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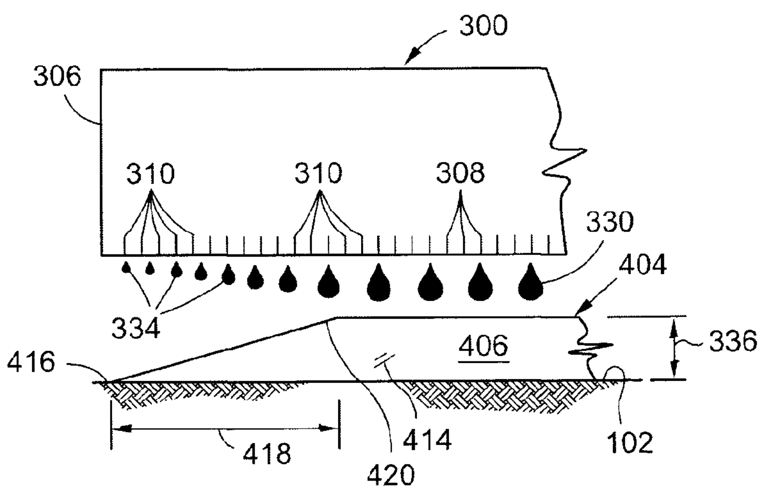
(54) **Titre : MAINTIEN DE L'INTENSITE D'IMAGE AU MOYEN DU CHEVAUCHEMENT DE BANDES DE GRADIENT D'IMAGE**
(54) **Title: MAINTAINING IMAGE INTENSITY USING OVERLAPPING IMAGE GRADIENT BANDS**



(57) **Abrégé/Abstract:**
A system for printing an image on a surface may include a robot having at least one arm. A printhead may be mounted to the arm and may be movable by the arm over a surface along a rastering path while printing an image slice on the surface. The image slice may have opposing side edges. The printhead may be configured to print the image slice with an image gradient band along at least one of opposing side edges wherein an image intensity within the image gradient band decreases from an inner portion of the image gradient band toward the side edge.

ABSTRACT

A system for printing an image on a surface may include a robot having at least one arm. A printhead may be mounted to the arm and may be movable by the arm over a surface along a rastering path while printing an image slice on the surface. The image slice may have opposing side edges. The printhead may be configured to print the image slice with an image gradient band along at least one of opposing side edges wherein an image intensity within the image gradient band decreases from an inner portion of the image gradient band toward the side edge.

MAINTAINING IMAGE INTENSITY USING OVERLAPPING IMAGE GRADIENT BANDS

FIELD

The present disclosure relates generally to coating application systems and, more particularly, to an automated system and method of printing images on a surface using a robotic mechanism.

BACKGROUND

The painting of an aircraft is a relatively challenging and time-consuming process due to the wide range of dimensions, the unique geometry, and the large amount of surface area on an aircraft. For example, the wings protruding from the fuselage can interfere with the painting process. The height of the vertical tail above the horizontal tail can present challenges in accessing the exterior surfaces of the vertical tail. Adding to the time required to paint an aircraft are complex paint schemes that may be associated with an aircraft livery. In this regard, the standard livery of an airline may include images or designs with complex geometric shapes and color combinations and may include the name and logo of the airline which may be applied to different locations of the aircraft such as the fuselage, the vertical tail, and the engine nacelles.

Conventional methods of painting an aircraft require multiple steps of masking, painting, and demasking. For applying an aircraft livery with multiple colors, it may be necessary to perform masking, painting, and demasking for each color in the livery and which may add to the overall amount of time required to paint the aircraft. In addition, the aircraft livery must be applied in a precise manner to avoid gaps that may otherwise expose a typically-white undercoat which may detract from the overall appearance of the aircraft. Furthermore, the process of applying paint to the aircraft surfaces must be carried out with a high level of control to ensure an acceptable level of coating thickness to meet performance (e.g., weight) requirements.

As can be seen, there exists a need in the art for a system and method for painting an aircraft including applying complex and/or multi-colored images in a precise, cost-effective, and timely manner.

SUMMARY

In one embodiment, there is provided a system for printing an image on a surface. The system includes a robot having at least one arm, and a printhead mounted to the arm and movable by the arm over a surface along a rastering path while printing an image slice on the surface. The printhead is configured to print each image slice with an image gradient band along at least one of opposing side edges of the image gradient band. An image intensity within each image gradient band decreases along a direction transverse to the direction of the rastering path from an inner portion of the image gradient band toward a side edge. The arm is configured to move the printhead in parallel relation to an existing image slice in a manner such that the image gradient band of the new image slice overlaps the image gradient band of the existing image slice such that the image intensity of an overlap of the image gradient bands is substantially equivalent to the image intensity of the inner portion of at least one of the new image slice and the existing image slice.

The printhead may include an array of nozzles distributed along a printhead width. The printhead may be configured to generate the image gradient band by ejecting droplets in at least one of the following manners progressively larger droplet spacing along a direction toward the side edge, and progressively smaller droplet size along a direction toward the side edge.

The printhead may be an inkjet printhead.

In another embodiment, there is provided a method for printing an image on a surface. The method involves positioning an arm of a robot adjacent to a surface, the arm having a printhead mounted to the arm; moving, using the arm, the printhead over

the surface along a rastering path while printing a new image slice on the surface in parallel relation to an existing image slice. The method further involves printing an image gradient band along at least one side edge of the image slice when printing the new image slice, the image gradient band having an image intensity that decreases along a direction transverse to the direction of the rastering path from an inner portion of the image gradient band toward the side edge. The method further involves moving the printhead in a manner such that the image gradient band of the new image slice overlaps the image gradient band of the existing image slice with an image intensity equivalent to the image intensity of an inner portion of at least one of the new image slice and the existing image slice. '

The printhead may include an array of nozzles for ejecting droplets, and forming the image gradient band may include ejecting progressively larger droplet spacings along a direction toward the side edge, and ejecting progressively smaller droplet sizes along a direction toward the side edge.

In another embodiment, there is provided a system for printing an image on a surface. The system inclides a robot having at least one arm, an inkhet printhead mounted to the arm and movable by the arm over a surface along a rastering path while printing an image slice on the surface. The printhead is configured to print the image slice with an image gradient band along at least one of opposing side edges of the image gradient band wherein an image intensity within the image gradient band decreases from an inner portion of the image gradient band toward the side edge. The robot is configured to electronically offset groups of nozzles actively ejecting droplets in a manner such that a side edge of the new image slice is aligned with the side edge of the existing image slice.

The arm may be configured to move the printhead in parallel relation to an existing image slice in a manner such that an image gradient band of a new image slice overlaps an image gradient band of the existing image slice.

The printhead is configured to print the image gradient band of the new image slice and the existing image slice such that an overlap of image gradient bands has an image intensity equivalent to the image intensity of the inner portion of at least one of the new image slice and the existing image slice.

The printhead may include an array of nozzles distributed along a printhead width. The printhead may be configured to generate the image gradient band by ejecting droplets in at least one of the following manners progressively larger droplet spacing along a direction toward the side edge, and progressively smaller droplet size along a direction toward the side edge.

The system may include a reference line printing mechanism configured to print a reference line on the surface when printing the new image slice, and a reference line sensor configured to sense the reference line of an existing image slice and transmit a signal to the robot causing the arm to adjust the printhead such that a side edge of the new image slice is aligned with the side edge of the existing image slice.

The reference line printing mechanism may include at least one nozzle of the printhead.

The robot may be configured to adjust the lateral position of the printhead in a manner such that a side edge of the new image slice is aligned with the side edge of the existing image slice.

The system may include at least one high-bandwidth actuator coupling the printhead to an end of the arm, and the high-bandwidth actuator configured to adjust at least one of an orientation and a position of the printhead relative to the surface during movement of the printhead along the rastering path.

The high-bandwidth actuator may be configured to adjust the printhead along at least one of the following directions a transverse direction of translation parallel to the surface and perpendicular to the rastering path, a normal direction of translation normal to the surface; and a roil direction of rotation about an axis parallel to the rastering path.

The high-bandwidth actuator may include a first actuator, a second actuator, and a third actuator arranged in an in-plane tripod configuration and each having an upper end and a lower end, the upper ends pivotably coupled to an end of the arm of the robot. The lower ends may be pivotably coupled to the printhead; the upper ends of the first and third actuator is spaced apart from one another. The lower ends of the first and third actuator may be spaced apart from one another. The upper end of the second actuator may be located adjacent to the upper end of the first actuator. The lower end of the second actuator may be located adjacent to the lower end of the third actuator such that the second actuator extends diagonally between the upper end of the first actuator and the lower end of the third actuator. The first, second, and third actuators may enable adjustment of the printhead along the transverse direction, the normal direction, and the roll direction.

In another embodiment, there is provided a method for printing an image on a surface. The method involves positioning an arm of a robot adjacent to a surface, the arm having a printhead mounted to the arm, and moving, using the arm, the printhead over the surface along a rastering path while printing an image slice on the surface. The method further involves printing an image gradient band along at least one side edge of the image slice when printing the image slice, the image gradient band having an image intensity that decreases along a direction toward the side edge. The robot is configured to electronically offset groups of nozzles actively ejecting droplets in a manner such that a side edge of the new image slice is aligned with the side edge of the existing image slice.

Moving the printhead and printing the image gradient band may include moving the printhead along the rastering path to print a new image slice in parallel relation to an existing image slice in a manner such that the image gradient band of the new image slice overlaps the image gradient band of the existing image slice.

Printing the image gradient band may include printing the image gradient band of the new image slice and the existing image slice in a manner such that an overlap of the image gradient bands has an image intensity equivalent to the image intensity of an inner portion of' at least one of the new image slice and the existing image slice.

The printhead may include an array of nozzles for ejecting droplets, forming the image gradient band may include ejecting progressively larger droplet spacings along a direction toward the side edge, and ejecting progressively smaller droplet sizes along a direction toward the side edge.

The features, functions and advantages that have been discussed can be achieved independently in various embodiments of the present disclosure or may be combined in yet other embodiments, further details of which can be seen with reference to the following description and drawings below.

BRIEF DESCRIPTION OF THE DRAWINGS

These and other features of the present disclosure will become more apparent upon reference to the drawings wherein like numbers refer to like parts throughout and wherein:

Figure **1** is a block diagram of an example of an image forming system;

Figure **2** is perspective view of an aircraft surrounded by a plurality of gantries supporting one or more image forming systems for printing one or more images on the aircraft;

Figure **3** is a perspective view of the aircraft showing one of the gantries positioned adjacent to a vertical tail and supporting an image forming system for printing an image on the vertical tail;

Figure **4** is an end view of the aircraft showing image forming systems positioned on opposite sides of the aircraft;

Figure **5** is a perspective view of a robot taken along line **5** of Figure **4** and illustrating the robot mounted to a crossbeam of a gantry and having a printhead mounted on an arm of the robot;

Figure **6** is a side view of the image forming system taken along line **6** of Figure **4** and illustrating the printhead printing an image on the vertical tail;

Figure **7** is a plan view of an example of a printhead being moved along a rastering path to form an image slice having an image gradient band overlapping the image gradient band of an adjacent image slice;

Figure **8** is a sectional view of a printhead taken along line **8** of Figure **7** and illustrating overlapping image gradient bands of the image slices printed by the printhead;

Figure **9** is a magnified view of a portion of a printhead taken along line **9** of Figure **8** and showing progressively increasing droplet spacings as may be ejected by active nozzles to form an image gradient band;

Figure **10** is a magnified view of a portion of a printhead showing progressively decreasing droplet sizes as may be ejected by the nozzles to form an image gradient band;

Figure **11** is a diagrammatic sectional view of adjacent image slices with overlapping image gradient bands;

Figure **12** is a plan view of the adjacent image slices of Figure **11** showing the overlapping image gradient bands;

Figure **13** is an example of a printhead printing a reference line while printing a new image slice;

Figure **14** is a sectional view taken along line **14** of Figure **13** and illustrating a printhead including a reference line printing mechanism and one or more reference line sensors for sensing the reference line of an existing image slice;

Figure **15** is a magnified view taken long line **15** of Figure **14** and showing one of the nozzles of the printhead printing the reference line while the remaining nozzles of the printhead print the image slice;

Figure **16** is a magnified view of an example of a printhead having a reference line sensor for sensing the reference line of an existing image slice;

Figure **17** is a side view of an example of a robot having one or more high-bandwidth actuators coupling the printhead to an arm of the robot;

Figure **18** is a side view of an example of a plurality of high-bandwidth actuators coupling a printhead to an arm of a robot;

Figure **19** is a side view of the printhead after repositioning by the high-bandwidth actuators into alignment with the reference line and reorientation of the printhead face parallel to the surface;

Figure **20** is a perspective view of an example of a delta robot having a plurality of high-bandwidth actuators coupling the printhead to an arm of a robot;

Figure **21** is a flowchart having one or more operations that may be included in method of printing an image on a surface wherein the parallel image slices each have one or more image gradient bands along the side edges of the image slices;

Figure **22** is a flowchart having one or more operations that may be included in a method of printing an image on a surface wherein the image slices have a reference line for aligning a new image slice with an existing image slice.

DETAILED DESCRIPTION

Referring now to the drawings wherein the showings are for purposes of illustrating various embodiments of the present disclosure, shown in Figure **1** is a block diagram of an example of an image forming system **200** as may be implemented for robotically (e.g., automatically or semi-automatically) printing an image **400** (Figure **2**) on a surface **102**. The system **200** may include a robot **202** (a robotic mechanism) and/or at least one arm (e.g., a first and second arm **210**, **212**). The printhead **300** may be mounted on an arm (e.g., the second arm **212**). In some examples, the system **200** may include one or more high-bandwidth actuators **250** coupling the printhead **300** to the end **214** (Figure **5**) of the arm. As described below, such high-bandwidth actuators **250** may provide precise and rapid control over the position and orientation of the printhead **300** during printing of an image slice **404**.

The printhead **300** may be configured as an inkjet printhead having a plurality of nozzles **308** or orifices for ejecting droplets **330** (Figure **10**) of ink, paint, or other fluids or colorants onto a surface **102** to form an image **400**. The inkjet printhead **300** may be configured as a thermal inkjet printer, a piezoelectric printer, or a continuous printer. However, the printhead **300** may be provided in other configurations such as a dot matrix printer or other printer configurations capable of printing an image **400** on a surface **102**.

The image forming system **200** may print image slices **404** on a surface **102** along a series of parallel rastering paths **350** (Figure **7**). The parallel image slices **404** may collectively form an image **400**. In one example, the printhead **300** may print an image slice **404** in overlapping relation to an adjacent image slice **404**. In this regard, the printhead **300** may be configured to print an image slice **404** with an image gradient band **418** along at least one side edge **416** (Figure **6**) of the image slice **404**. The image gradient band **418** of one image slice **404** may overlap the image gradient band **418** of an adjacent image slice **404**. The image intensity within an image gradient band **418** may decrease along the direction transverse to the direction of the rastering path **350**. By overlapping the image gradient bands **418** of adjacent image slices **404**, gaps in the image **400** may be prevented. In the present disclosure, the image intensity within overlapping image gradient bands **418** may result in a substantially uniform image gradient across the width of an image **400** such that the overlaps may be visually imperceptible. In one example, the image intensity within the overlapping image gradient bands **418** may be substantially equivalent to the image intensity within an inner portion **414** of each image slice **404**.

In another example of the image forming system **200**, the printhead **300** may include a reference line printing mechanism **320** that may print a reference line **322** during the printing of an image slice **404**. For example, a reference line **322** may be printed along a side edge **416** of an image slice **404**. The printhead **300** may include a reference line sensor **326** configured to detect and/or sense the reference line **322** of an existing image slice **408** and transmit a path-following-error signal to the robot **202** causing the robot arm (Figure **5**) or high-bandwidth actuators **250** (see Figures **17-20**) to correct or adjust the printhead **300** (e.g., in real time) such that the side edge **416** of the new image slice **406** is maintained in alignment with the side edge **416** of the existing image slice **408** during the printing of the new image slice **406**. In this manner, the reference line **322** may allow the printhead **300** to precisely follow the rastering path **350** of a previously-printed image slice **404** such that the side edges **416** of the new and existing image slices **406**, **408** (Figure **7**) are aligned in non-gapping and/or non-overlapping relation to one another, and thereby avoiding gaps between adjacent image slices **404** which may otherwise detract from the quality of the image **400**.

Figure **2** is perspective view of an aircraft **100** and a gantry system which may be implemented for supporting one or more image forming systems **200** as disclosed herein. The aircraft **100** may have a fuselage **104** having a nose **106** at a forward end and an empennage **108** at an aft end of the fuselage **104**. The top of the fuselage **104** may be described as the crown, and the bottom of the fuselage **104** may be described as the keel. The aircraft **100** may include a pair of wings **114** extending outwardly from the fuselage **104**. One or more propulsion units may be mounted to the aircraft **100** such as to the wings **114**. The empennage **108** may include a horizontal tail **110** and a vertical tail **112**.

In Figure **2**, the gantry system may be housed within a hangar **120** and may include a plurality of gantries **124** positioned on one or more sides on the aircraft **100**.

Each one of the gantries **124** may include a pair of vertical towers **126** that may be movable via a motorized base **128** along a floor track system **130** that may be coupled to or integrated into a floor **122**. Each gantry **124** may include a crossbeam **132** extending between the towers **126**. The crossbeam **132** of each gantry **124** may include a personnel platform **134**. In addition, the crossbeam **132** may support at least one robot **202** that may be movable along the crossbeam **132**. The gantry system may provide a means for positioning the robot **202** such that the printhead **300** has access to the crown, the keel, and other exterior surfaces **102** of the aircraft **100** including the sides of the fuselage **104**, the vertical tail **112**, the propulsion units, and other surfaces **102**.

Although the system **200** and method of the present disclosure is described in the context of printing images on an aircraft **100**, the system **200** and method may be implemented for printing images on any type of surface, with out limitation. In this regard, the surface **102** may be a surface of a motor vehicle including a tractor-trailer, a building, a banner, or any other type of movable or non-movable structure, object, article, or material having a surface to be printed. The surface may be planar, simply curved, and/or complexly curved.

Figure **3** shows a gantry **124** positioned adjacent to the vertical tail **112**. A robot **202** mounted to the crossbeam may support an image forming system **200** for printing an image **400** on the vertical tail **112**. In Figure **3**, the image **400** is shown as a flag which may be printed on the vertical tail **112** such as by using ink from an inkjet printhead **300**. However, the printhead **300** may be configured to apply images using other fluids including, but not limited to paint, pigment, and/or other colorants and/or fluids. In addition, the image forming system **200** disclosed herein is not limited to forming graphic images.

In the present disclosure, the term "image" includes any type of coating that may be applied to a surface **102** (Figure **2**). An image may have a geometric design, any number of color(s) including a single color, and/or may be applied in any type of coating composition(s). In one example, the image **400** may include a graphic design, a logo, lettering, symbols, and/or any other types of indicia. In this regard, an image **400** may include an aircraft livery **402** which may comprise a geometric design or pattern that may be applied to the exterior surfaces **102** of an aircraft **100**, as described above. The image **400** may include a reproduction of a photograph. Even further, an image **400** may be a monotone coating of paint, ink, or other colorant or fluid, and is not limited to a graphic design, logo, or lettering or other indicia.

Figure **4** is an end view of an aircraft **100** showing image forming systems **200** positioned on opposite sides of the aircraft **100**. Each image forming system **200** may include a robot **202** having one or more arms and a printhead **300** coupled to a terminal end **214** (Figure **4**) of the arm of the robot **202**. One of the image forming systems **200** is shown printing an image **400** (e.g., a flag) on a vertical tail **112**. The other image forming system **200** is shown a printing an image **400** such as the geometric design of an aircraft livery **402** (e.g., see Figure **2**) on a side of fuselage **104**.

Although the robot **202** of the image forming system **200** is described as being mounted on a gantry **124** supported on a crossbeam **132** suspended between a pair of towers **126** (Figures **1-5**), the robot **202** may be supported in any manner, without limitation. For example, the robot **202** may be suspended from an overhead gantry **124** (not shown). Alternatively, the robot **202** may be mounted on another type of movable platform. Even further, the robot **202** may be non-movably or fixedly supported on a shop floor (not shown) or other permanent feature.

Figure **5** is a perspective view of a robot **202** mounted to a crossbeam **132** of a gantry **124** and having a printhead **300** mounted on an arm of the robot **202**. The robot **202** may be movable along guide rails **206** extending along a lengthwise direction of the crossbeam **132**. In the example shown, the robot **202** may include a robot base **204**, a first arm **210**, and a second arm **212**, with the printhead **300** mounted on the end **214** of the second arm **212**. The robot base **204** may allow for rotation of the robot base **204** about a first axis **216** relative to the crossbeam **132**. The first arm **210** may be rotatable about a second axis **218** defined by a joint coupling the first arm **210** to the robot base **204**. The second arm **212** may be rotatable about a third axis **220** defined by a joint coupling the second arm **212** to the first arm **210**. In addition, the second arm **212** may be swivelable about a fourth axis **222** extending along a length of the second arm **212**. The length of the second arm **212** may be extendable and retractable to define a fifth axis **224** of movement.

In Figure **4**, **5** the printhead **300** is shown being rotatable about a sixth axis **226** defined by a joint coupling the printhead **300** to the second arm **212**. The robot base **204** may include a robot drive system (not shown) for propelling the robot base **204** along the length of the crossbeam **132** and defining a seventh axis **228** of movement of the robot **202**. The robot **202** may include a controller **208** for controlling the operation of the base **204**, the arms, and/or the printhead **300**. Although shown as having a first arm **210** and a second arm **212**, the robot **202** may include any number of arms and joints for movement about or along any number of axes to allow the printhead **300** to reach any one of a variety of different locations and orientation relative to a surface **102**. In some examples, the robot **202** may be devoid of a base **204** and/or the robot may comprise a single arm to which the printhead **300** may be coupled.

Figure **6** is a side view of the image forming system **200** printing an image **400** on the vertical tail **112**. The first arm **210** and second arm **212** may be movable relative to the base **204** of the robot **202** to position the printhead **300**. The printhead **300** is movable by the arms over the surface **102** along one or more rastering paths **350** to print an image slice **404** on the surface **102**. The printhead **300** may be moved along parallel rastering paths **350** to form parallel images slices **404** that collectively define the image **400**. The robot **202** may be configured to maintain the orientation of the printhead face **304** parallel to the local position on the surface **102** as the printhead **300** is moved over the surface **102**.

Figure **7** shows an example of a printhead **300** being moved along a rastering path **350** to form an image slice **404**. Each one of the rastering paths **350** is shown as being straight when viewed from above along a direction normal to the surface **102**. However, the printhead **300** may be moved along a rastering path **350** that is curved or a combination of curved and straight. The printhead **300** may sequentially print a plurality of parallel image slices **404** side-by-side to collectively form an image **400** on the surface **102**.

Figure **8** is a sectional view of a printhead **300** printing image slices **404** on a surface **102**. The printhead width **302** may be oriented parallel to a transverse direction **354** (Figure **13**) to the rastering path **350**. The printhead **300** may include a plurality of nozzles **308** or orifices distributed between opposing widthwise ends **306** of the printhead **300**. For example, an inkjet printhead may include thousands of orifices. The printhead **300** may eject droplets **330** (Figure **10**) of ink, paint, or other fluids from the orifices to form a coating having a coating thickness **336** on the surface **102**.

Each image slice **404** (Figure **8**) may have opposing side edges **416** defining a bandwidth **410** of the image slice **404**. The printhead **300** may be configured to print an image slice **404** with an image gradient band **418** along at least one of the side edges **416**. In the example shown, an image slice **404** may contain an inner portion **414** bounded on opposite sides by an image gradient band **418**. An image gradient band **418** may be described as a band within which the intensity of the color of the image slice **404** changes (e.g., decreases) along a transverse direction **354** relative to the direction of the rastering path **350** from an inner boundary **420** of the image gradient band **418** to the side edge **416**. For example, the inner portion **414** of the image slice **404** may be black in color. Within the image gradient band, the color may gradually change from black at the inner boundary **420** (e.g., a relatively high intensity) to white (e.g., a relatively low intensity) at the side edge **416** of the image slice **404**. An image gradient band **418** of an image slice **404** may be wider than the inner portion **414** of the image slice **404**. For example, an image gradient band **418** may be no more than **30**% the bandwidth **410** of the image slice **404**.

The printhead **300** may be moved along the rastering paths **350** such that the image gradient bands **418** of the image slices **404** overlap. The overlapping rastering paths **350** may allow for gaps and overlaps representing deviations from the nominal spacing between adjacent image slices **404** resulting in a reduced likelihood that such deviations from the nominal image slice spacing are visually perceptible. In this regard, the image gradient bands **418** on the side edges **416** of the adjacent image slices **404**, when superimposed, result in imperceptible image edges even with imperfect tracking by the robot **202** along the rastering paths **350**. In this manner, the image gradient bands **418** allow for printing of complex, intricate, and multi-colored images in multiple, single-pass image slices **404** on large-scale surfaces **102** using large-scale rastering devices such as the robot **202** shown in Figures **1-5**.

Figure **9** is a magnified view of a printhead **300** showing one example for forming an image gradient band **418**. As indicated above, the decrease in the intensity of the image gradient band **418** may be achieved by reducing or tapering the coating thickness **336** along a transverse direction **354** (Figure **13**) from the inner boundary **420** of the image gradient band **418** to the side edge **416** of the image slice **404**. The droplet spacing **332** may be uniform within the inner portion **414** of the image slice **404**. In Figure **9**, the coating thickness **336** within the image gradient band **418** may be tapered by progressively increasing the droplet spacing **332** between the droplets **330** ejected by the nozzles **308**. In this regard, some of the nozzles **308** (e.g., orifices) of the printhead **300** in the area wherein the image gradient band **418** is to be printed may be electronically deactivated and may be referred to as inactive nozzles **312**, and only active nozzles **310** within the image gradient band **418** may eject droplets **330** to form the image gradient band **418**. In other examples, the printhead **300** may be provided with progressively larger gaps between nozzles **308** for the area wherein the image gradient band **418** is to be printed.

Figure **10** is a magnified view showing another example of a printhead **300** forming an image gradient band **418** by maintaining the nozzles **308** as active nozzles **310** producing a uniform droplet spacing, and progressively decreasing the droplet size **334** in the area where the image gradient band **418** is to be formed. In still further examples, and image gradient band **418** may be formed by a combination of controlling the droplet spacing **332** and controlling the droplet size **334**. However, other techniques may be implemented for forming image gradient band **418** and are not limited to the examples shown in the Figures and described above. The printhead **300** may be configured to form the image gradient band **418** with an image gradient that is linearly decreasing. Alternatively, the image gradient within the image gradient band **418** may be non-linear.

Figure **11** is a diagrammatic sectional view of adjacent image slices **404** with overlapping image gradient bands **418**. Shown is the coating thickness **336** (Figure **10**) in the image gradient band **418** and in the inner portion **414** of each image slice **404**. Figure **12** is a plan view of the image slices **404** of Figure **11** showing the overlapping image gradient bands **418** and the parallel rastering paths **350** of the image slices **404**. In the system **200** as shown, the arm (Figure **7**) may move the printhead **300** to print a new image slice **406** in parallel relation to an existing image slice **408** (e.g., a previously-printed image slice **404**) in a manner such that an image gradient band **418** of the new image slice **406** (Figure **8**) overlaps an image gradient band **418** of the existing image slice **408**. In this regard, the side edge **416** of each image slice **404** may be aligned with an inner boundary **420** of an overlapping or overlapped image gradient band **418**. However, in an example not shown, the printhead **300** may print image slices **404** in a manner to form a gap between the side edge **416** of an image gradient band **418** of a new image slice **406** and an existing image slice **408**. As indicated above, the printhead **300** may print the image gradient band **418** of the new image slice **406** and the existing image slice **408** such that the overlap has an image intensity equivalent to the image intensity of the inner portion **414** of the new image slice **406** and/or the existing image slice **408**.

In a still further example not shown, the printhead **300** (Figure **10**) may form an image gradient end on at least one of opposing ends of an image slice **404**. An image gradient end may have an image intensity that may decrease toward an end edge (not shown) of the image slice **404**. Such an image gradient end may provide a means for blending (e.g., feathering) the image slice **404** with the color and design of the existing color and design of the surface **102** area surrounding the newly-applied image **400**. For example, the system may apply a newly-applied image **400** to a portion of a surface that may have undergone reworking such as the removal and/or replacement of a portion of a composite skin panel (not shown) and/or underlying structure. The image gradient ends of the newly-applied image slices **404** may provide a means for blending into the surrounding surface **102**. The image gradient end may also facilitate the blending on a new image slice **406** with the image gradient end of another image **400** located at an end of a rastering path **350** of the new image slice **406**.

Referring to Figure **13**, shown is an example of a printhead **300** mounted on an end **214** of a robot arm and being movable by the arm over a surface **102** along a rastering path **350** while printing a new image slice **406** adjacent to an existing image slice **408**. The printhead **300** may include a reference line printing mechanism **320** configured to print a reference line **322** when printing the new image slice **406**. The reference line **322** may provide a means for the printhead **300** to precisely track the rastering path **350** of an existing image slice **408**. The printhead **300** may include a reference line sensor **326** such as an image detection system for sensing the reference line **322** and providing path error feedback to the controller **208** (Figure **14**) to allow the robot **202** to generate path correction inputs to the printhead **300** such that the side edge **416** of the new image slice **406** is maintained in alignment with the side edge **416** of the existing image slice **408**.

Figure **14** shows an example of a printhead **300** printing an image slice **404** adjacent to an existing image slice **408**. The existing image slice **408** may include a reference line **322** along one of the side edges **416**. The printhead **300** may have one or more reference line sensors **326** mounted on each one of the widthwise ends **306** of the printhead **300**. One of the reference line sensors **326** may be configured to sense the reference line **322** of an existing image slice **408**. In addition, the printhead **300** may include one or more position sensors **314** for monitoring the position and/or orientation of the printhead **300** relative to the surface **102**. In some examples, the reference lines **322** sensor may be configured as position sensors **314** to sense the position and/or orientation of the printhead **300** in addition to sensing the reference line **322**.

The position sensors **314** at one or both of the widthwise ends **306** of the printhead **300** may measure a normal spacing **338** of the printhead **300** from the surface **102** along a direction locally normal to the surface **102**. Feedback provided by the position sensors **314** to the controller **208** may allow the controller **208** to adjust the arm position such that the face of the printhead **300** is maintained at a desired normal spacing **338** from the surface **102** such that the droplet may be accurately placed on the surface **102**. In further examples, the controller **208** may use continuous or semi-continuous feedback from the position sensors **314** to rotate the printhead **300** as necessary along a roll direction **358** such that the face of the printhead **300** is maintained parallel to the surface **102** as the printhead **300** is moved over the surface **102** which may have a changing and/or curved contour.

Figure **15** shows an example of a printhead **300** wherein the reference line printing mechanism **320** comprises one or more dedicated nozzles **308** configured to print the reference line **322** on at least one of opposing side edges **416** of a new image slice **406**. The remaining nozzles **308** of the printhead **300** may be configured to print the image slice **404**. In other examples not shown, the reference line printing mechanism **320** may comprise a dedicated line-printing device that may be mounted on the printhead **300** and configured to print a reference line **322** while the nozzles **308** of the printhead **300** print the image slice **404**.

The printhead **300** may print the reference line **322** to be visible within a certain spectrum such as the visible spectrum and/or the infrared spectrum. In some examples, the reference line **322** may have a thickness that prevents detection by the human eye beyond a certain distance (e.g., more than **10** feet) from the surface **102**. In other examples, the reference line **322** may be printed as a series of spaced dots (e.g., every **0.01** inch) which may be visually imperceptible beyond a certain distance to avoid detracting from the quality of the image. In still other examples, the color of the reference line **322** may be imperceptible relative to the local color of the image **400**, or the reference line **322** may be invisible in normal ambient lighting conditions (e.g., shop light or sunlight) and may be fluorescent under a fluorescent light that may be emitted by the reference line sensor **326**. Even further, the reference line **322** may be invisible within the visible spectrum, or the reference line **322** may initially be visible under ambient light and may fade over time under ambient conditions such as due to exposure to ultraviolet radiation.

In still further examples, the reference line **322** may be printed with at least one encoding pattern **324** (e.g., see Figure **13**) along at least a portion of the reference line **322**. The encoding pattern **324** may comprise a system of line segments or dashes separated by gaps. The encoding pattern **324** may represent information about the image slice **404**. For example, the encoding pattern **324** may represents information regarding the distance from the current location (e.g., the location where the encoding pattern **324** is currently detected) of the printhead **300** relative to an end **412** of the image slice **404**. Such information may be included in the signal transmitted to the controller **208** to allow the controller **208** to control the operation of the printhead **300**. For example, the encoding pattern **324** may signal the controller **208** to synchronize or align a new image slice **406** being printed with the existing image slice **408**, or to signal to the controller **208** to halt the ejection of droplets **330** in correspondence with the end of the existing image slice **408**.

Figure **16** is a magnified view of an example of a printhead **300** having a reference line sensor **326** for sensing a reference line **322** of an image slice **404**. The reference line sensor **326** may transmit to the controller **208** (Figure **14**) a path-following-error signal representing the lateral spacing **340** between the reference line **322** and an indexing feature. The indexing feature may be the centerline of the reference line sensor **326**, a hardpoint on the printhead **300** such as the nozzle **308** at an extreme end of the printhead **300**, or some other indexing feature. As the printhead **300** is moved along a rastering path **350**, the reference line sensor **326** may sense and transmit (e.g., continuously, in real-time) the path-following-error signal to the controller **208** representing the lateral spacing **340**. Based **204** on the signal, the controller **208** may cause the lateral position of the printhead **300** to be adjusted (e.g., by the arm) such that the side edge **416** of the new image slice **406** is maintained in alignment with the side edge **416** of an existing image slice **408**.

The reference line sensor **326** may be configured as an optical sensor of a vision system. In Figure **16**, the optical sensor may emit an optical beam **328** for detecting the reference line **322**. The optical sensor may generate a signal representing the lateral location where the optical beam **328** strikes the reference line **322**. The signal may be transmitted to the robot **202** controller **208** on demand, at preprogrammed time intervals, continuously, or in other modes. In one example, the reference line sensor **326** may provide real-time alignment feedback to the robot **202** controller **208** for manipulating or adjusting the printhead **300** such that the side edges **416** of the new image slice **406** and existing image slice **408** are aligned. For example, the robot **202** may adjust the lateral position of the printhead **300** such that the side edges **416** of the new image slice **406** and the existing image slice **408** are aligned in non-gapped and/or non-overlapping relation as a new image slice **406** is being printed.

In other examples, instead of adjusting the lateral position of the printhead **300**, the robot controller **208** may maintain the lateral position of the printhead **300** during movement along the rastering path **350**, and the controller **208** may electronically control or shift the nozzles **308** on the printhead **300** that are actively ejecting droplets **330**. In this regard, a printhead **300** may have additional (e.g., unused) nozzles **308** located at one or both of the widthwise ends **306** of the printhead **300**. Upon the controller **208** determining that a new image slice **406** is misaligned with an existing image slice **408**, the controller **208** may activate one or more of the unused nozzles **308** at one of the widthwise ends **306**, and deactivate an equal number of nozzles **308** at an opposite widthwise end **306** of the printhead **300** to maintain the same image slice width of the new image slice **406** while effectively shifting the lateral position of the new image slice **406** without laterally moving the printhead **300**. In this regard, an image slice **404** may be electronically offset in real-time or near real-time such that the side edge **416** of the new image slice **406** is maintained in non-gapping and/or non-overlapping relation with the side edge **416** of an existing image slice **408**. In this manner, the reference line **322** may provide a means for the printhead **300** to precisely maintain a nominal distance of a new image slice **406** relative to the rastering path **350** of an existing or previous-applied image slice **404**, and thereby avoid gap between the image slices **404**.

Figure **17** is a side view of an example of a robot **202** having high-bandwidth actuators **250** coupling the printhead **300** to an arm of the robot **202** and showing the printhead **300** printing an image **400** (e.g., an aircraft livery **402**) on a surface **102** of a fuselage **104**. As indicated above, a relatively large robot **202** may be required for printing large surfaces **102**. Such a large-scale robot **202** may have a relatively high mass and relatively low stiffness which may result in an inherently large tolerance band of movement at the end **214** of the arm (e.g., the last axis of the robot) on which the printhead **300** may be mounted. In attempts to compensate for such inherently large tolerances, a large-scale robot **202** may require extensive computer programming (e.g., CNC or computer-numerical-control programming) which may add to production cost and schedule. By printing image slices **404** with the above-described image gradient bands **418** (Figures **7-12**) and/or reference lines **322** (Figures **13-16**), the robot-mounted printhead **300** of the present disclosure may print a high-quality image **400** on a surface **102** without the occurrence of gaps between adjacent image slices **404** that would otherwise detract from the overall quality of the image.

In Figure **17**, one or more high-bandwidth actuators **250** may be mounted in series with the one or more arms of the robot **202**. Such high-bandwidth actuators **250** may couple the printhead **300** to the last axis or arm of the robot **202** and provide a relatively small tolerance band for adjusting the an orientation and/or position of the printhead **300** relative to the surface **102** during movement of the printhead **300** along a rastering path **350** such that a new image slice **406** may be accurately aligned with an existing image slice **408**. The high-bandwidth actuators **250** may be described as high-bandwidth in the sense that the high-bandwidth actuators **250** may have small mass and inherently high stiffness which may result in increased precision and rapid response time in positioning and orienting a printhead **300** relative to the large mass, low stiffness, and corresponding slow response time of a large-scale robot **202**. Further in this regard, the high-bandwidth actuators **250** may rapidly respond to commands from the robot controller **208** based on path-following-error signals provided in real-time by the reference line sensor **326**.

Referring still to Figure **17**, the system **200** may include one or more high-bandwidth actuators **250** which may be configured to adjust the position of the printhead **300** along at least one of the following directions: (**1**) a transverse direction **354** of translation of the printhead **300** parallel to the surface **102** and perpendicular to the rastering path **350**, (**2**) a normal direction **356** of translation of the printhead **300** locally normal to the surface **102**, and (**3**) a roll direction **358** of rotation of the printhead **300** about an axis parallel to the rastering path **350**. In addition, one or more high-bandwidth actuators **250** may be configured to adjust the position of the printhead **300** along other directions including, but not limited to, a parallel direction **352** of translation which may be described as parallel to the primary direction of movement of the printhead **300** along the rastering path **350** during the printing of an image slice **404**.

Figure **18** shows an example of three (**3**) high-bandwidth actuators **250** coupling a printhead **300** to an arm of a robot **202** (Figure **17**). In an embodiment, the high-bandwidth actuators **250** include a first actuator **250**a, a second actuator **250**b, and a third actuator **250**c which may be generally aligned in an in-plane tripod configuration enabling adjustment of the printhead **300** along the transverse direction **354**, the normal direction **356**, and the roll direction **358** as described above. The first, second, and third actuators **250**a, **250**b, **250**c may each have an upper end **268** and a lower end **270**. The upper ends **268** of the first, second, and third actuators **250**a, **250**b, **250**c may be pivotably coupled to the end of the arm of the robot and may have parallel pivot axes. The lower ends **270** of the first, second, and third actuators **250**a, **250**b, **250**c may be pivotably coupled to the printhead **300** and may also have parallel pivot axes. As shown in Figure **18**, the upper ends **268** of the first **250**a and third actuator **250**c are spaced apart from one another at the pivotable attachment to the end of the arm **214**, and the lower ends **270** of the first **250**a and third actuator **250**c are spaced apart from one another at the pivotable attachment to the printhead **300**. In this regard, the first actuator **250**a and the third actuator **250**c may be oriented generally parallel to one another. However, the first actuator **250**a and the third actuator **250**c may be oriented non-parallel relation to one another without detracting from the movement capability of the printhead **300** along the transverse direction **354**, the normal direction **356**, and the roll direction **358**.

In Figure **18**, the upper end **268** of the second actuator **250**b may be located adjacent to the upper end **268** of the first actuator **250**a. The lower end **270** of the second actuator **250**b may be located adjacent to the lower end **270** of the third actuator **250**c such that the second actuator **250**b extends diagonally between the upper end **268** of the first actuator **250**a and the lower end **270** of the third actuator **250**c. In operation, the first, second, and third actuators **250**a, **250**b, **250**c may be extended and retracted by different amounts to adjust the printhead **300** along the transverse direction **354**, the normal direction **356**, and the roll direction **358**. In any one of the examples disclosed herein, one or more of the high-bandwidth actuators **250** may be configured as pneumatic cylinders or in other high-bandwidth actuator configurations including, but not limited to, hydraulic cylinders, electromechanical actuators, or other actuator configurations. In Figure **18**, the printhead face **304** is oriented non-parallel to the surface **102** and laterally offset relative to the reference line **322**.

Figure **19** is a side view of the printhead **300** after being repositioned by the high-bandwidth actuators **250** (e.g., the first, second, and third actuators **250**a, **250**b, **250**c) into alignment with the reference line **322** and reorientation of the printhead face **304** into parallel relation with the surface **102**. In this regard, the controller **208** (Figure **14**) may command the translation and re-orientation of the printhead **300** based on continuous input signals that may be received in real-time from the position sensors

314 and/or reference line sensors **326** tracking the reference line **322** during printing of a new image slice **406**. For example, the high-bandwidth actuators **250** may translate the printhead **300** along the transverse direction **354** and the normal direction **356** and may rotate the printhead **300** along the roll direction **358** to orient the printhead face **304** parallel the local surface **102** while aligning the side edge **416** of a new image slice **406** with the side edge **416** of an existing image slice **408**.

Figure **20** is a further example of high-bandwidth actuators **250** configured as a delta robot **252** and mounted in series with the robot arm and coupling the printhead **300** to the end **214** (Figure **19**) of the robot arm (Figure **17**). In Figure **20**, the delta robot **252** may include an actuator base **254** which may be attached to the end **214** of a robot arm (e.g., a second arm **212**). Three (**3**) actuator upper arms **256** may be pivotably coupled to the actuator base **254** and may have co-planar pivot axes oriented at **60** degrees relative to one another. Each actuator upper arm **256** may be coupled by a hinge joint **260** to a pair of actuator lower arms **258**. Each pair of actuator lower arms **258** may be configured as a parallelogram four-bar-mechanism. Each one of three (**3**) pairs of lower arms **258** may be pivotably coupled to an actuator platform **262** through six (**6**) hinge joints wherein each hinge joint is capable of rotation about a single axis. The three (**3**) parallelogram four-bar-mechanisms of the three (**3**) actuator lower arms **258** limit movement of the actuator platform **262** to translation (e.g., movement in the x-y direction) and extension (e.g., movement in the z-direction), and prevent rotation of the actuator platform **262**. In this regard, the actuator platform **262** is maintained in parallel relation with the actuator base **254** regardless of the direction of translation and/or extension of the actuator platform **262**. In an example not shown, the delta robot **252** may be provided with spherical joints (not shown) and upper and lower arms (not shown) arranged in a manner that maintains the actuator platform **262** in parallel relation to the actuator base **254** during translation and/or extension of the actuator platform **262**.

In Figure **20**, the translation capability of the actuator platform **262** provides for translation of the printhead **300** along the above-described transverse direction **354** (e.g., the y-direction) and normal direction **356** (e.g., the z-direction) relative to the surface **102** being printed. The high-bandwidth actuator **250** arrangement of Figure **20** may provide rotational capability of the printhead **300** along the roll direction **358** by means of one or more roll actuators **264** for pivoting the printhead **300** about one or more attachment links **266**. The upper ends of the attachment links **266** may be fixedly coupled to the actuator platform **262**. The lower ends of the attachment links **266** may be pivotably coupled to the printhead **300**. The high-bandwidth actuator **250** arrangement of Figure **20** may represent a low mass, high stiffness actuator system providing increased precision and improved response time for adjusting the position of the printhead **300** according to a path-following-error that may be resolved using the reference line sensor **326** tracking the reference line **322** of an existing image slice **408**. As indicated above, the high-bandwidth actuators **250** may adjust the position and/or orientation of the printhead **300** with a precision that may be unobtainable with the robot **202** acting alone.

Figure **21** is a flowchart of one or more operations that may be included in method **500** of printing an image **400** on a surface **102**. The method may be implemented using the system **200** described above. Step **502** of the method **500** may include positioning an arm of a robot **202** adjacent to a surface **102**. As indicated above, a printhead **300** may be mounted on an end **214** of the arm. In some examples, the printhead **300** may be an inkjet printhead **300** having an array of nozzles **308** or orifices for ejecting droplets **330** of ink, paint, or other fluids or colorants.

Step **504** of the method **500** may include moving, using the arm, the printhead **300** over the surface **102** along a rastering path **350** while the printhead **300** prints an image slice **404** on the surface **102**, as shown in Figure **7**. The printhead **300** may be moved by the arm along the rastering path **350** to print a new image slice **406** in parallel relation to an existing image slice **408**.

Step **506** of the method **500** may include printing an image gradient band **418** along at least one side edge **416** of an image slice **404** when printing the image slice **404** on the surface **102**, as shown in Figure **8**. As described above, the image gradient band **418** may have an image intensity that decreases along a transverse direction **354** (e.g., relative to the rastering path **350**) toward a side edge **416** of the image slice **404**. In some examples, the image gradient of the image gradient band **418** may be linear (e.g., a linear decrease in the image density) along the transverse direction **354**. In other examples, the image gradient of an image gradient band **418** may be non-linear.

As shown in Figure **8**, a printhead **300** may print a new image slice **406** such that the image gradient band **418** of the new image slice **406** overlaps the image gradient band **418** of an existing image slice **408**. For example, the side edge **416** of the new image slice **406** may be aligned with an inner boundary **420** of an overlapping or overlapped image gradient band, as mentioned above. The method may include printing, using the printhead **300**, the image gradient band **418** of the new image slice **406** and the existing image slice **408** such that the overlapping image gradient bands **418** have a collective image intensity that is equivalent to the image intensity of the inner portion **414** of the new image slice **406** and/or the existing image slice **408**

As shown in Figure **9** and mentioned above, an image gradient band **418** may be generated by ejecting droplets **330** from the printhead **300** nozzles **308** with progressively larger droplet spacings **332** along a direction toward the side edge **416** of the image slice **404** as compared to a uniform droplet spacing **332** for the nozzles **308** that print the inner portion **414** of the image slice **404**. As shown in Figure **10**, an image gradient band **418** may also be generated by ejecting progressively smaller droplet sizes **334** along a direction toward the side edge **416**. The method may optionally include forming a new image slice **406** with an image gradient end (not shown) on at least one of opposing ends of the new image slice **406** as a means to blend or feather the image slice **404** into an area bordering the new image slice **406**.

Figure **22** is a flowchart of one more operations that may be included in a further method **600** of printing an image **400** on a surface **102**. Step **602** of the method **600** may include printing, using a printhead **300** mounted on an arm of a robot **202**, a new image slice **406** on the surface **102** while moving the printhead **300** over the surface **102** along a rastering path **350**. Step **604** of the method **600** may include printing a reference line **322** on the surface **102** when printing the new image slice **406**, as shown in Figure **13** and described above. The printhead **300** may include a reference line printing mechanism **320** configured to print the reference line **322** on the surface **102** when printing the new image slice **406**. In some examples, the reference line printing mechanism **320** may comprise at least one nozzle **308** of the printhead **300** which may eject ink or paint that is a different color that the ink or paint ejected by adjacent nozzles **308**. In other examples, the reference line printing mechanism **320** may comprise a dedicated reference line printer (not shown).

The printhead **300** may print a reference line **322** on at least one of opposing side edges **416** of a new image slice **406** when printing the new image slice **406**. The step of printing the reference line **322** may include printing the reference line **322** with at least one encoding pattern **324** along at least a portion of the reference line **322**. The encoding pattern **324** may comprise a series of line segments separated by gaps. The encoding pattern **324** may alternatively or additionally comprise localized changes in the color of the reference line **322**, or a combination of both line segments, gaps, color changes, and other variations in the reference line for encoding information. The encoding pattern **324** may represent information regarding the image slice **404** such as the distance to the end **412** of the image slice **404** or other information about the image **400**. The information may be transmitted to the controller **208** which may adjust one or more printing operations based on the information contained in the encoding pattern **324**.

Step **606** of the method **600** may include sensing, using a reference line sensor **326** included with the printhead **300**, the reference line **322** of an existing image slice **408** while printing the new image slice **406**. As indicated above, a reference line sensor **326** may sense the reference line **322** of an existing image slice **408** and transmit a signal to the robot **202** and/or controller **208** causing the arm to adjust the printhead **300** such that the side edge **416** of the new image slice **406** is aligned with and/or is maintained in non-gapping and non-overlapping relation with the side edge **416** of the existing image slice **408**.

Step **608** of the method **600** may include adjusting the lateral position of the new image slice **406** based on a sensed position of the reference line **322** to align a side edge **416** of the new image slice **406** with the side edge **416** of the existing image slice **408**. In one example, the method may include detecting a misalignment of the side edge **416** of a new image slice **406** with the side edge **416** of an existing image slice **408** and providing real-time alignment feedback to the robot **202** and/or controller **208** for manipulating or adjusting the lateral position of the printhead **300** such that the side edge **416** of the new image slice **406** is aligned with the side edge **416** of the existing image slice **408**. In this regard, the step of adjusting the lateral position of the new image slice **406** may include transmitting a signal from the reference line sensor **326** (e.g., an optical sensor) to the robot **202** and/or controller **208**. The robot **202** and/or controller **208** may determine a correction input for the robot based on the misalignment of the printhead **300**.

The method may include adjusting the position of the printhead **300** such that the side edge **416** of the new image slice **406** is maintained in non-gapped and non-overlapping relation with the side edge **416** of the existing image slice **408**. In this regard, the lateral position of the printhead **300** may be physically adjusted to align the side edge **416** of the new image slice **406** with the side edge **416** of the existing image slice **408**. Alternatively, the method may include electronically shifting the nozzles **308** that are actively ejecting droplets **330** to align the side edge **416** of the new image slice **406** with the side edge **416** of the existing image slice **408**, as mentioned above.

The adjustment of the position and/or orientation of the printhead **300** may be facilitated using one or more high-bandwidth actuators **250** coupling the printhead **300** to an end **214** of an arm of the robot **202**, as described above and illustrated in Figures **17-20**. The high-bandwidth actuators **250** may adjust an orientation and/or position of the printhead **300** relative to the surface **102** during movement of the printhead **300** along the rastering path **350**. The reference line sensor **326** may sense the reference line **322** and transmit a signal to the robot **202** for determining an adjustment to the lateral position of the printhead **300**. The robot **202** and/or controller **208** may command the high-bandwidth actuators **250** to adjust the position of the printhead **300** such that the side edge **416** of the new image slice **406** is maintained in non-gapped relation with the side edge **416** of the existing image slice **408**.

The method may include adjusting the printhead **300** by translating the printhead **300** along a transverse direction **354** parallel to the surface **102** and perpendicular to the rastering path **350**, translating the printhead **300** along a normal direction **356** that is normal to the surface **102**, and/or rotating the printhead **300** along a roll direction **358** about an axis parallel to the rastering path **350**. The high-bandwidth actuators **250** may provide increased precision and rapid response time in adjusting the position and/or orientation of the printhead **300**.

Additional modifications and improvements of the present disclosure may be apparent to those of ordinary skill in the art. Thus, the particular combination of parts described and illustrated herein is intended to represent only certain embodiments of the present disclosure and is not intended to serve as limitations of alternative embodiments or devices within the spirit and scope of the disclosure.

EMBODIMENTS IN WHICH AN EXCLUSIVE PROPERTY OR PRIVILEGE IS CLAIMED ARE DEFINED AS FOLLOWS:

1. A system for printing an image on a surface, comprising:

a robot having at least one arm;

a printhead mounted to the arm and movable by the arm over a surface along a rastering path while printing an image slice on the surface;

the printhead configured to print each image slice with an image gradient band along at least one of opposing side edges of the image gradient band wherein an image intensity within each image gradient band decreases along a direction transverse to the direction of the rastering path from an inner portion of the image gradient band toward a side edge; and

wherein the arm is configured to move the printhead in parallel relation to an existing image slice in a manner such that the image gradient band of the new image slice overlaps the image gradient band of the existing image slice such that the image intensity of an overlap of the image gradient bands is substantially equivalent to the image intensity of the inner portion of at least one of the new image slice and the existing image slice.

2. The system of claim **1**, wherein:

the printhead includes an array of nozzles distributed along a printhead width;

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the printhead is configured to generate the image gradient band by ejecting droplets in at least one of the following manners:

progressively larger droplet spacing along a direction toward the side edge; and

progressively smaller droplet size along a direction toward the side edge.

3. The system of claim **1**, wherein the printhead is an inkjet printhead.

4. A method for printing an image on a surface, comprising:

positioning an arm of a robot adjacent to a surface, the arm having a printhead mounted to the arm;

moving, using the arm, the printhead over the surface along a rastering path while printing a new image slice on the surface in parallel relation to an existing image slice;

printing an image gradient band along at least one side edge of the image slice when printing the new image slice, the image gradient band having an image intensity that decreases along a direction transverse to the direction of the rastering path from an inner portion of the image gradient band toward the side edge; and

moving the printhead in a manner such that the image gradient band of the new image slice overlaps the image gradient band of the existing image slice with an image intensity equivalent to the image intensity of an inner portion of at least one of the new image slice and the existing image slice.

5. The method of claim **4**, wherein the printhead includes an array of nozzles for ejecting droplets and forming the image gradient band includes:

ejecting progressively larger droplet spacings along a direction toward the side edge; and

ejecting progressively smaller droplet sizes along a direction toward the side edge.

6. A system for printing an-image on a surface, comprising:

a robot having at least one arm;

an inkjet printhead mounted to the arm and movable by the arm over a surface along a rastering path while printing an image slice on the surface,

wherein the printhead is configured to print the image slice with an image gradient band along at least one of opposing side edges of the image gradient band wherein an image intensity within the image gradient band decreases from an inner portion of the image gradient band toward the side edge; and

whereien the robot is configured to electronically offset groups of nozzles actively ejecting droplets in a manner such that a side edge of the new image slice is aligned with the side edge of the existing image slice.

7. The system of Claim **6**, wherein the arm is configured to move the printhead in parallel relation to an existing image slice in a manner such that an image gradient band of a new image slice overlaps an image gradient band of the existing image slice.

8. The system of Claim **7**, wherein the printhead is configured to print the image gradient band of the new image slice and the existing image slice such that an overlap of image gradient bands has an image intensity equivalent to the image intensity of the inner portion of at least one of the new image slice and the existing image slice.

9. The system of any one of Claims **6** to **8**, wherein:

the printhead includes an array of nozzles distributed along a printhead width; and

the printhead is configured to generate the image gradient band by ejecting droplets in at least one of the following manners:

progressively larger droplet spacing along a direction toward the side edge; and

progressively smaller droplet size along a direction toward the side edge.

10. The system of any one of Claims **6** to **9** further comprising:

a reference line printing mechanism configured to print a reference line on the surface when printing the new image slice; and a reference line sensor configured to sense the reference line of an existing image slice and transmit a signal to the robot causing the arm to adjust the printhead such that a side edge of the new image slice is aligned with the side edge of the existing image slice.

11. The system of Claim **10**, wherein the reference line printing mechanism comprises at least one nozzle of the printhead.

12. The system of any one of Claims **6** to **11**, wherein the robot is configured to adjust the lateral position of the printhead in a manner such that a side edge of the new image slice is aligned with the side edge of the existing image slice.

13. The system of any of Claims **6 to 12**, further including at least one high-bandwidth actuator coupling the printhead to an end of the arm wherein the high-bandwidth actuator is configured to adjust at least one of an orientation and a position of the printhead relative to the surface during movement of the printhead along the rastering path.

14. The system of Claim **13**, wherein:

the high-bandwidth actuator is configured to adjust the printhead along at least one of the following directions:

a transverse direction of translation parallel to the surface and perpendicular to the rastering path;

a normal direction of translation normal to the surface; and a roil direction of rotation about an axis parallel to the rastering path.

15. The system of Claim **14**, wherein:

the high-bandwidth actuator includes a first actuator, a second actuator, and a third actuator arranged in an in-plane tripod configuration and each having an upper end and a lower end;

the upper ends are pivotably coupled to an end of the arm of the robot,

the lower ends are pivotably coupled to the printhead;

the upper ends of the first and third actuator being spaced apart from one another;

the lower ends of the first and third actuator are spaced apart from one another;

the upper end of the second actuator are located adjacent to the upper end of the first actuator;

the lower end of the second actuator being located adjacent to the lower end of the third actuator such that the second actuator extends diagonally between the upper end of the first actuator and the lower end of the third actuator; and

the first, second, and third actuators enabling adjustment of the printhead along the transverse direction, the normal direction, and the roll direction.

16. A method for printing an image on a surface, comprising:

positioning an arm of a robot adjacent to a surface, the arm having a printhead mounted to the arm;

moving, using the arm, the printhead over the surface along a rastering path while printing an image slice on the surface; and

printing an image gradient band along at least one side edge of the image slice when printing the image slice, the image gradient band having an image intensity that decreases along a direction toward the side edge,

wherein the robot is configured to electronically offset groups of nozzles actively ejecting droplets in a manner such that a side edge of the new image slice is aligned with the side edge of the existing image slice.

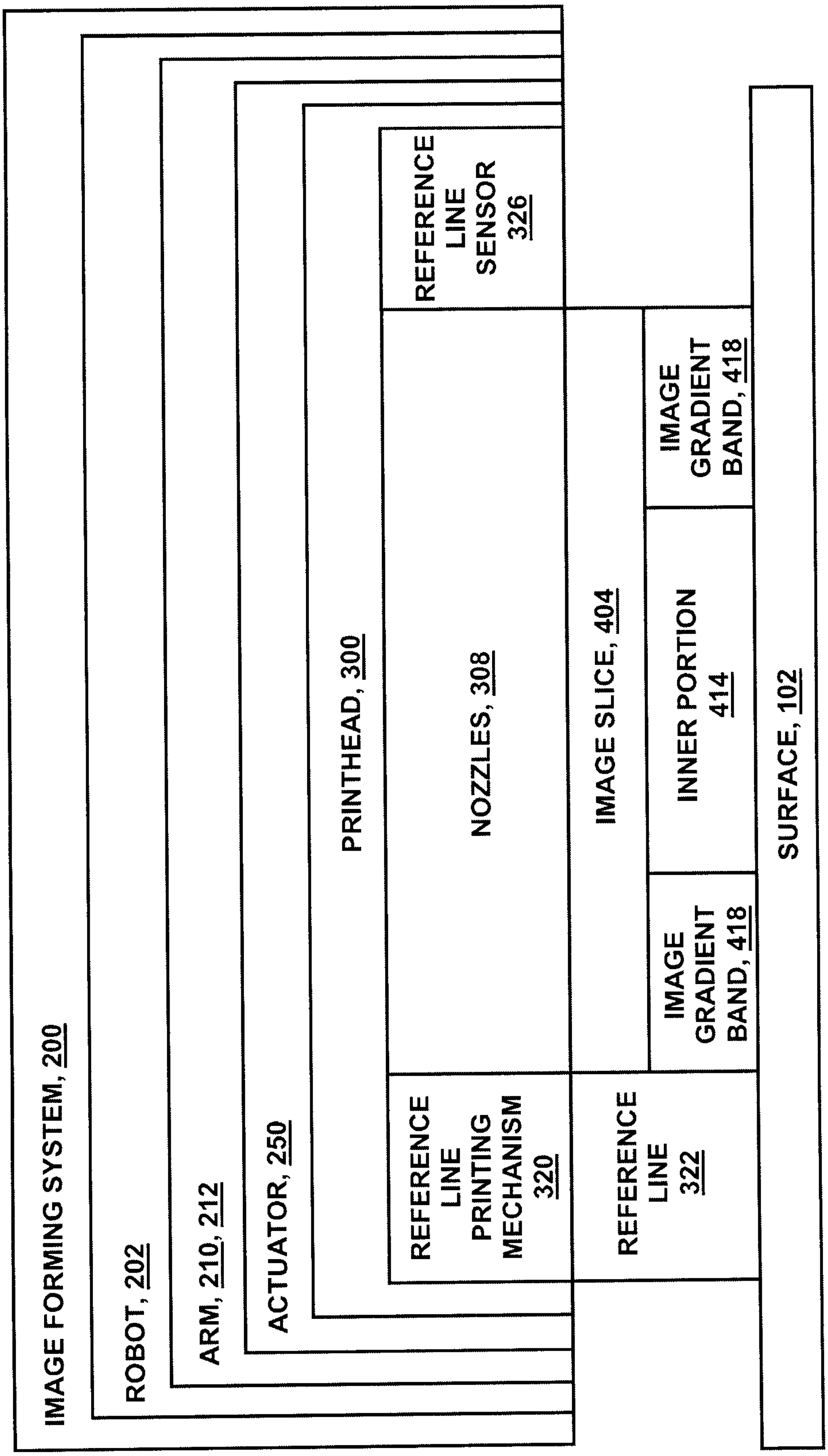
17. The method of Claim **16**, wherein moving the printhead and printing the image gradient band include moving the printhead along the rastering path to print a new image slice in parallel relation to an existing image slice in a manner such that the image gradient band of the new image slice overlaps the image gradient band of the existing image slice.

18. The method of Claim **17**, wherein printing the image gradient band includes printing the image gradient band of the new image slice and the existing image slice in a manner such that an overlap of the image gradient bands has an image intensity equivalent to the image intensity of an inner portion of' at least one of the new image slice and the existing image slice.

19. The method of any one of Claims **16** to **18**, wherein the printhead includes an array of nozzles for ejecting droplets, and forming the image gradient band includes:

ejecting progressively larger droplet spacings along a direction toward the side edge; and

ejecting progressively smaller droplet sizes along a direction toward the side edge.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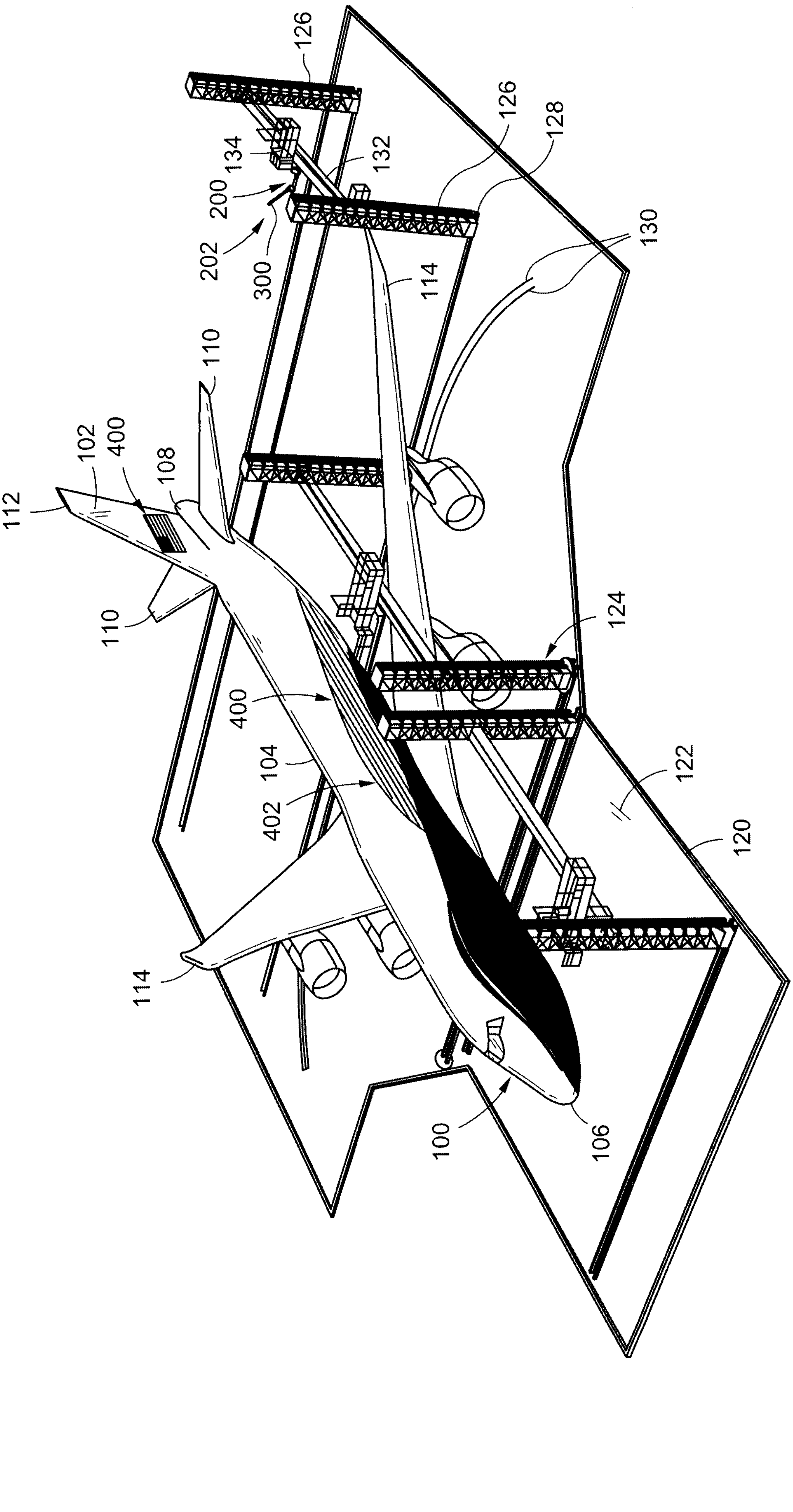
ROBOT, 202
ARM, 210, 212
ACTUATOR, 250
PRINTHEAD, 300
REFERENCE LINE SENSOR 326
NOZZLES, 308
REFERENCE LINE PRINTING MECHANISM 320
IMAGE SLICE, 404
REFERENCE LINE 322
IMAGE GRADIENT BAND, 418
INNER PORTION 414
IMAGE GRADIENT BAND, 418
SURFACE, 102

FIG. 1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106

FIG. 2

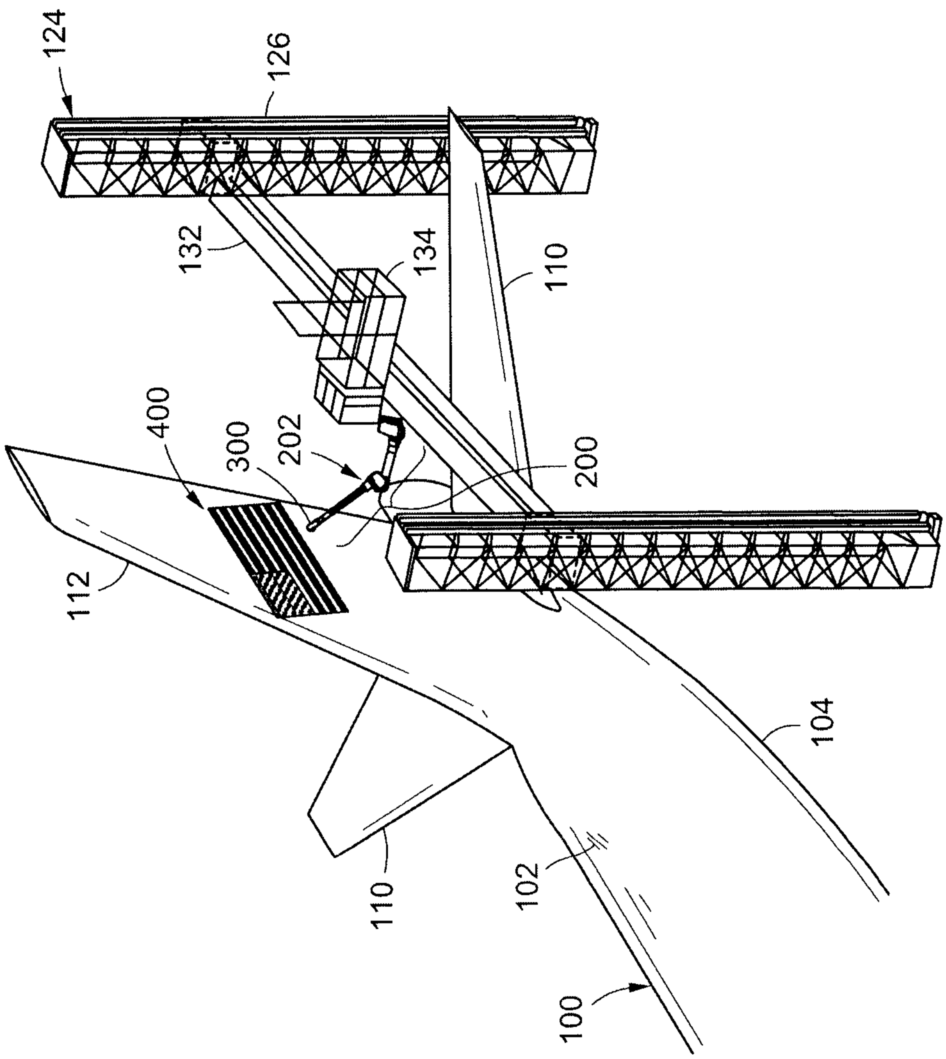

FIG. 3

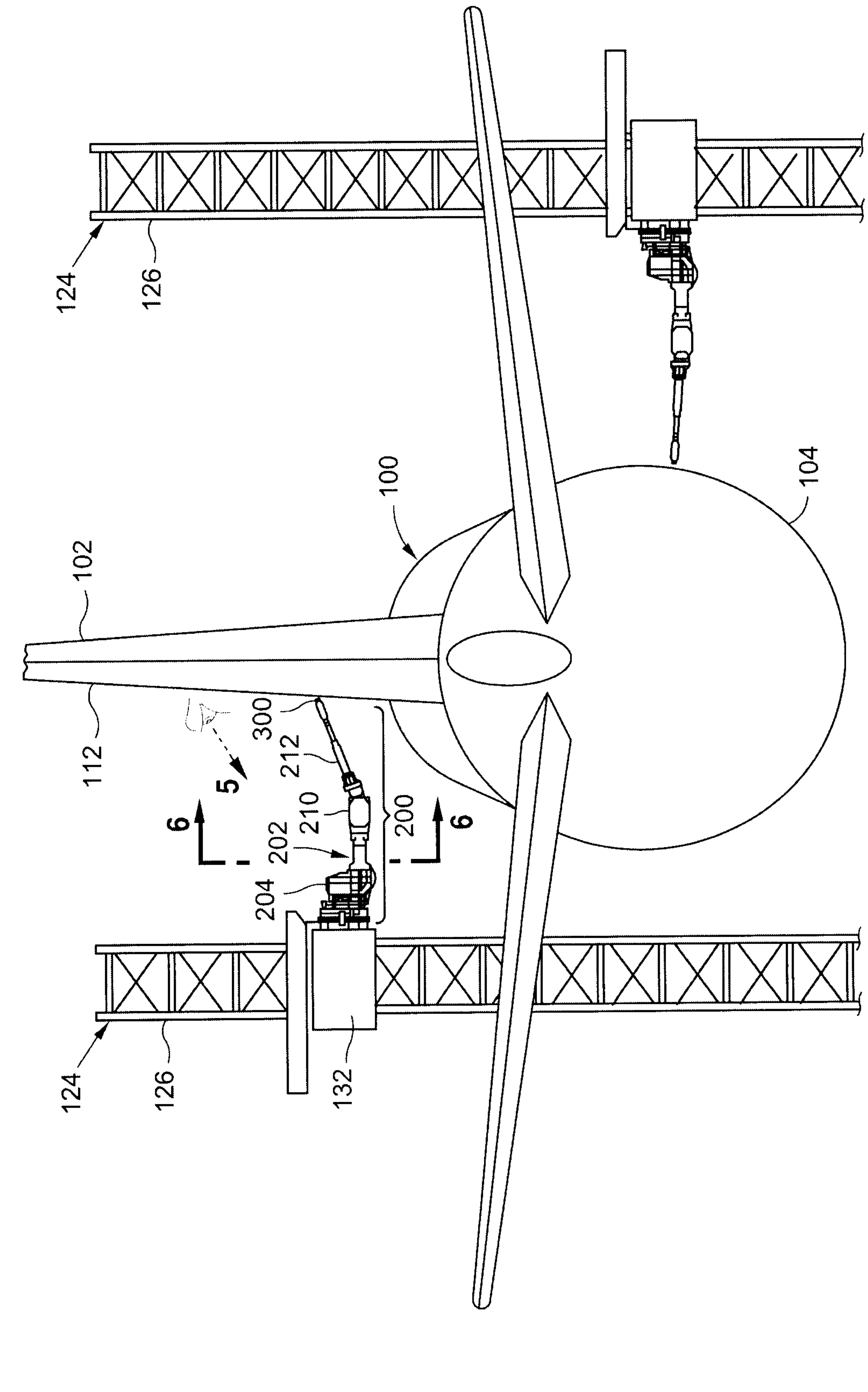

FIG. 4

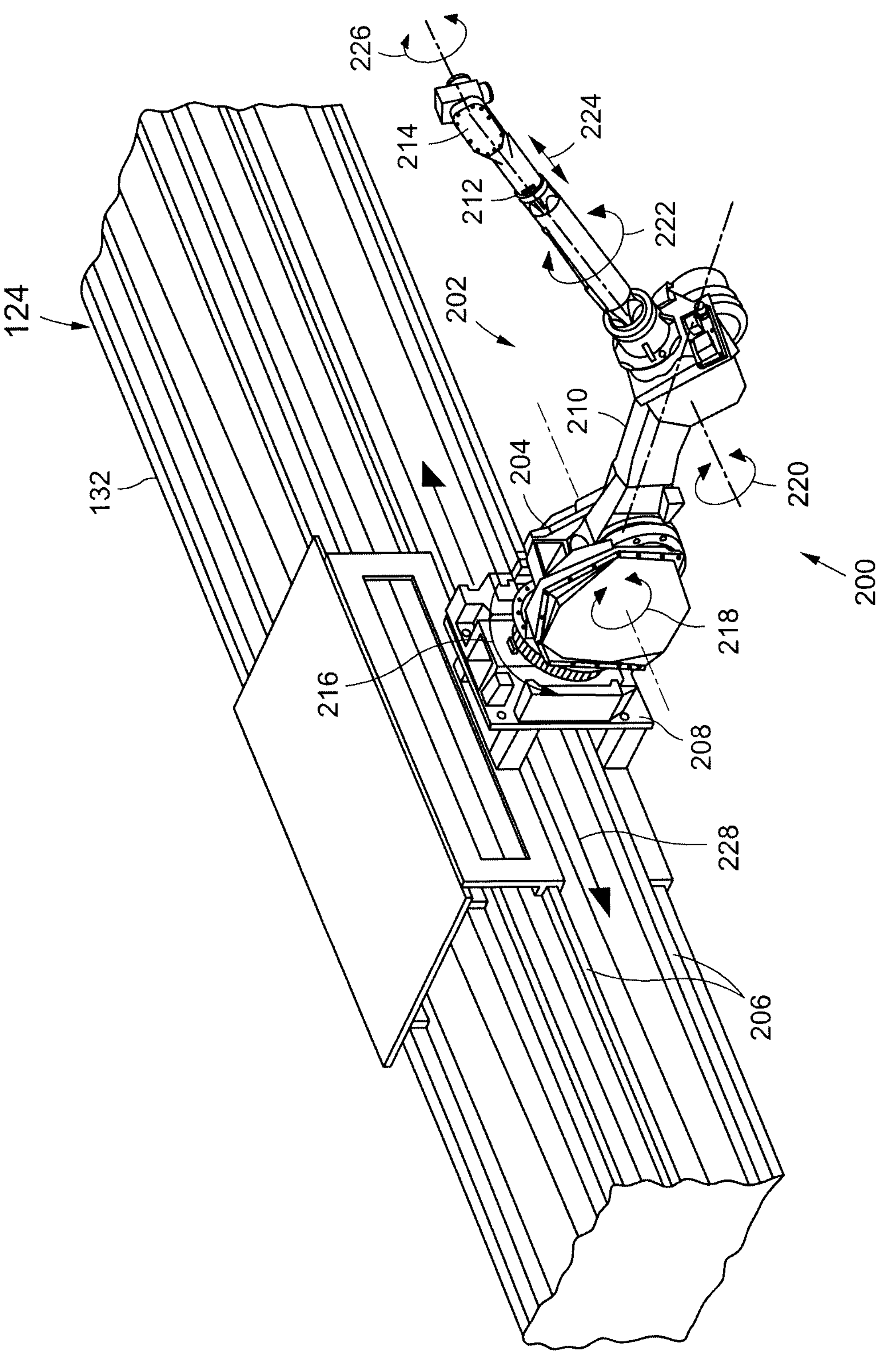
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FIG. 5

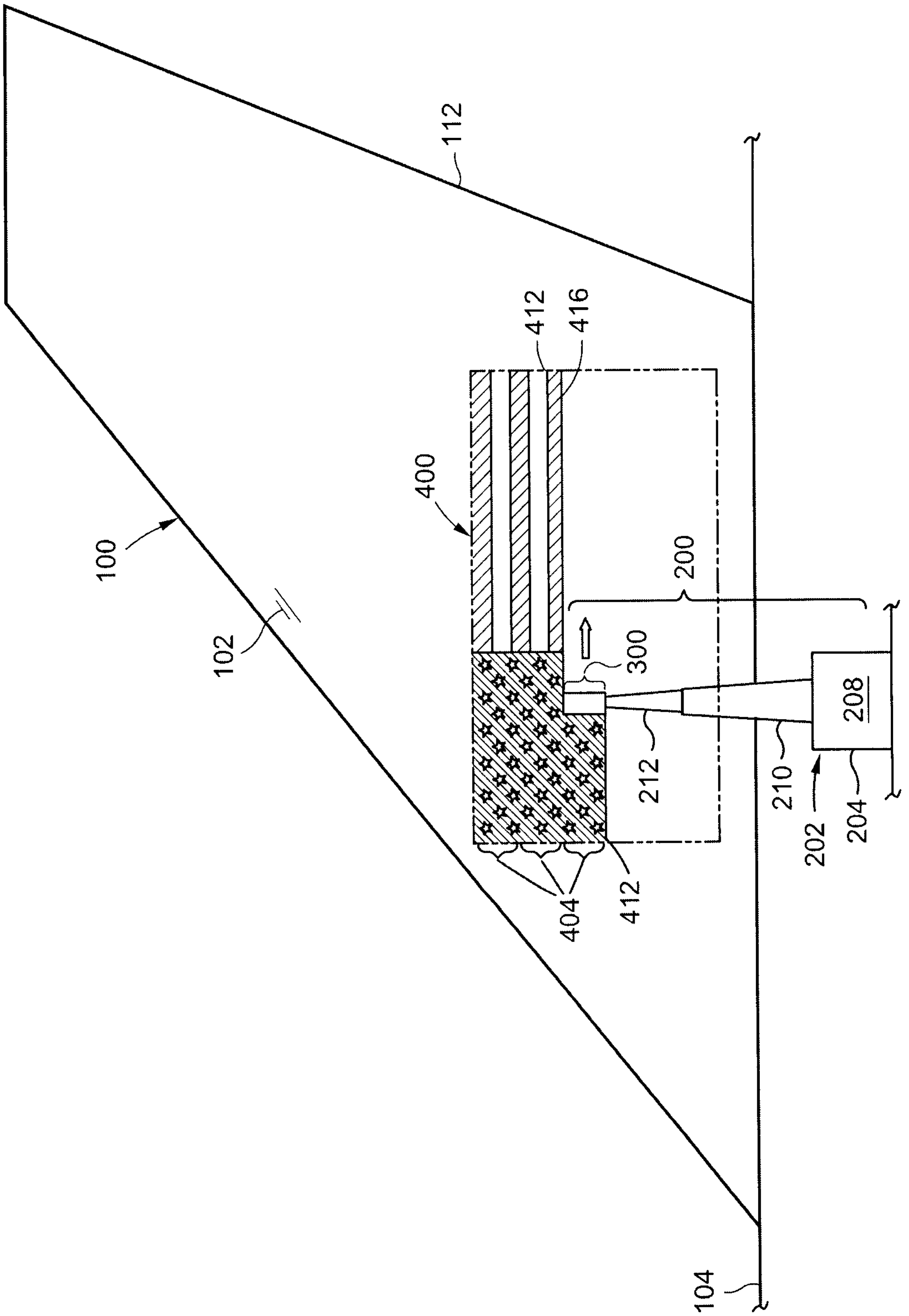

FIG. 6

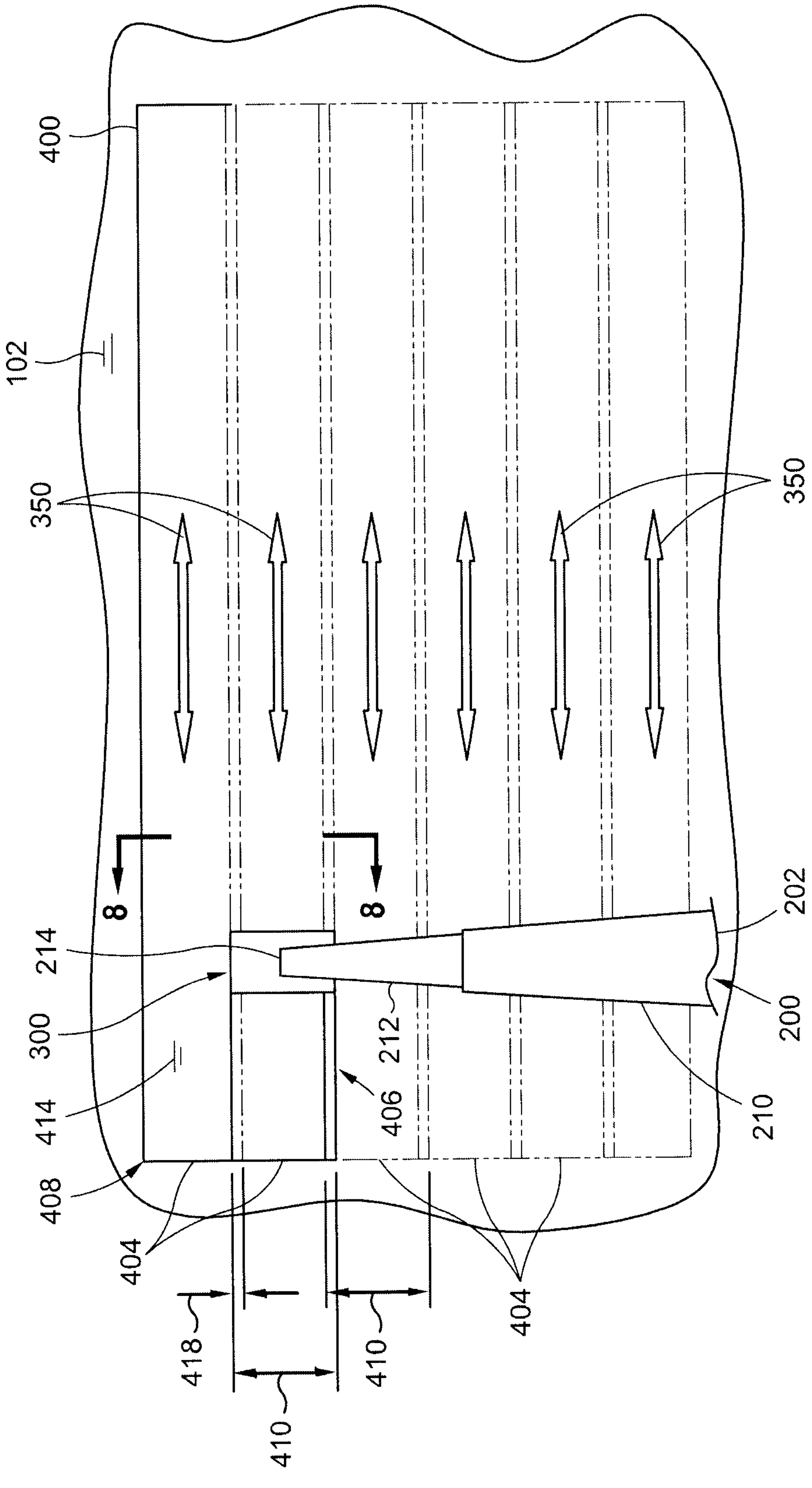
400
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FIG. 7

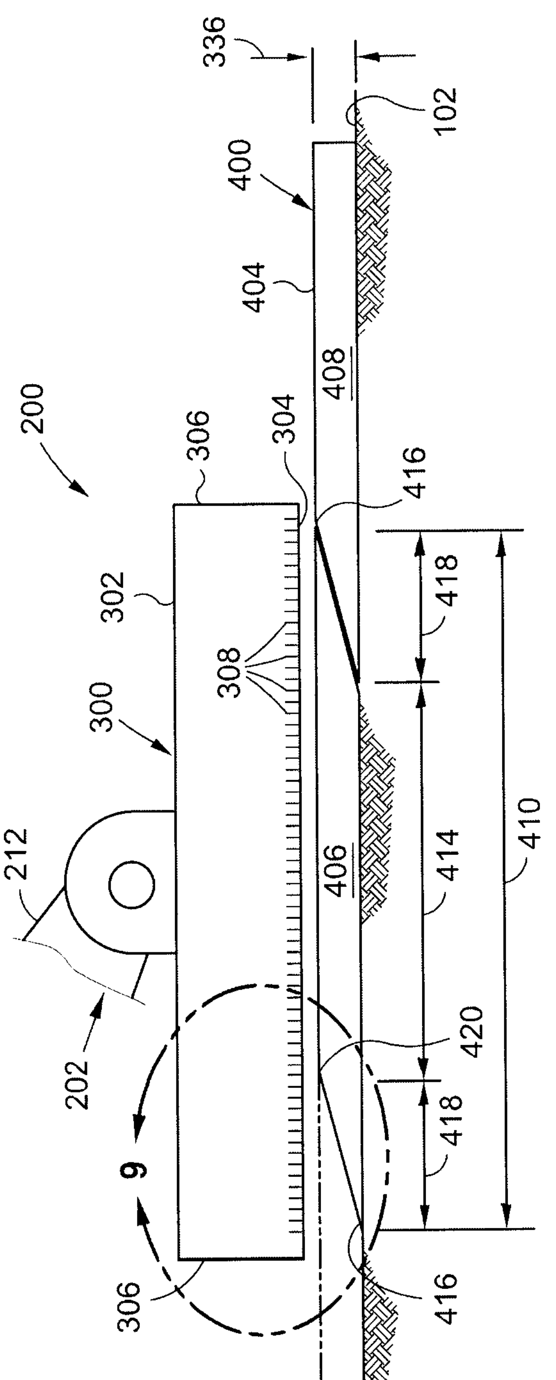

FIG. 8

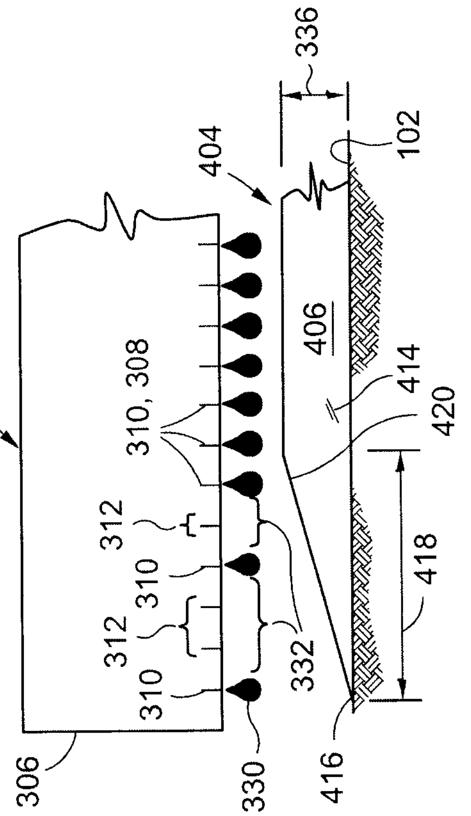

FIG. 9

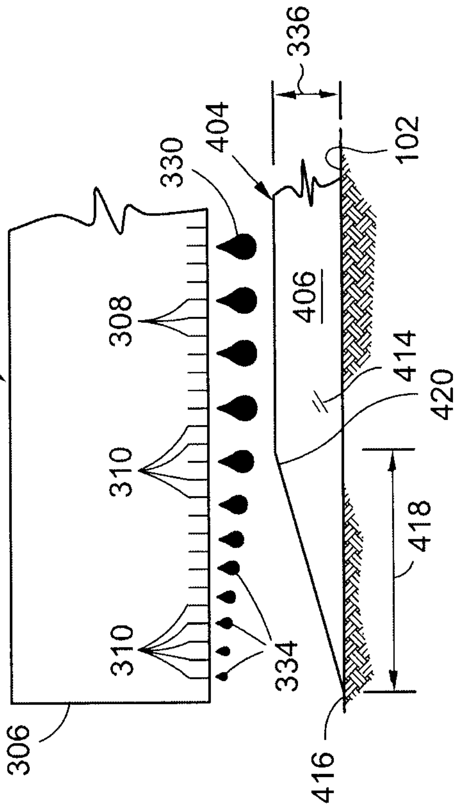

FIG. 10

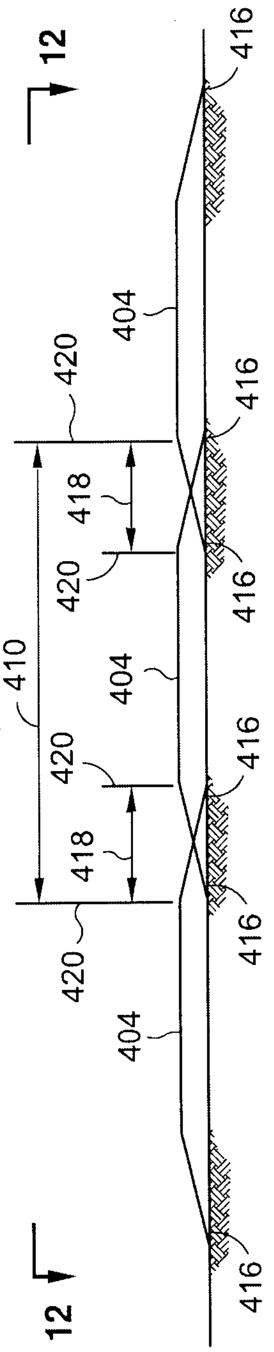
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FIG. 11

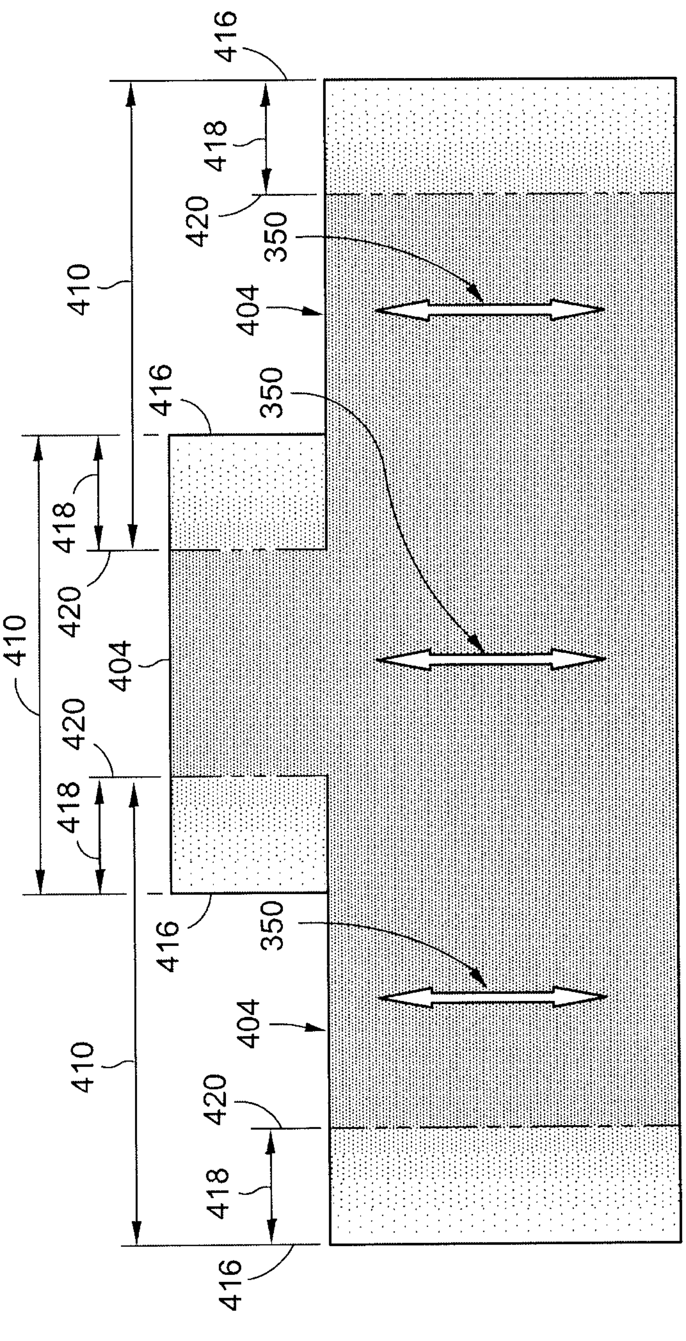
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FIG. 12

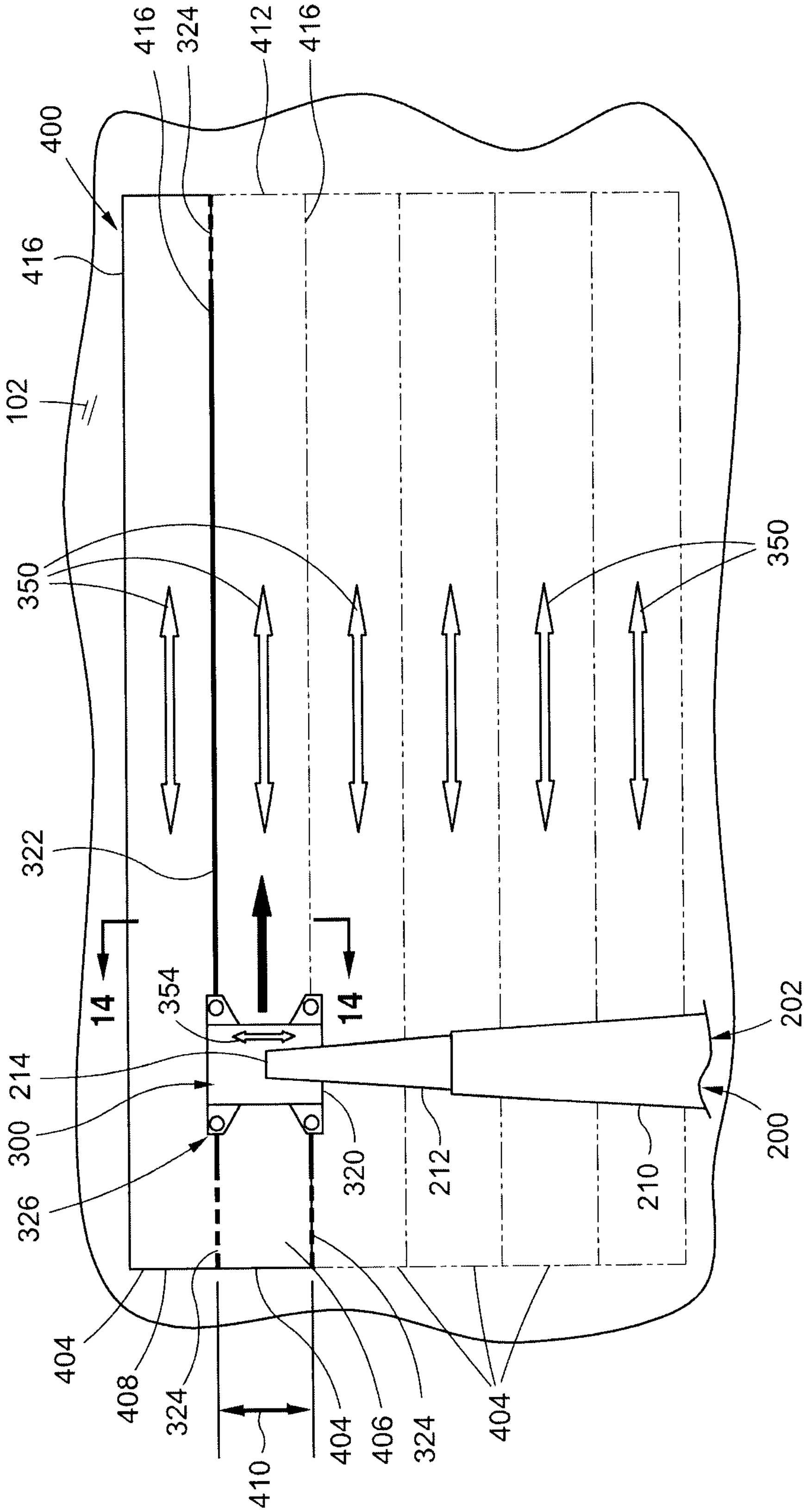
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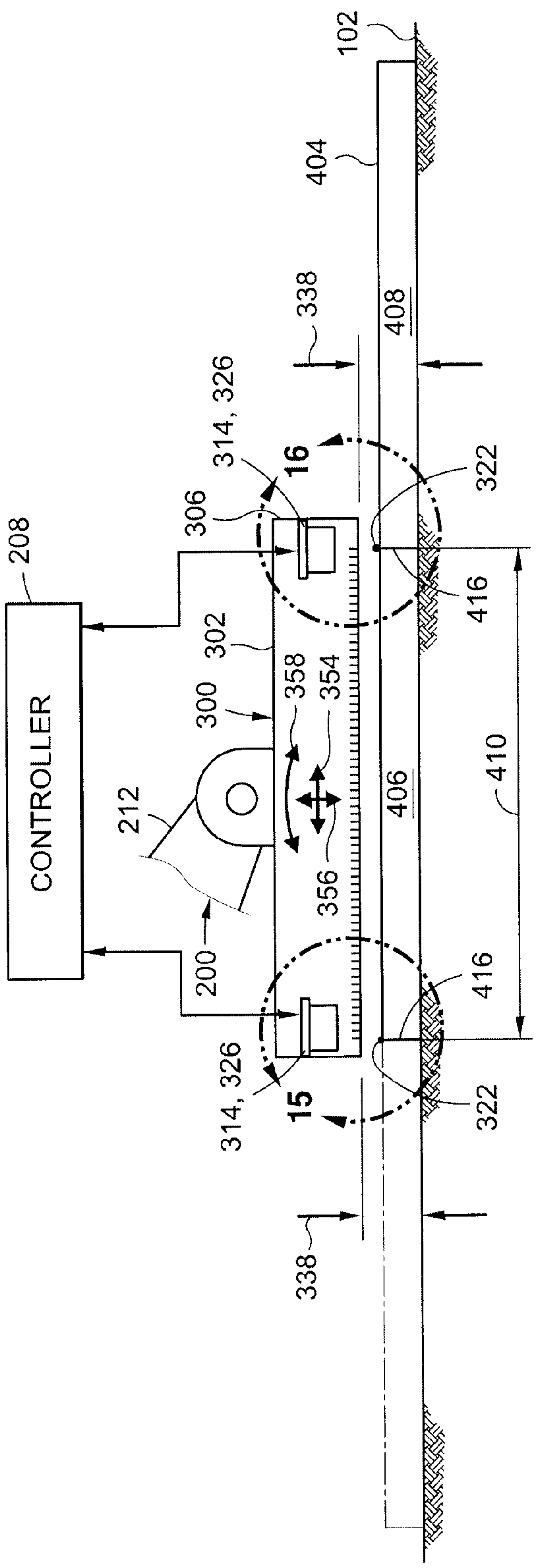
FIG. 13


102
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314, 326
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FIG. 14

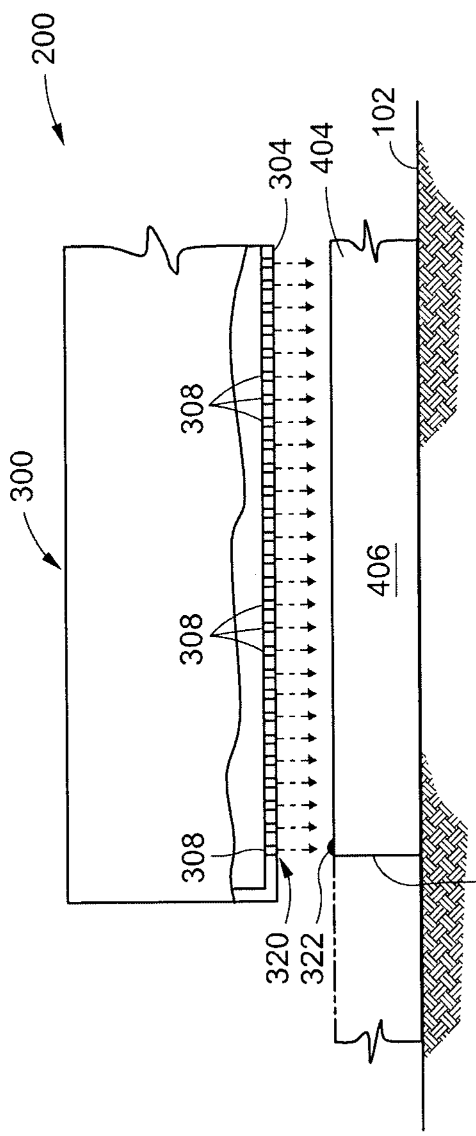
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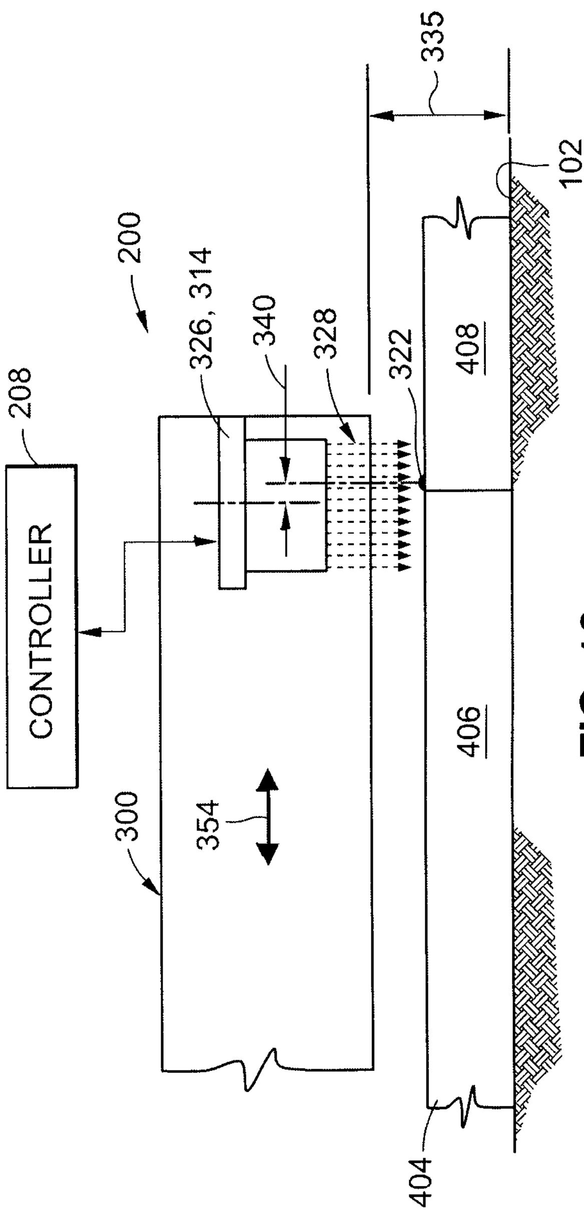
FIG. 15


335
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404

FIG. 16

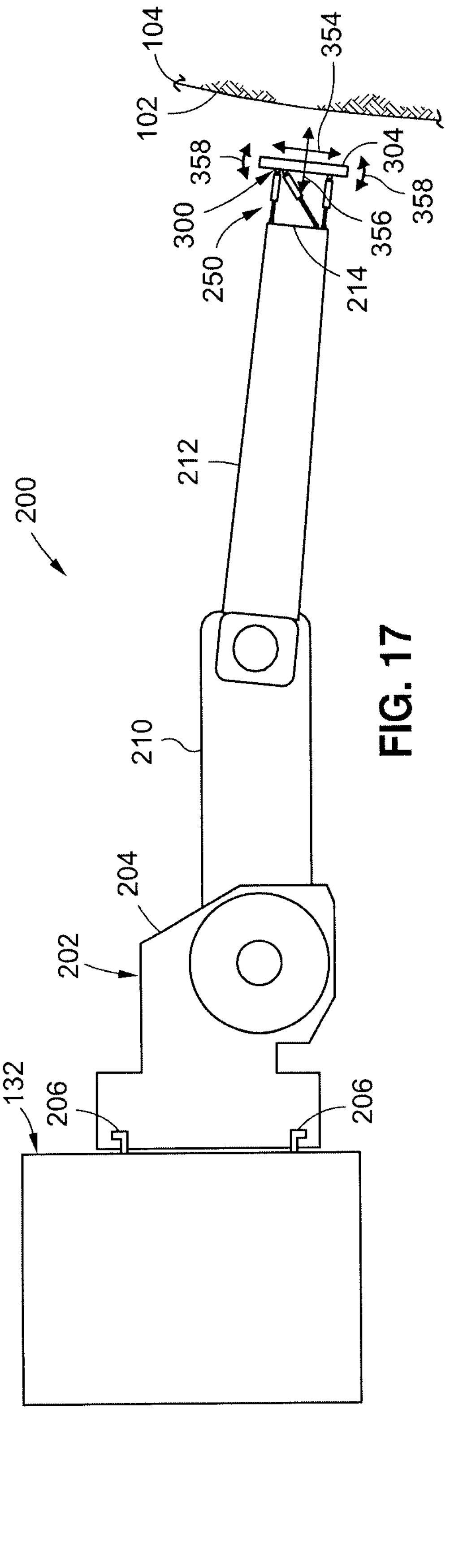

FIG. 17

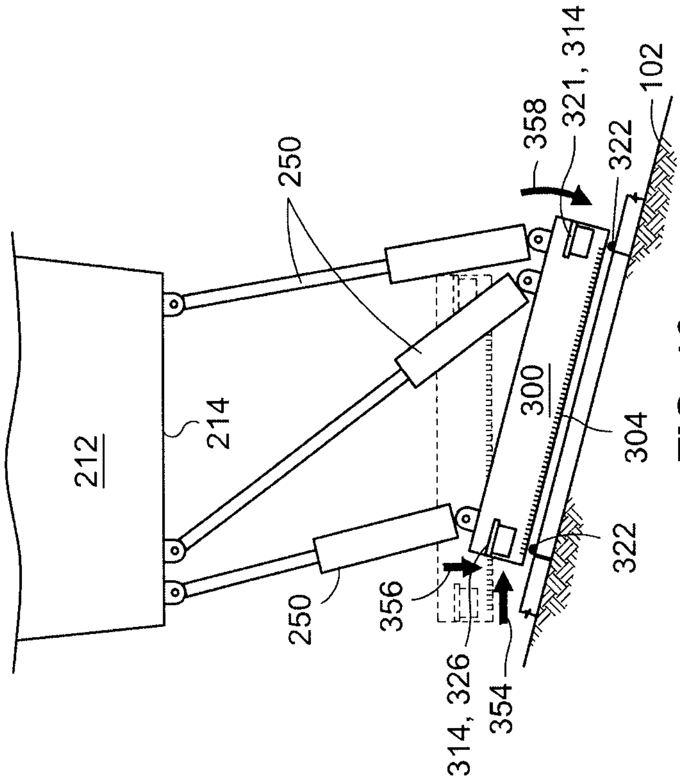

FIG. 19

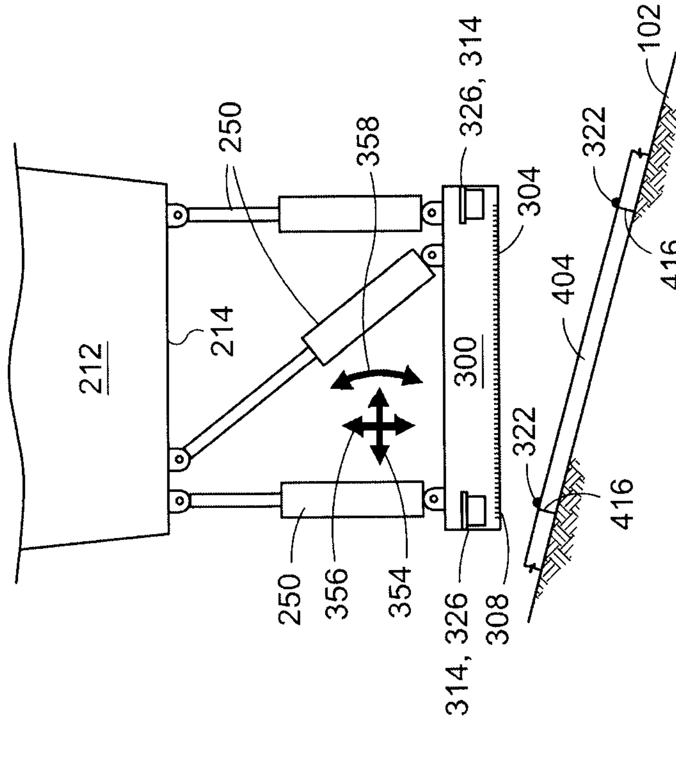

FIG. 18

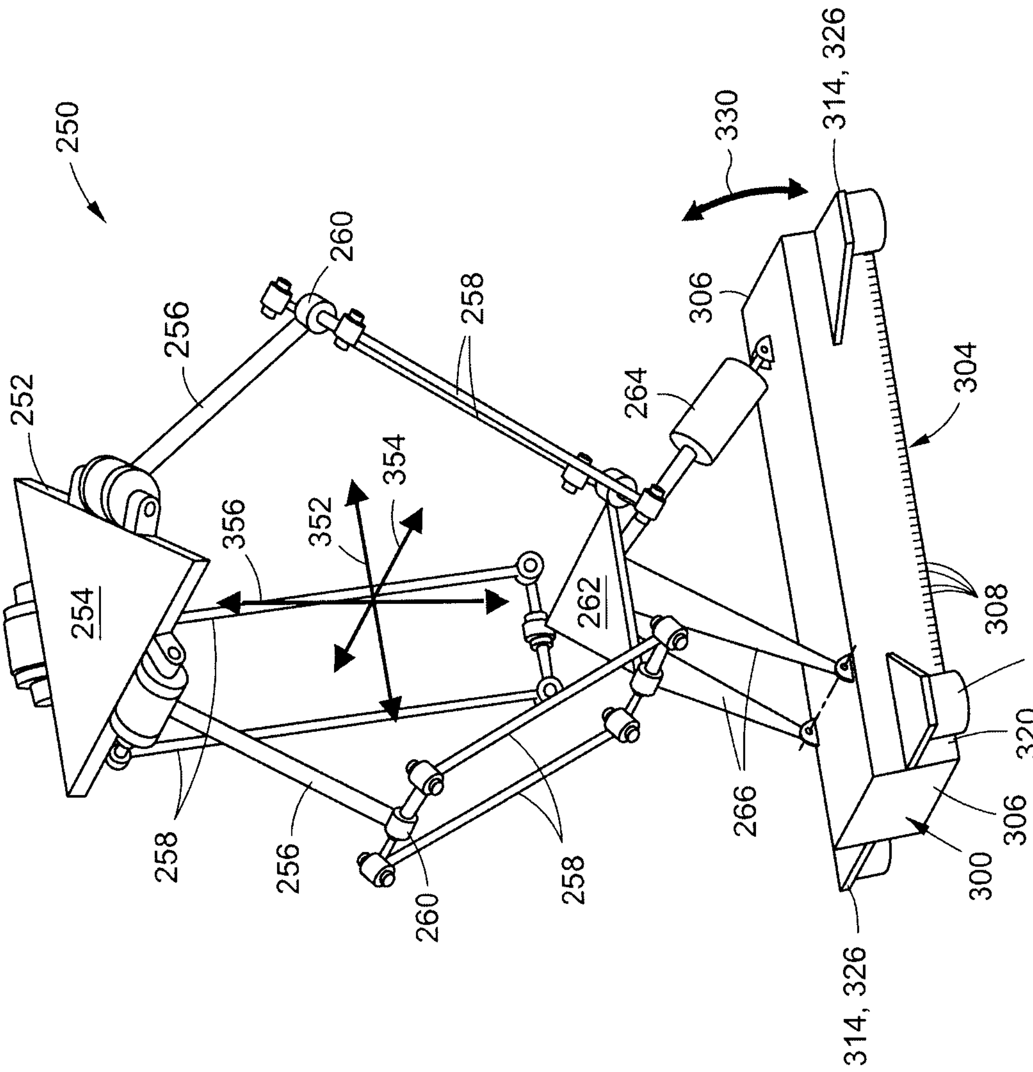
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FIG. 20

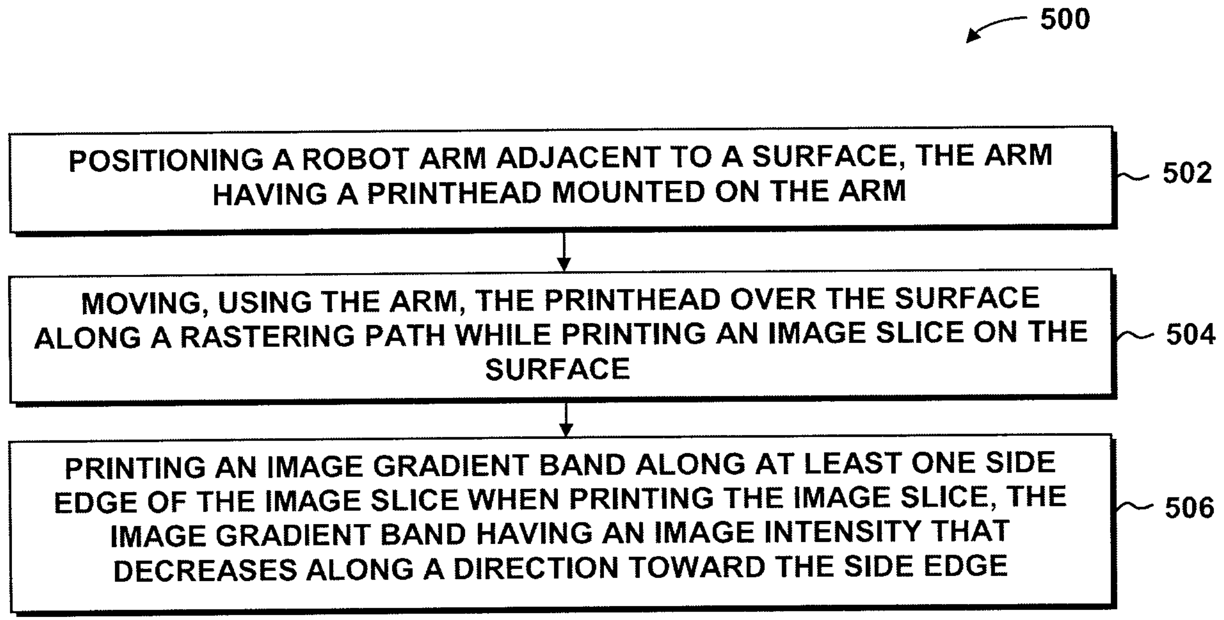

500
POSITIONING A ROBOT ARM ADJACENT TO A SURFACE, THE ARM HAVING A PRINTHEAD MOUNTED ON THE ARM
502
MOVING, USING THE ARM, THE PRINTHEAD OVER THE SURFACE ALONG A RASTERING PATH WHILE PRINTING AN IMAGE SLICE ON THE SURFACE
504
PRINTING AN IMAGE GRADIENT BAND ALONG AT LEAST ONE SIDE EDGE OF THE IMAGE SLICE WHEN PRINTING THE IMAGE SLICE, THE IMAGE GRADIENT BAND HAVING AN IMAGE INTENSITY THAT DECREASES ALONG A DIRECTION TOWARD THE SIDE EDGE
506

FIG. 21

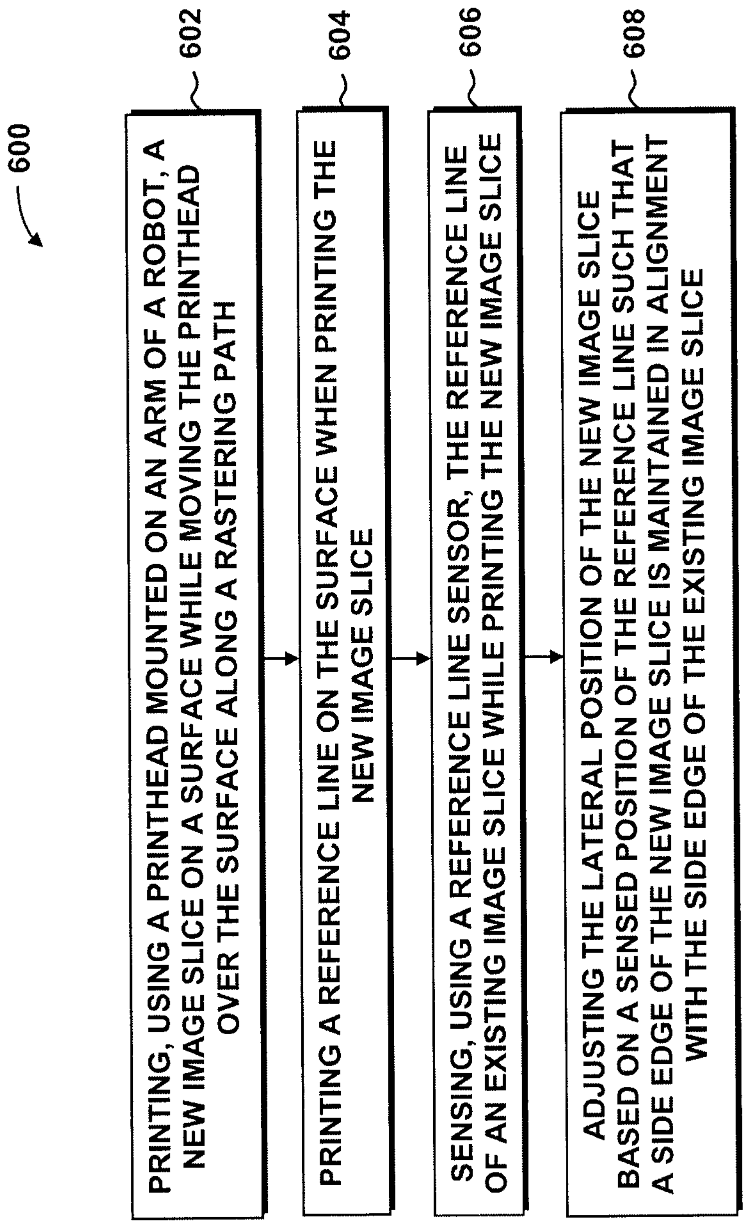
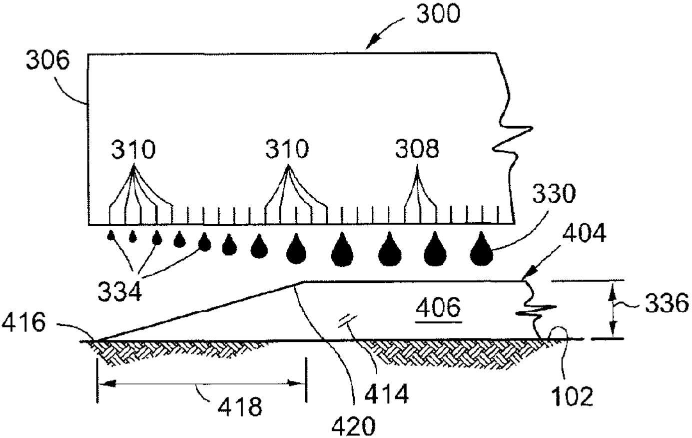

600
PRINTING, USING A PRINTHEAD MOUNTED ON AN ARM OF A ROBOT, A NEW IMAGE SLICE ON A SURFACE WHILE MOVING THE PRINTHEAD OVER THE SURFACE ALONG A RASTERING PATH
602
PRINTING A REFERENCE LINE ON THE SURFACE WHEN PRINTING THE NEW IMAGE SLICE
604
SENSING, USING A REFERENCE LINE SENSOR, THE REFERENCE LINE OF AN EXISTING IMAGE SLICE WHILE PRINTING THE NEW IMAGE SLICE
606
ADJUSTING THE LATERAL POSITION OF THE NEW IMAGE SLICE BASED ON A SENSED POSITION OF THE REFERENCE LINE SUCH THAT A SIDE EDGE OF THE NEW IMAGE SLICE IS MAINTAINED IN ALIGNMENT WITH THE SIDE EDGE OF THE EXISTING IMAGE SLICE
608

FIG. 22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