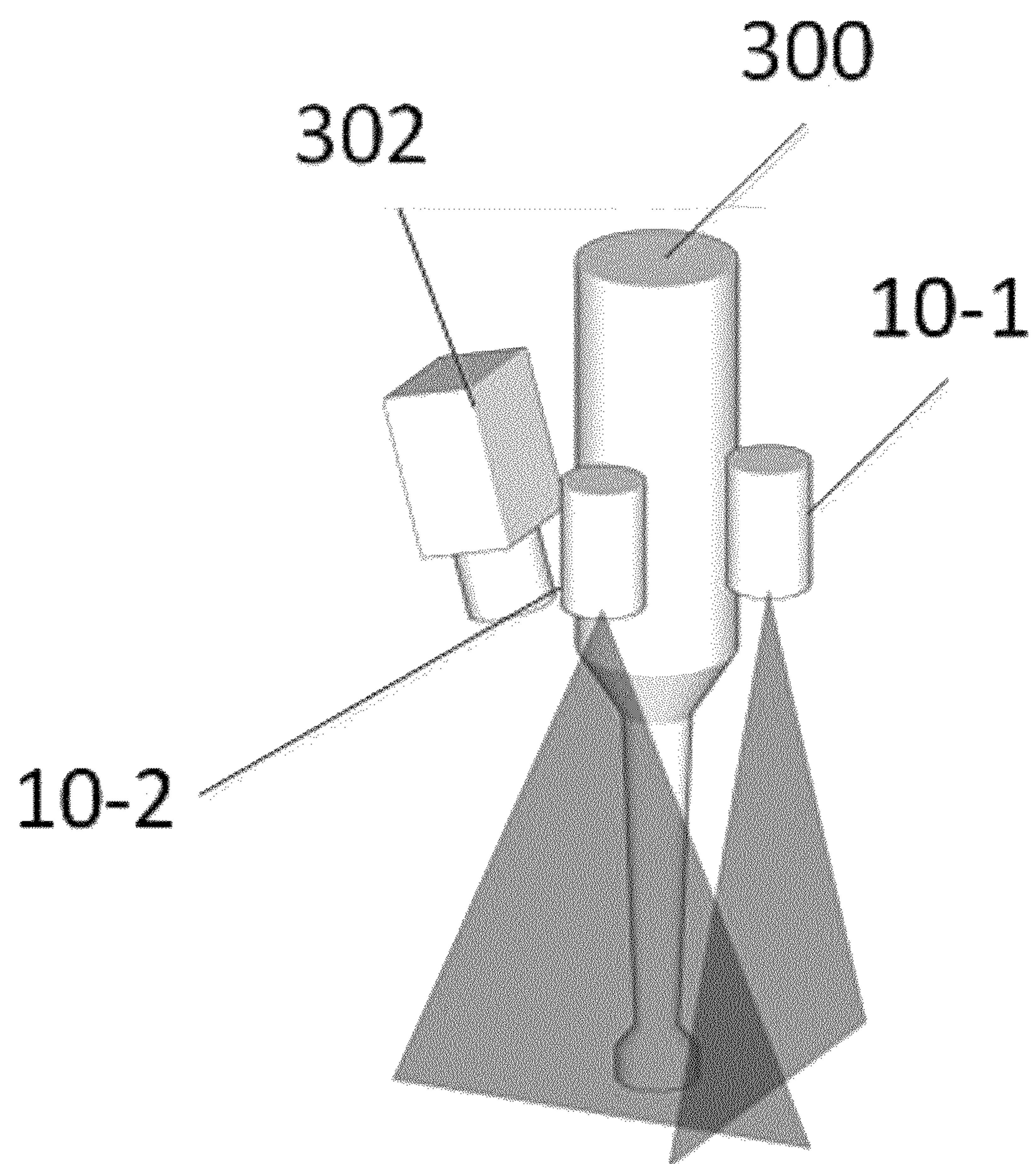


Figure 10

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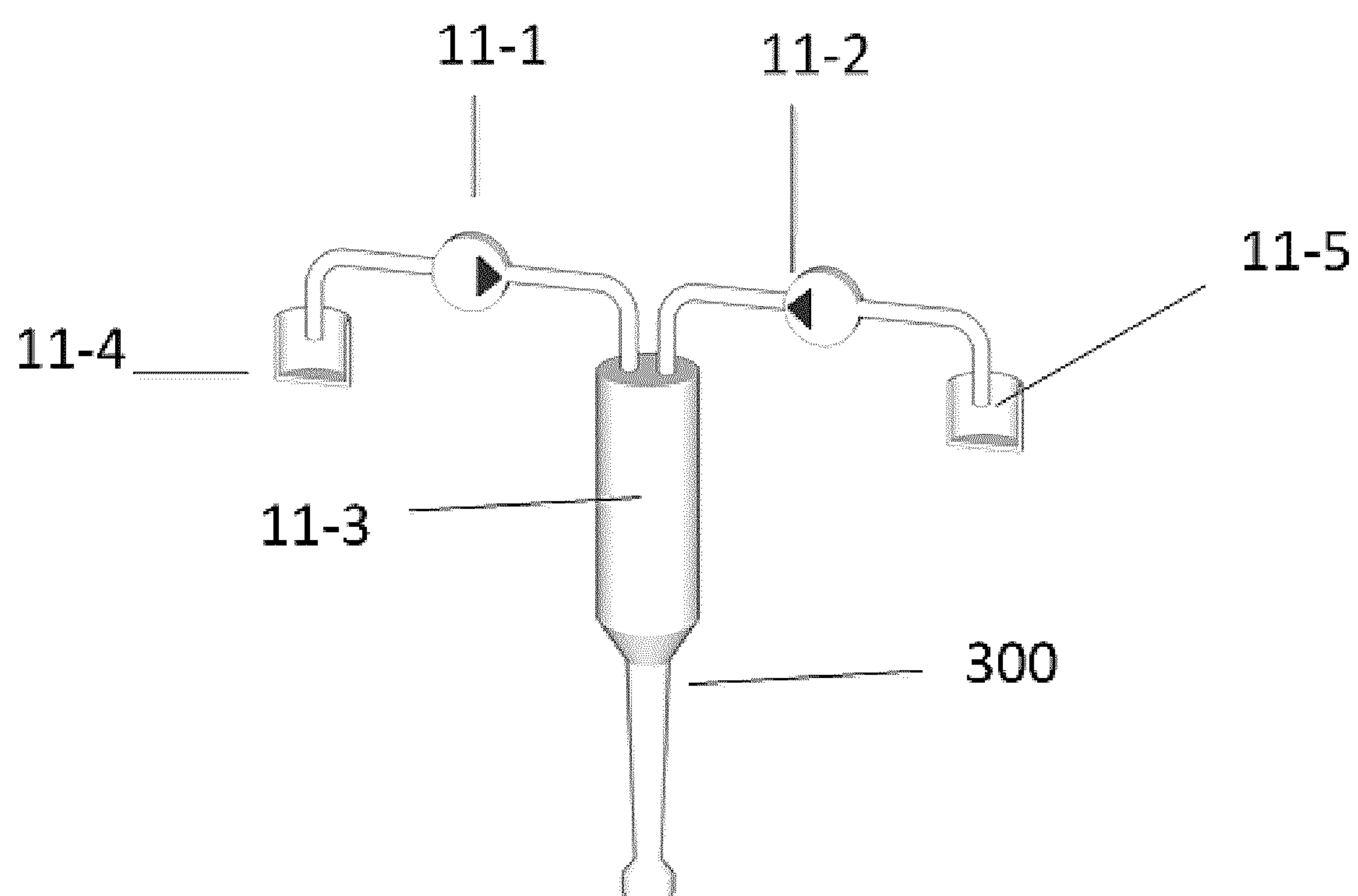


Figure 11

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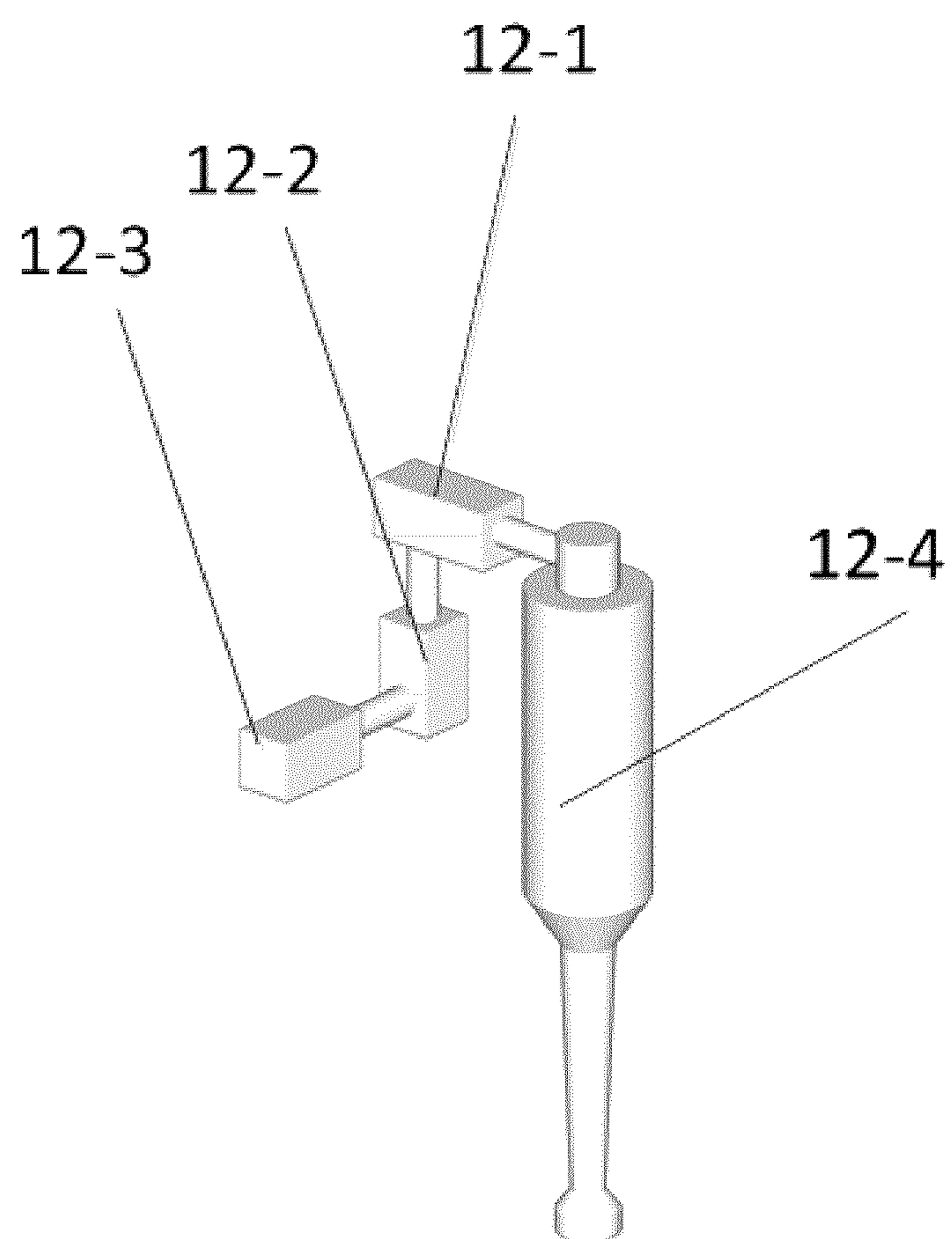


Figure 12

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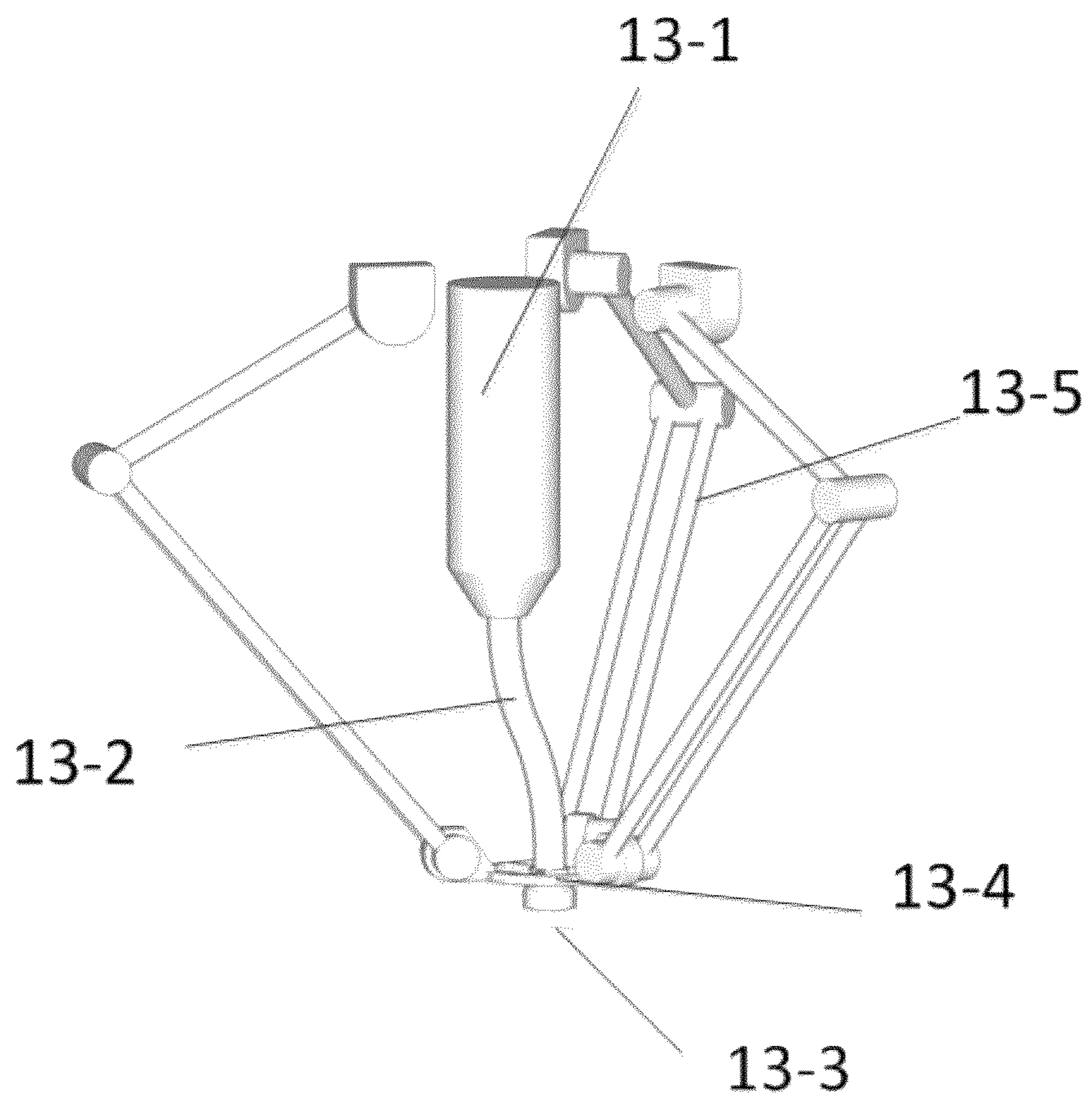


Figure 13

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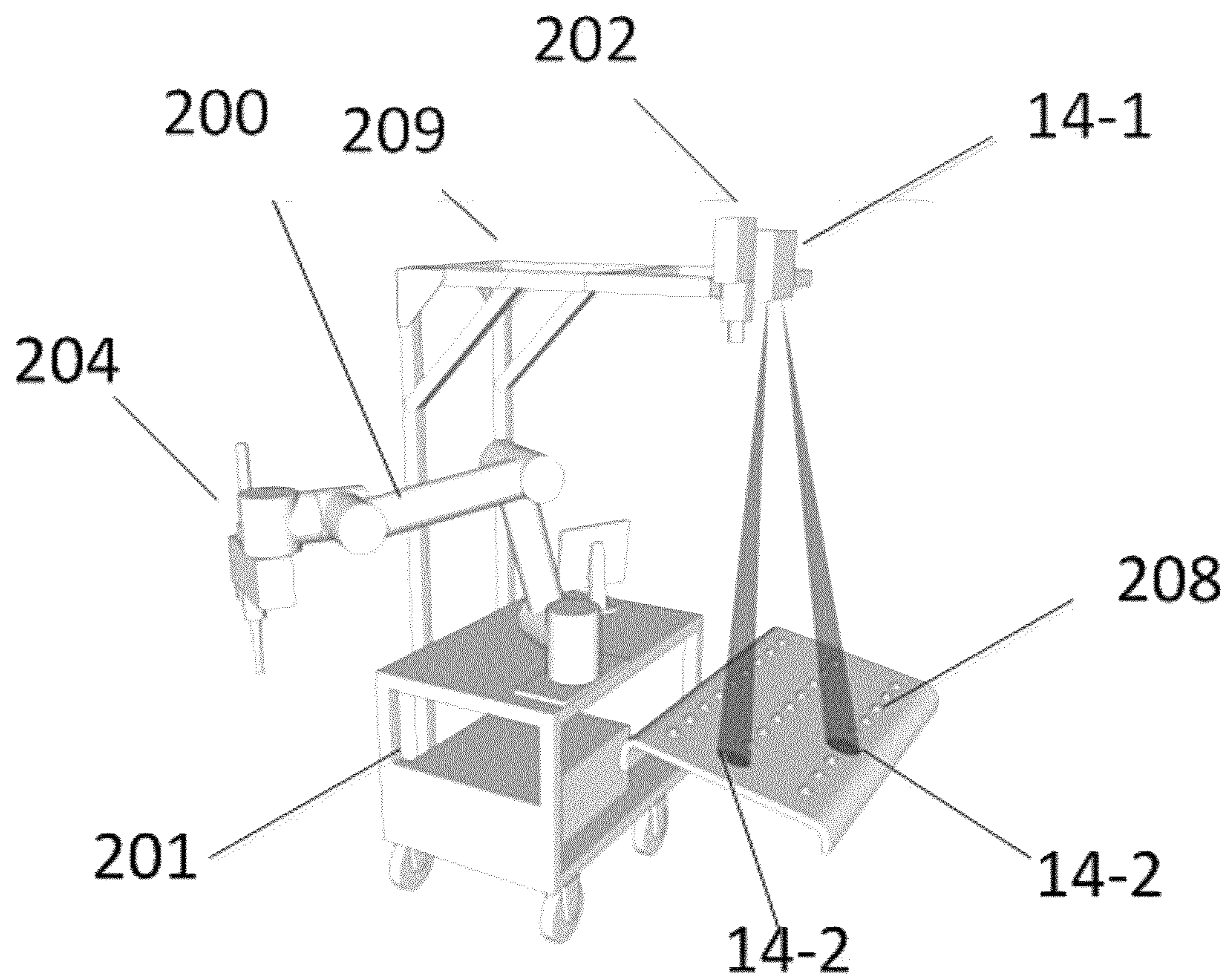


Figure 14

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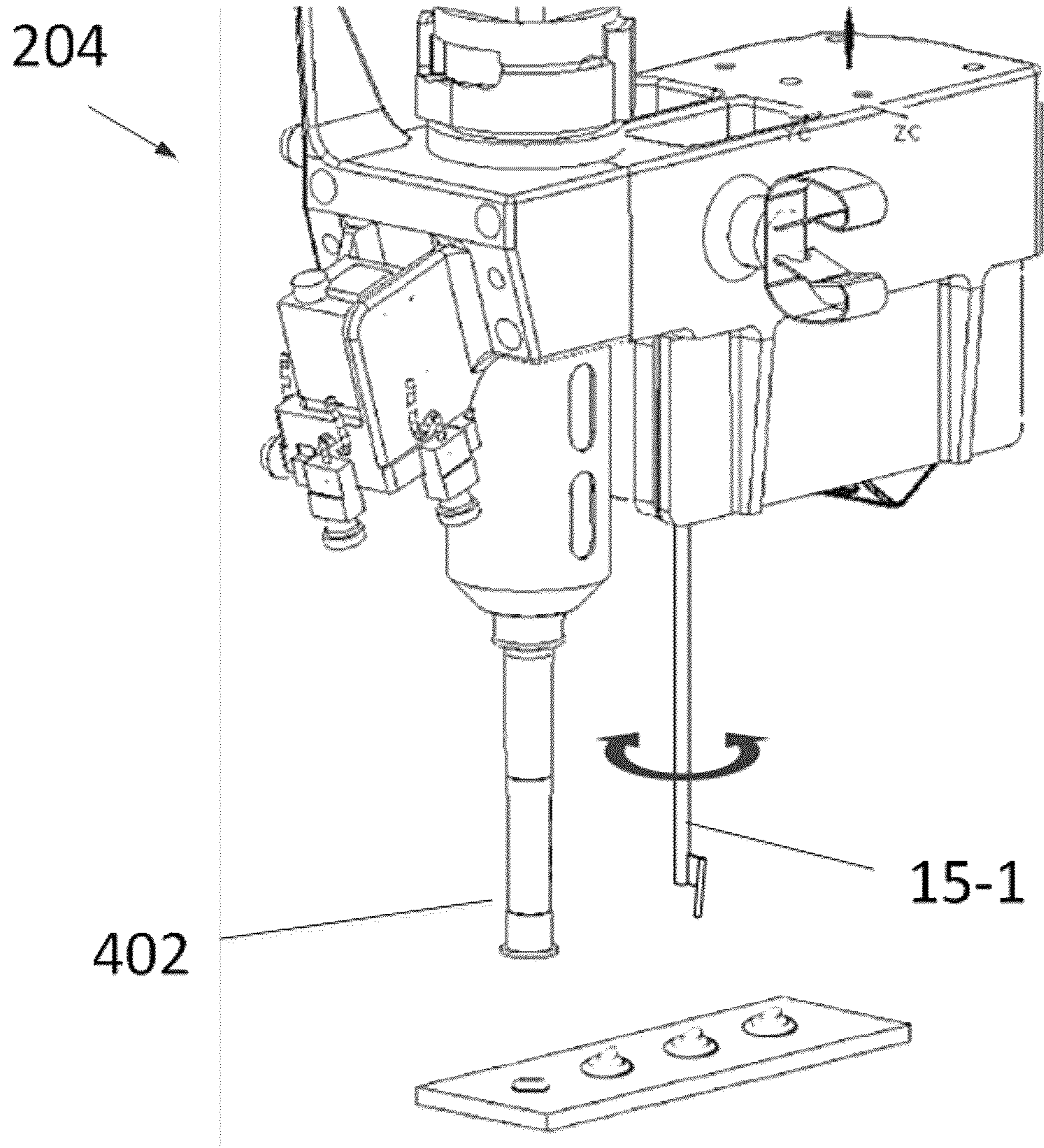


Figure 15

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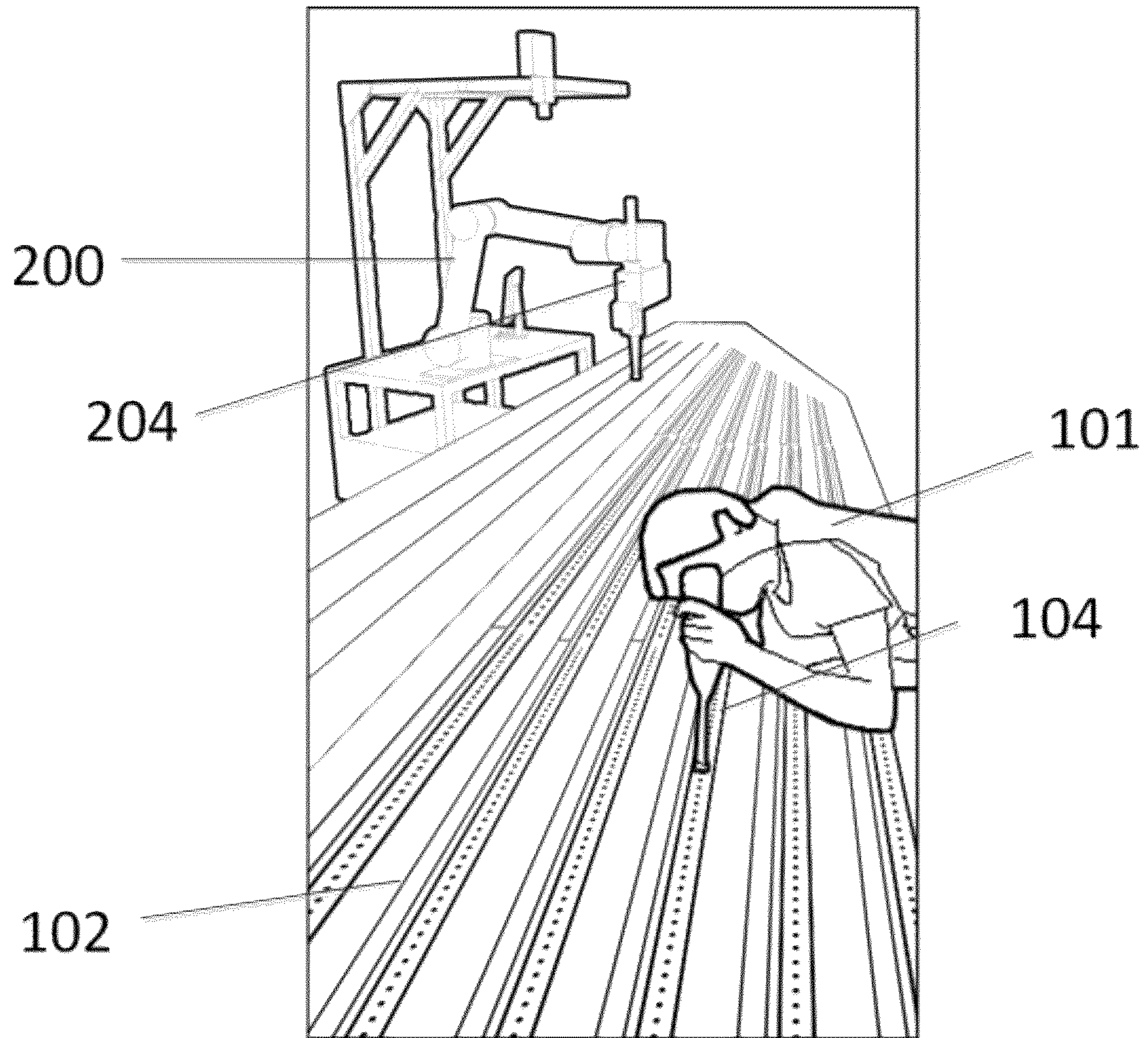


Figure 16

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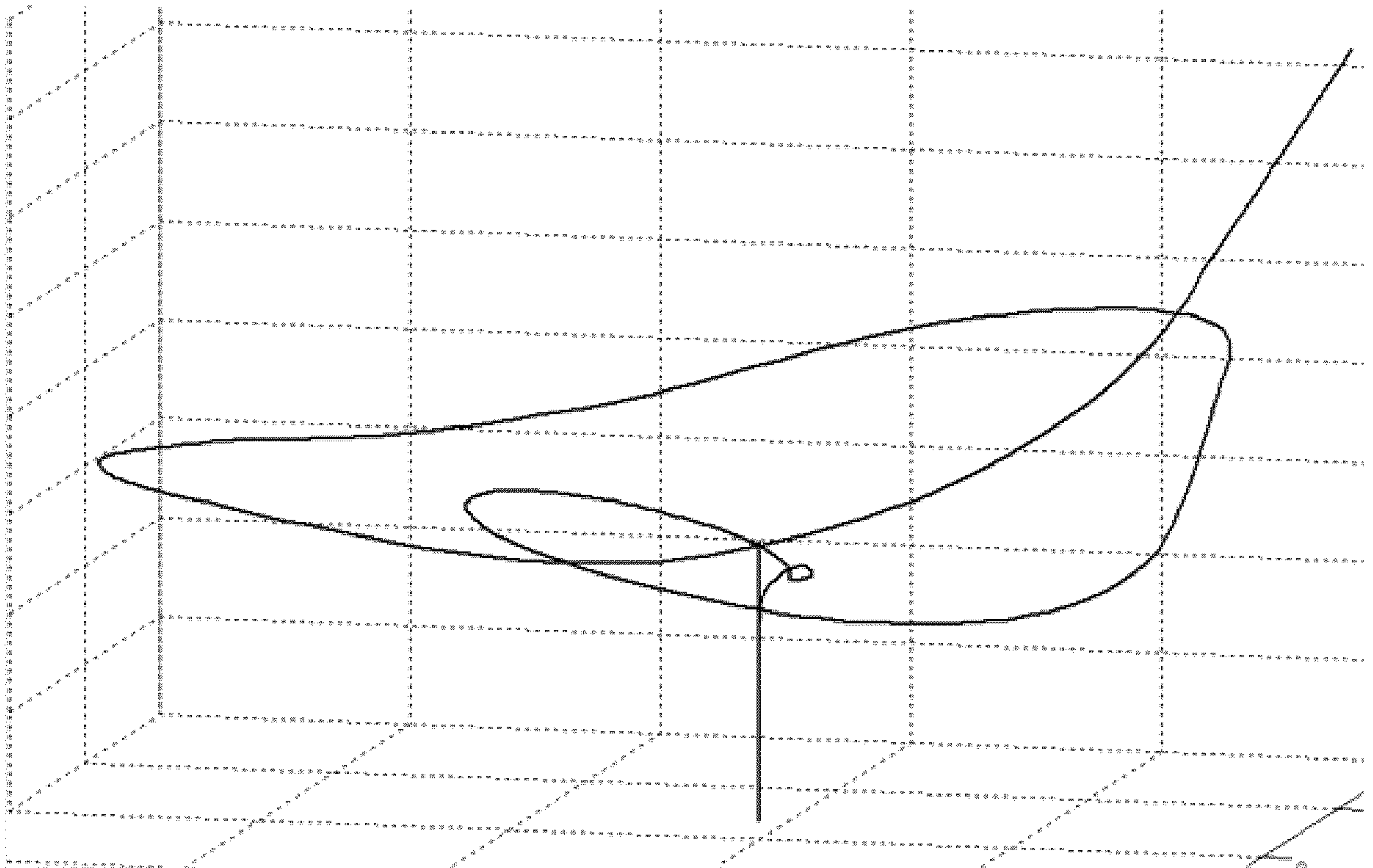


Figure 17

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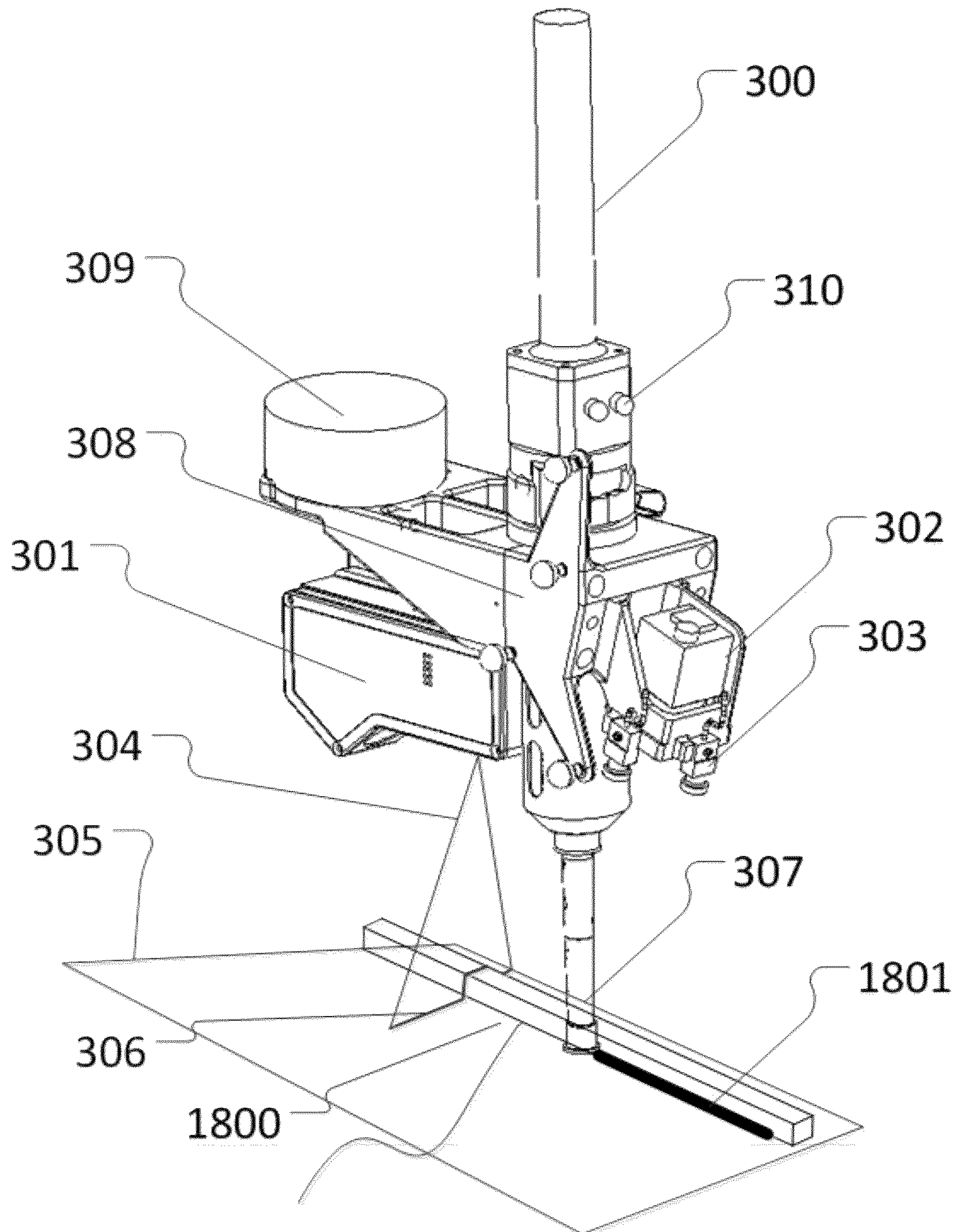


Figure 18

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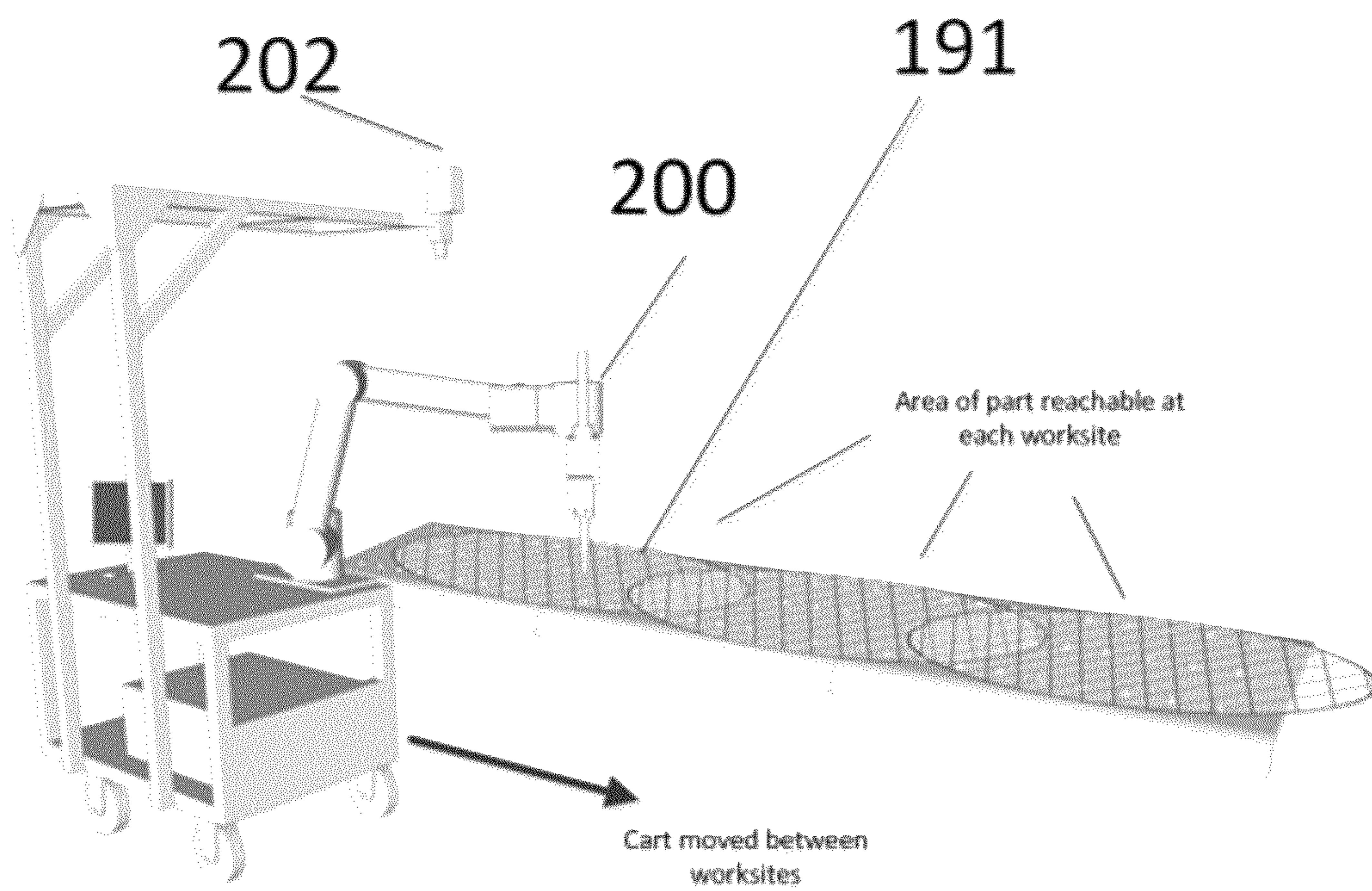


Figure 19

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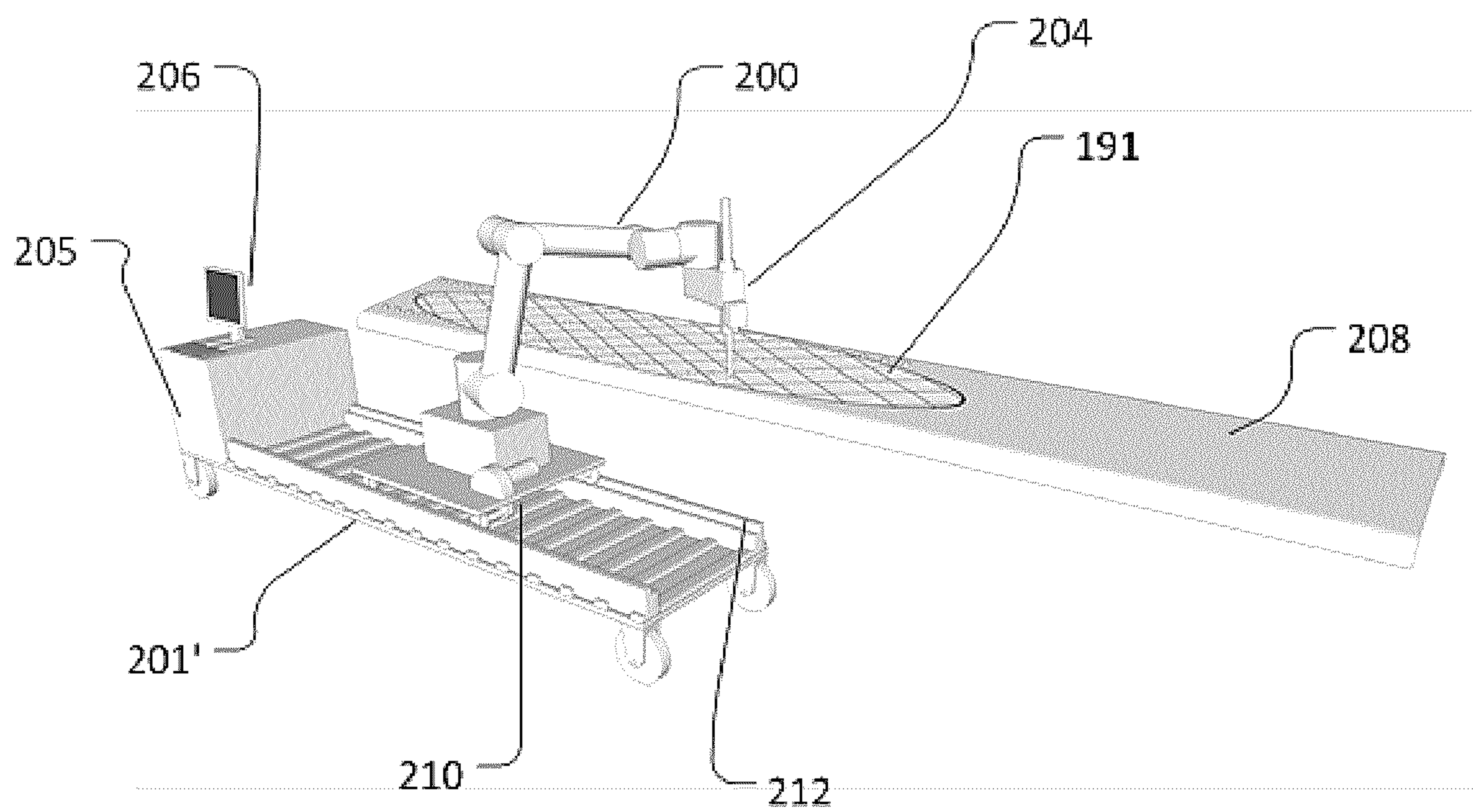


Figure 20

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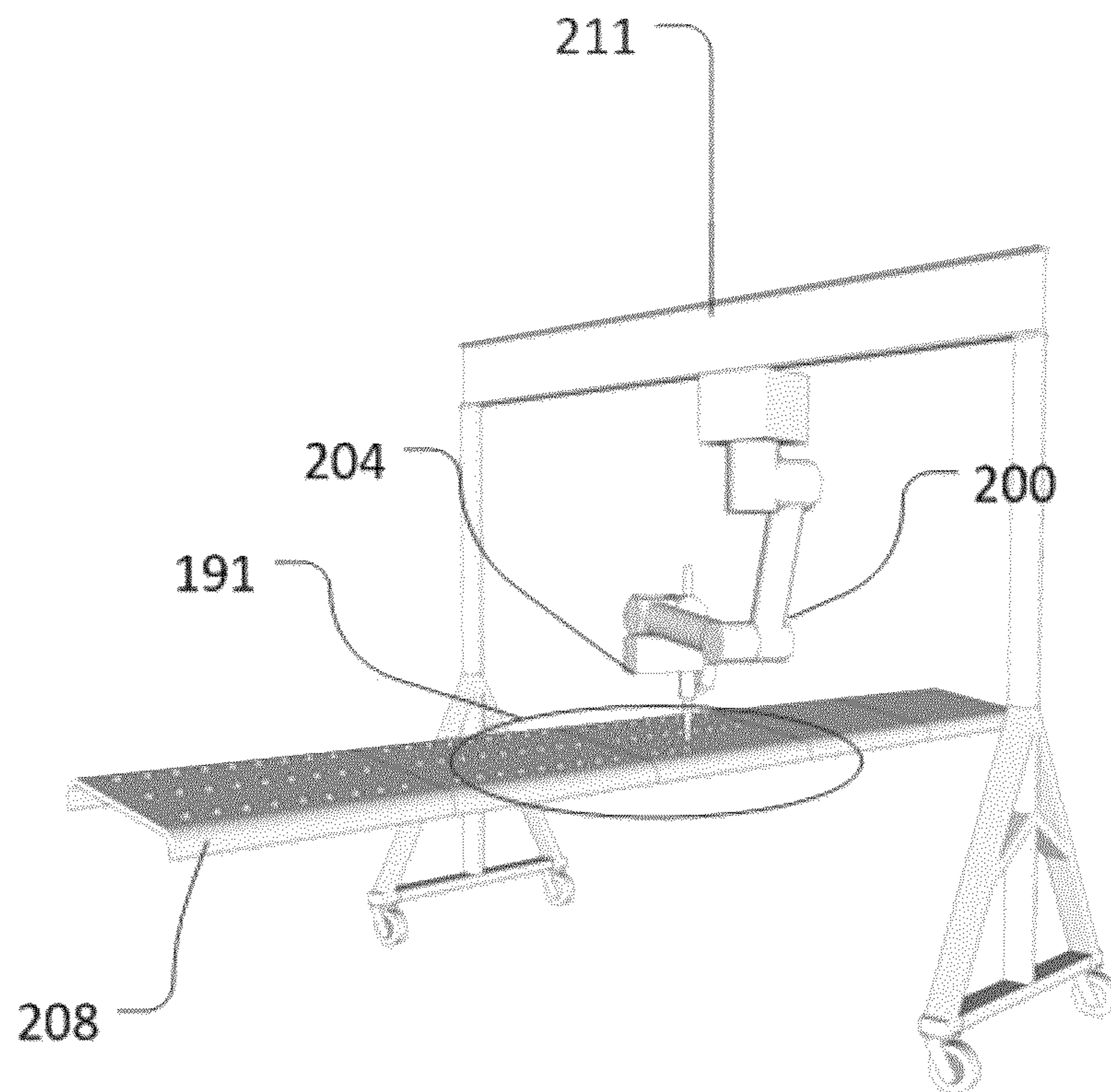


Figure 21

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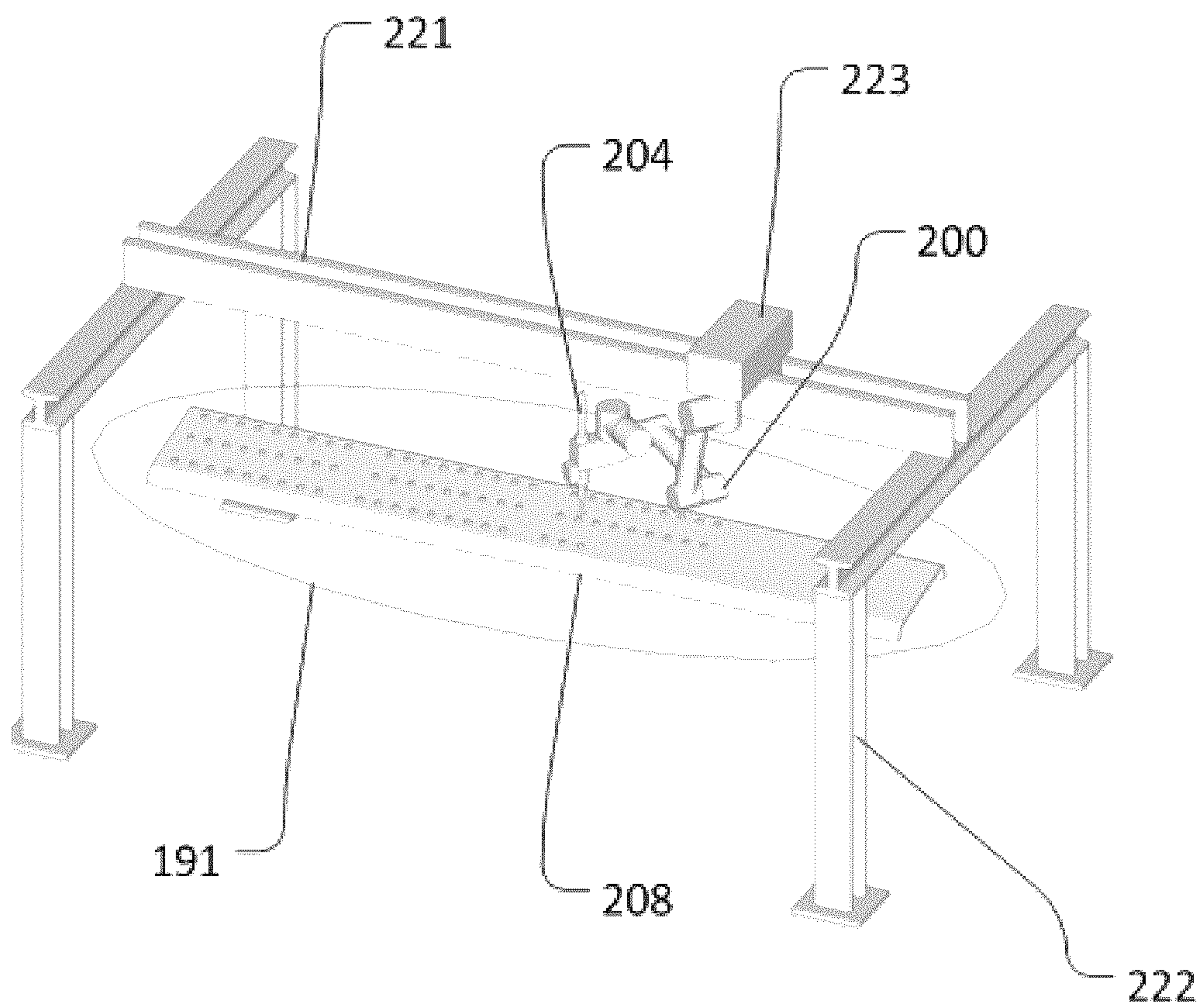


Figure 22

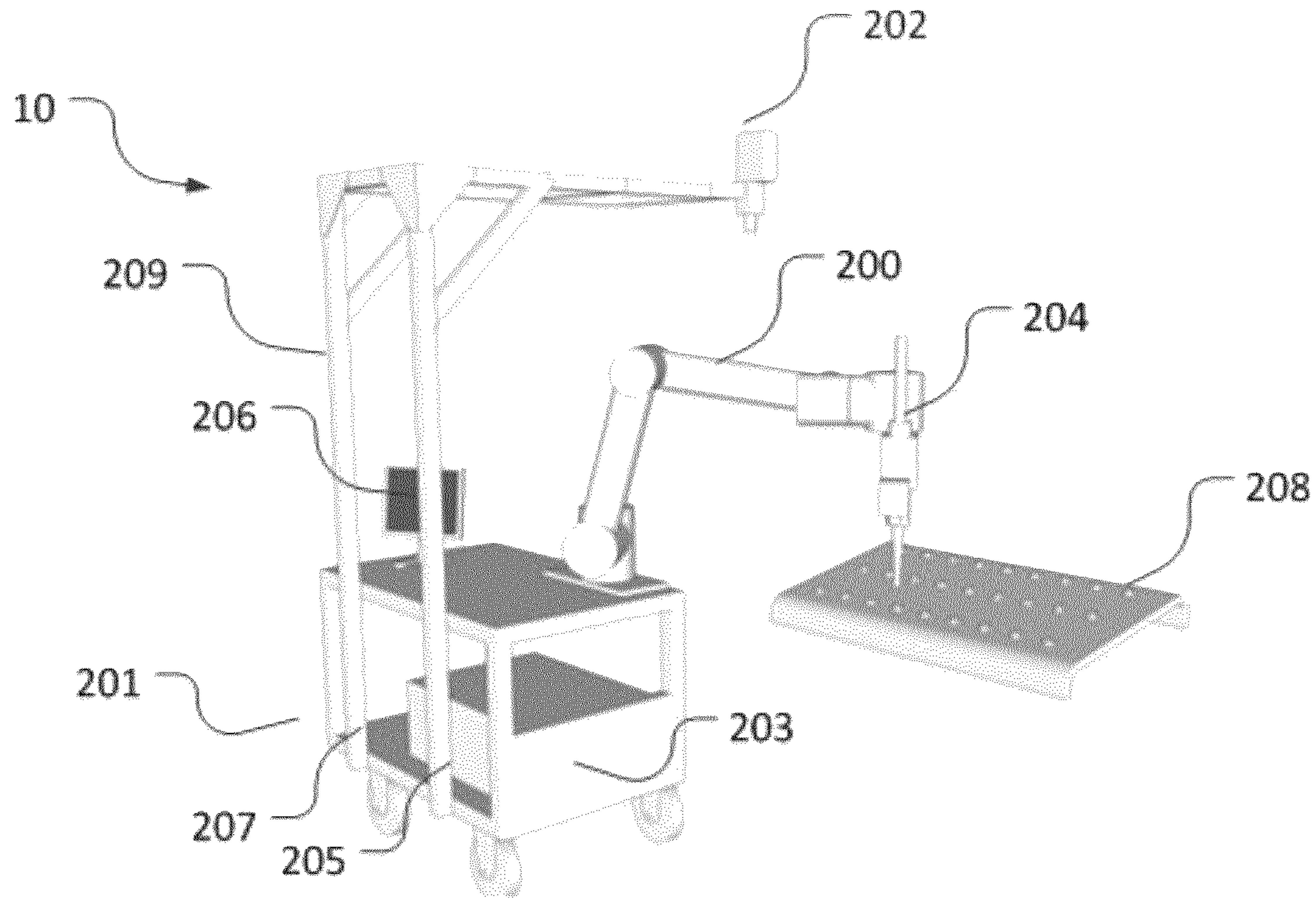


Figure 2