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(54) **USER INTERFACE FOR SUPERVISED AUTONOMOUS GRASPING**

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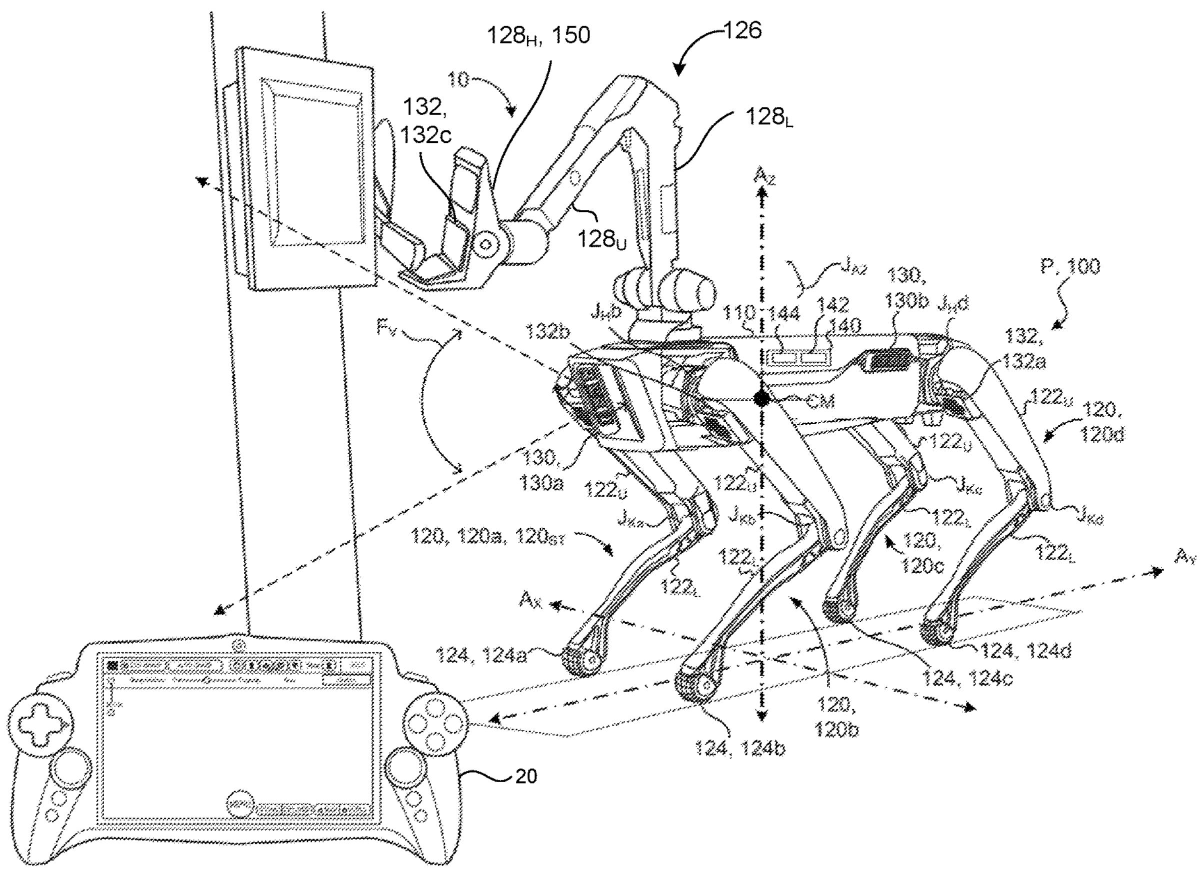
(57) **ABSTRACT**

A computer-implemented method, executed by data processing hardware of a robot, includes receiving sensor data for a space within an environment about the robot. The method includes receiving, from a user interface (UI) in communication with the data processing hardware, a user input indicating a user-selection of a location within a two-dimensional (2D) representation of the space. The location corresponds to a position of a target object within the space. The method includes receiving, from the UI, a plurality of grasping inputs designating an orientation and a translation for an end-effector of a robotic manipulator to grasp the target object. The method includes generating a three-dimensional (3D) location of the target object based on the received sensor data and the location corresponding to the user input. The method includes instructing the end-effector to grasp the target object using the generated 3D location and the plurality of grasping inputs.



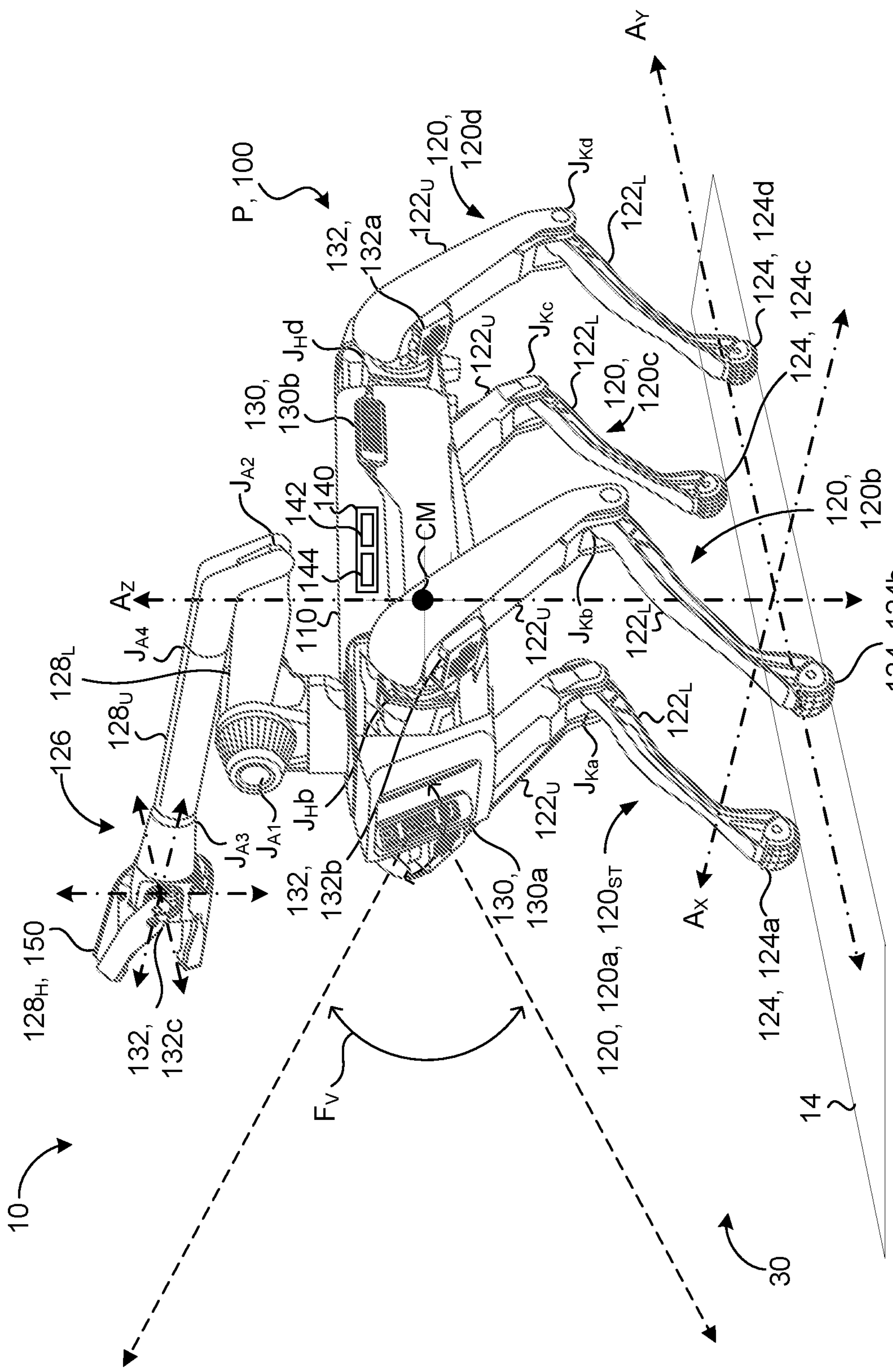
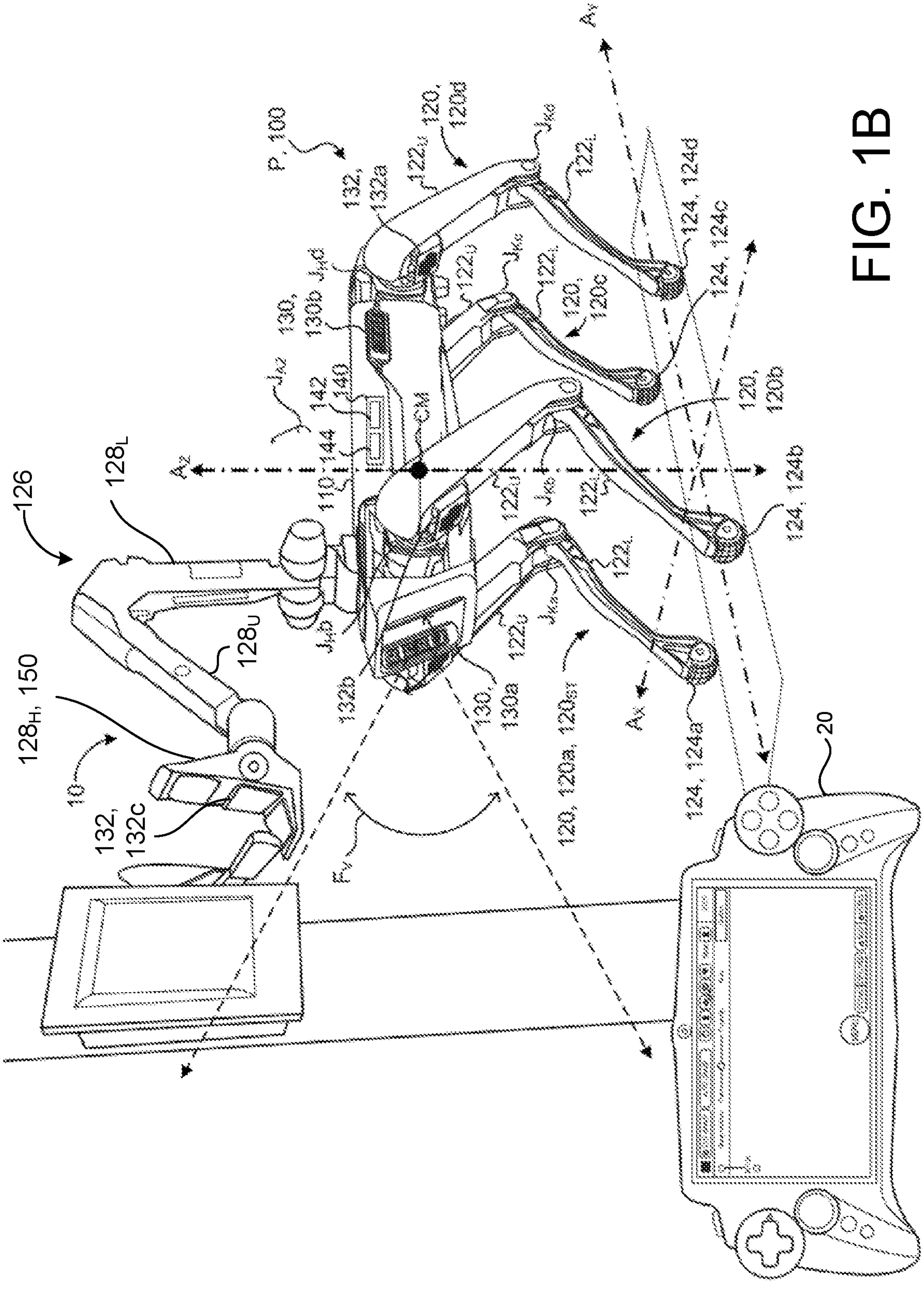

10
30
14
P, 100
120, 120d
120, 120c
120, 120b
120, 120a, 120ST
122U
122L
124, 124a
124, 124b
124, 124c
124, 124d
126
128H, 150
128U
128L
130, 130a
130, 130b
132, 132a
132, 132b
132, 132c
110
140
142
144
CM
AX
AY
AZ
FV
JA1
JA2
JA3
JA4
JHb
JHd
JKa
JKb
JKc
JKd

FIG. 1A



P, 100
132, 132a
120, 120d
130, 130b
142
140
144
110
CM
126
128L
128U
128H, 150
10
132, 132c
132b
130, 130a
120, 120a, 120ST
120, 120b
120, 120c
124, 124a
124, 124b
124, 124c
124, 124d
20

FIG. 1B

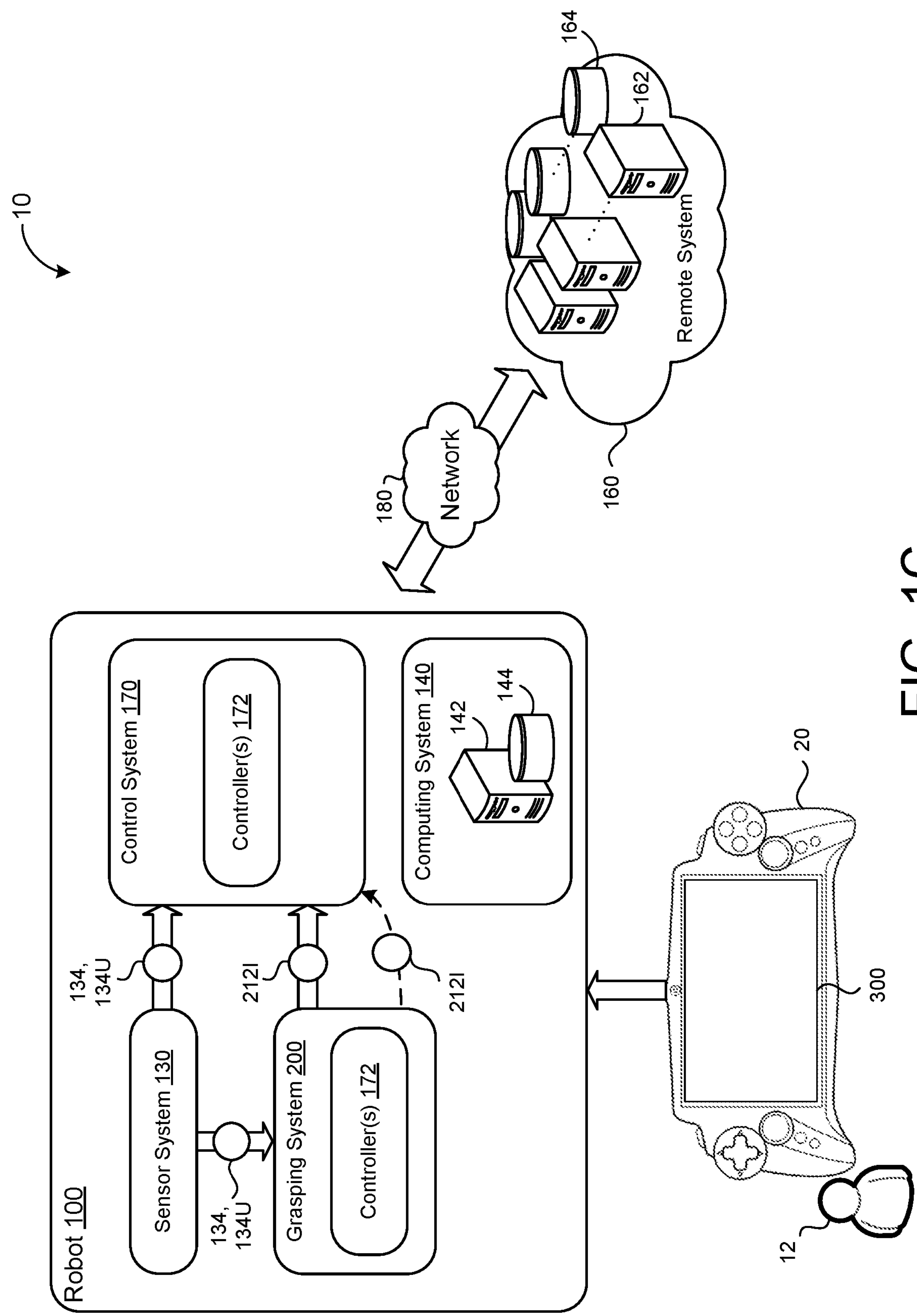

10
Robot 100
Sensor System 130
Grasping System 200
Controller(s) 172
Control System 170
Controller(s) 172
Computing System 140
142
144
134, 134U
134, 134U
212I
212I
Network
180
Remote System
160
162
164
20
300
12

FIG. 1C

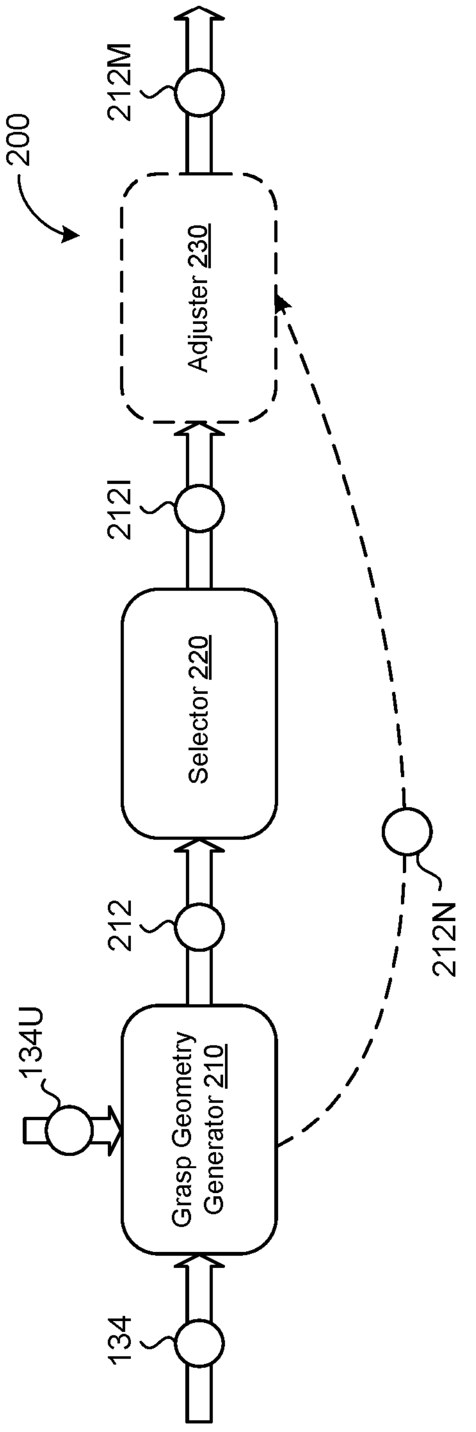

200
134
134U
Grasp Geometry Generator 210
212
Selector 220
212I
Adjuster 230
212M
212N

FIG. 2A

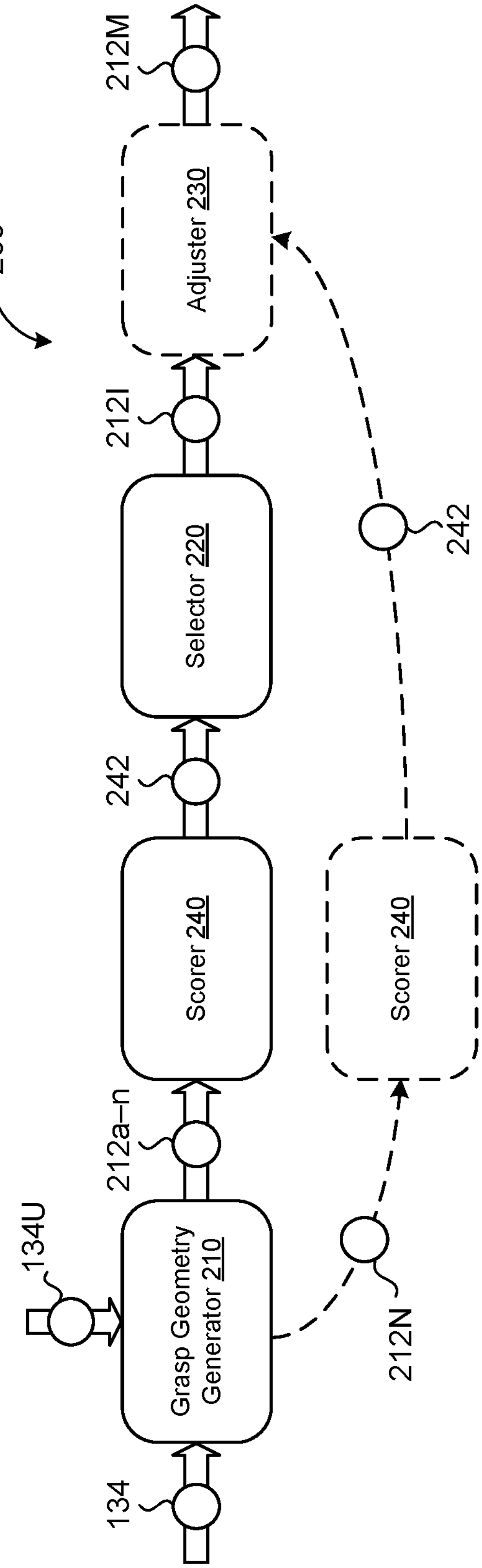

200
134
134U
Grasp Geometry Generator 210
212a–n
Scorer 240
242
Selector 220
212I
Adjuster 230
212M
212N
Scorer 240
242

FIG. 2B

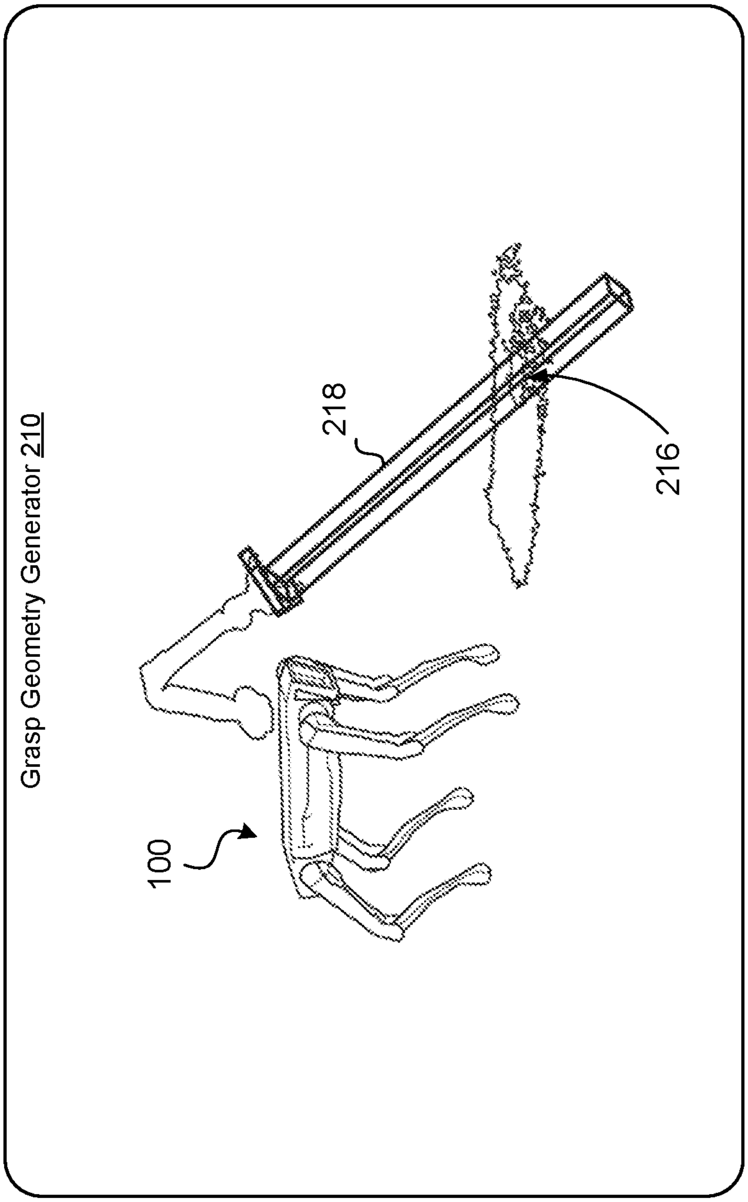


FIG. 2C

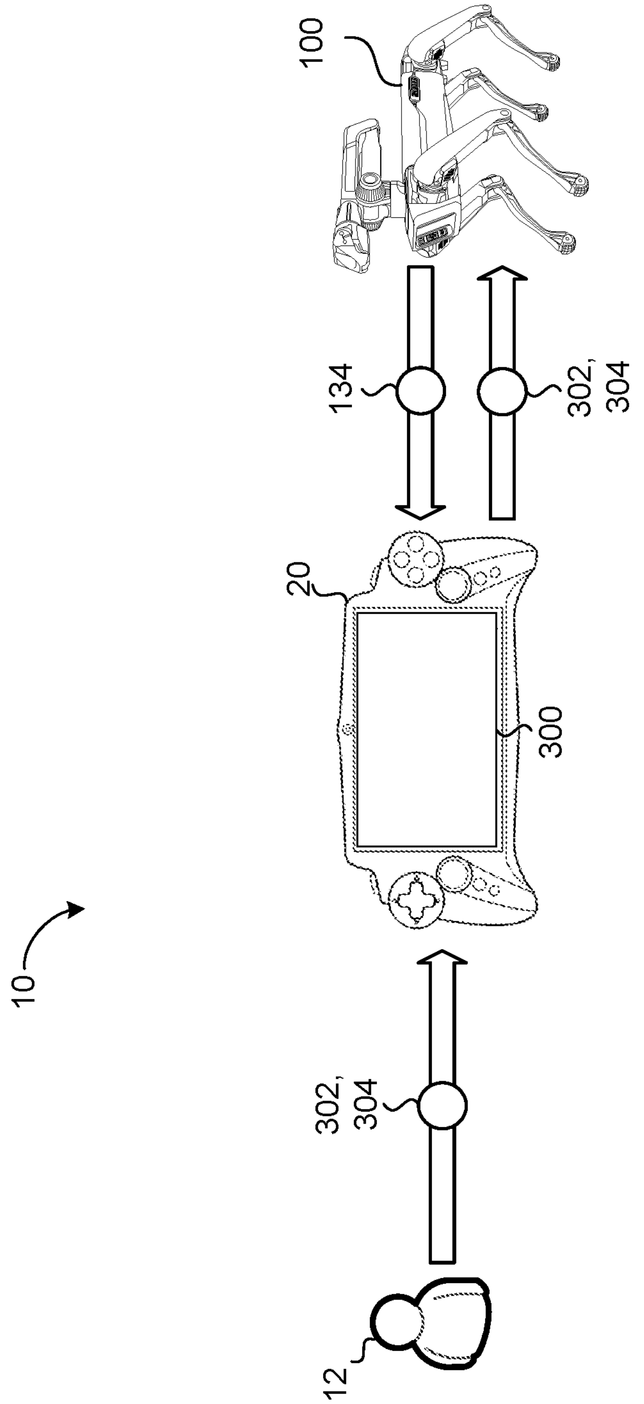


FIG. 3A

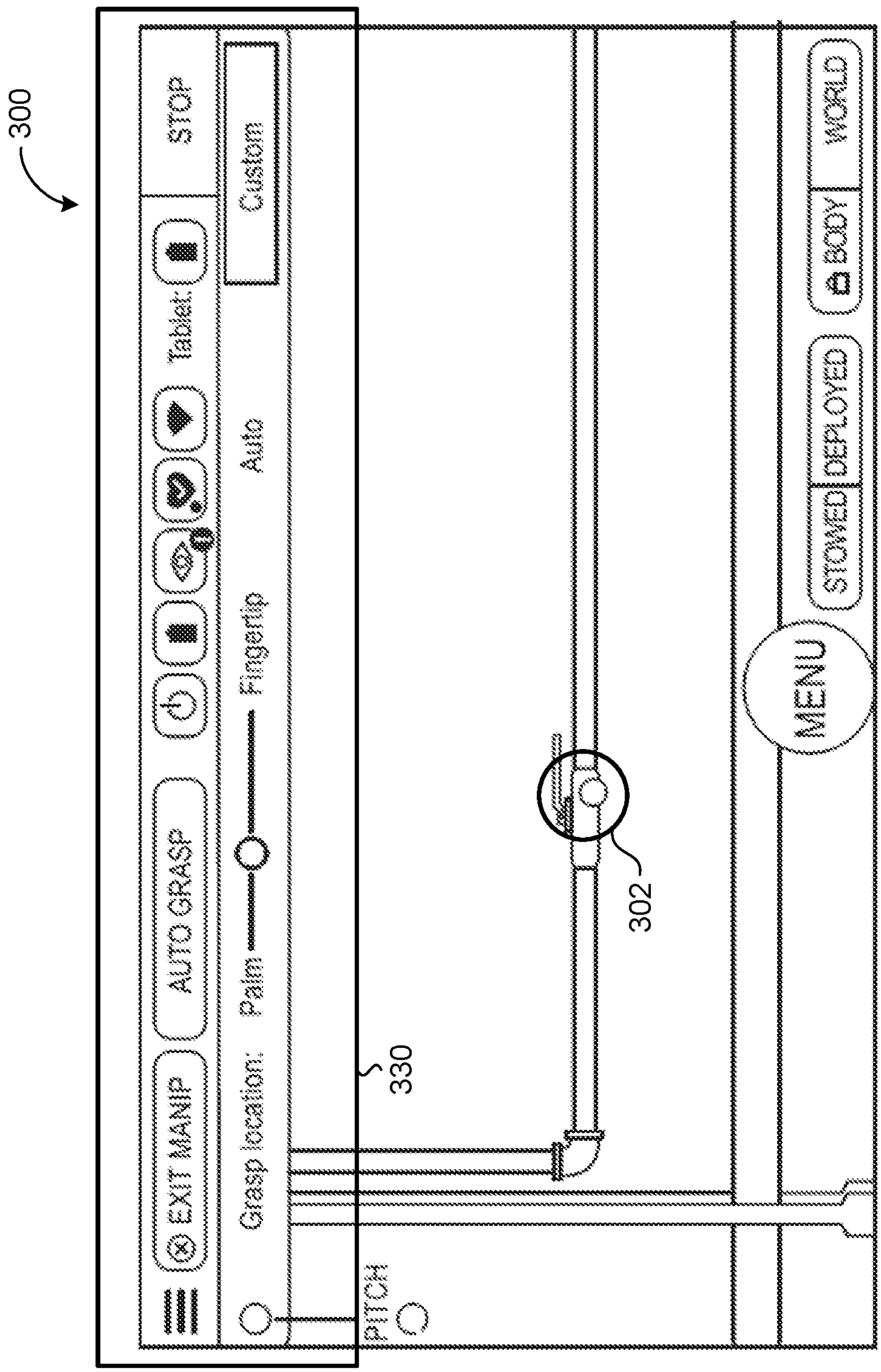

300
STOP
Tablet
Custom
AUTO GRASP
EXIT MANIP
Grasp location:
Palm
Fingertip
Auto
PITCH
330
302
MENU
STOWED
DEPLOYED
BODY
WORLD

FIG. 3B

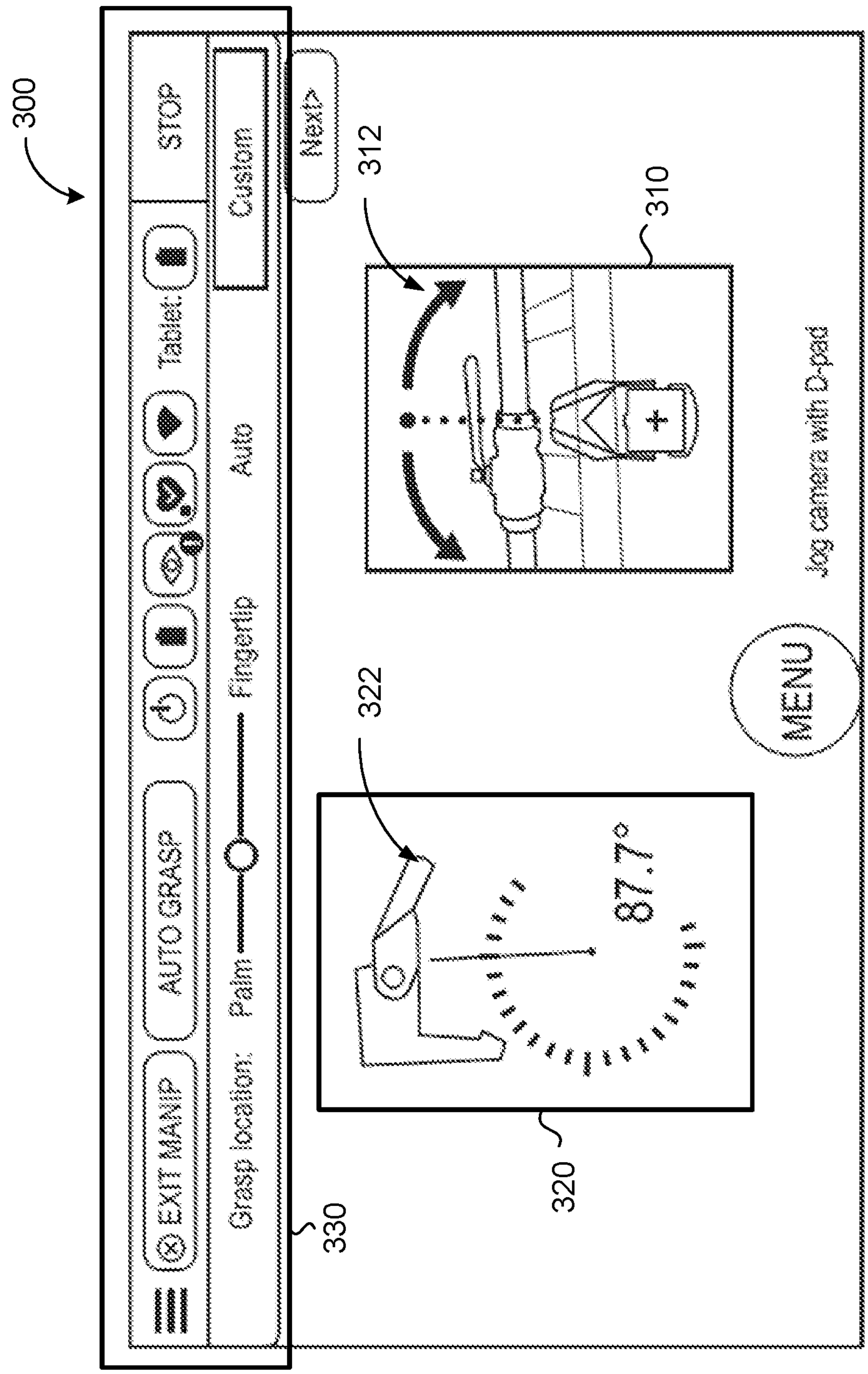

300
STOP
Custom
Next>
Tablet:
Auto
Fingertip
Grasp location:
Palm
AUTO GRASP
EXIT MANIP
312
310
Jog camera with D-pad
MENU
322
87.7°
320
330

FIG. 3C

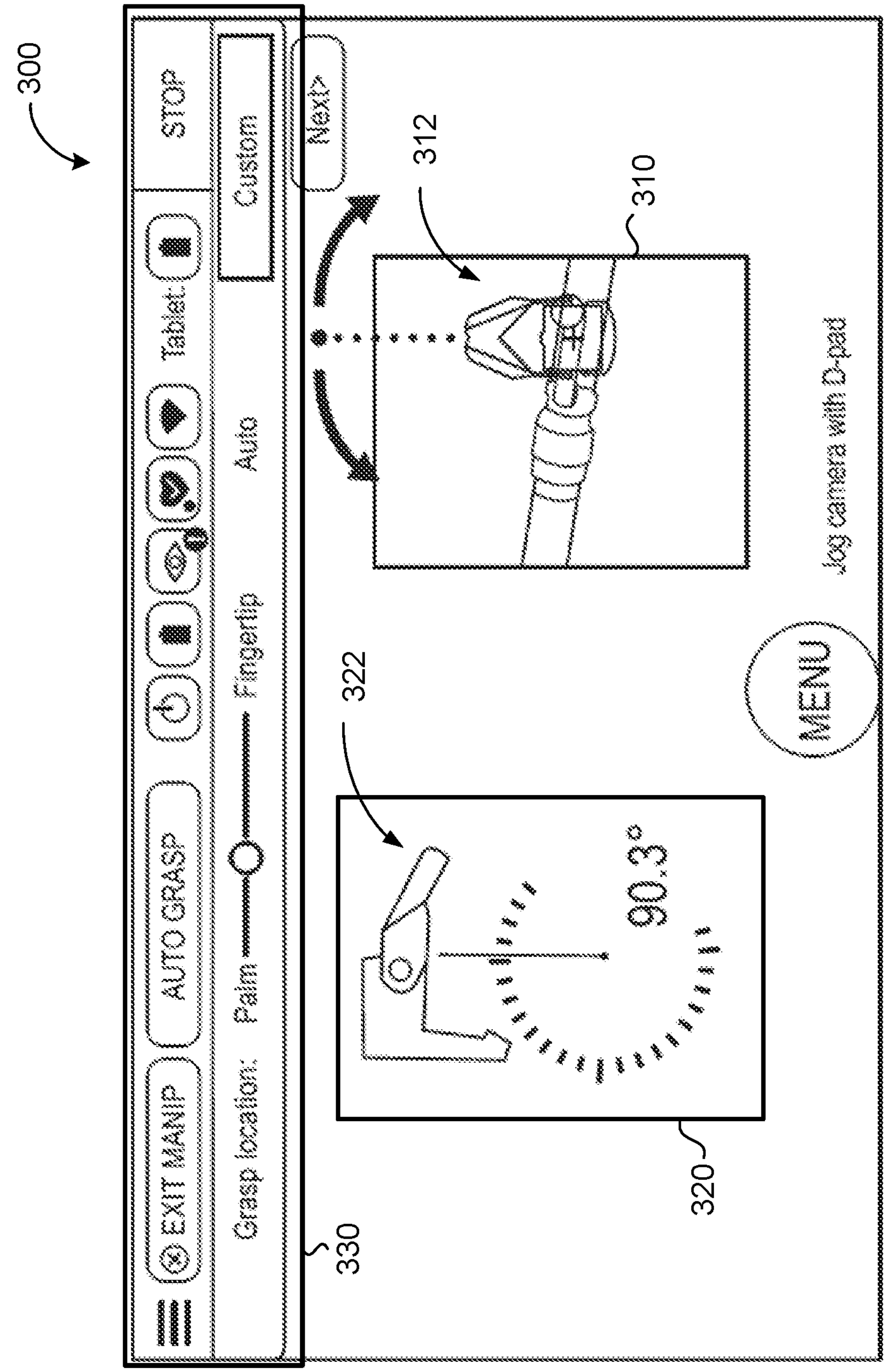

300
STOP
Custom
Next>
Tablet
Auto
Grasp location:
Palm
Fingertip
EXIT MANIP
AUTO GRASP
312
310
322
320
330
90.3°
MENU
Jog camera with D-pad

FIG. 3D

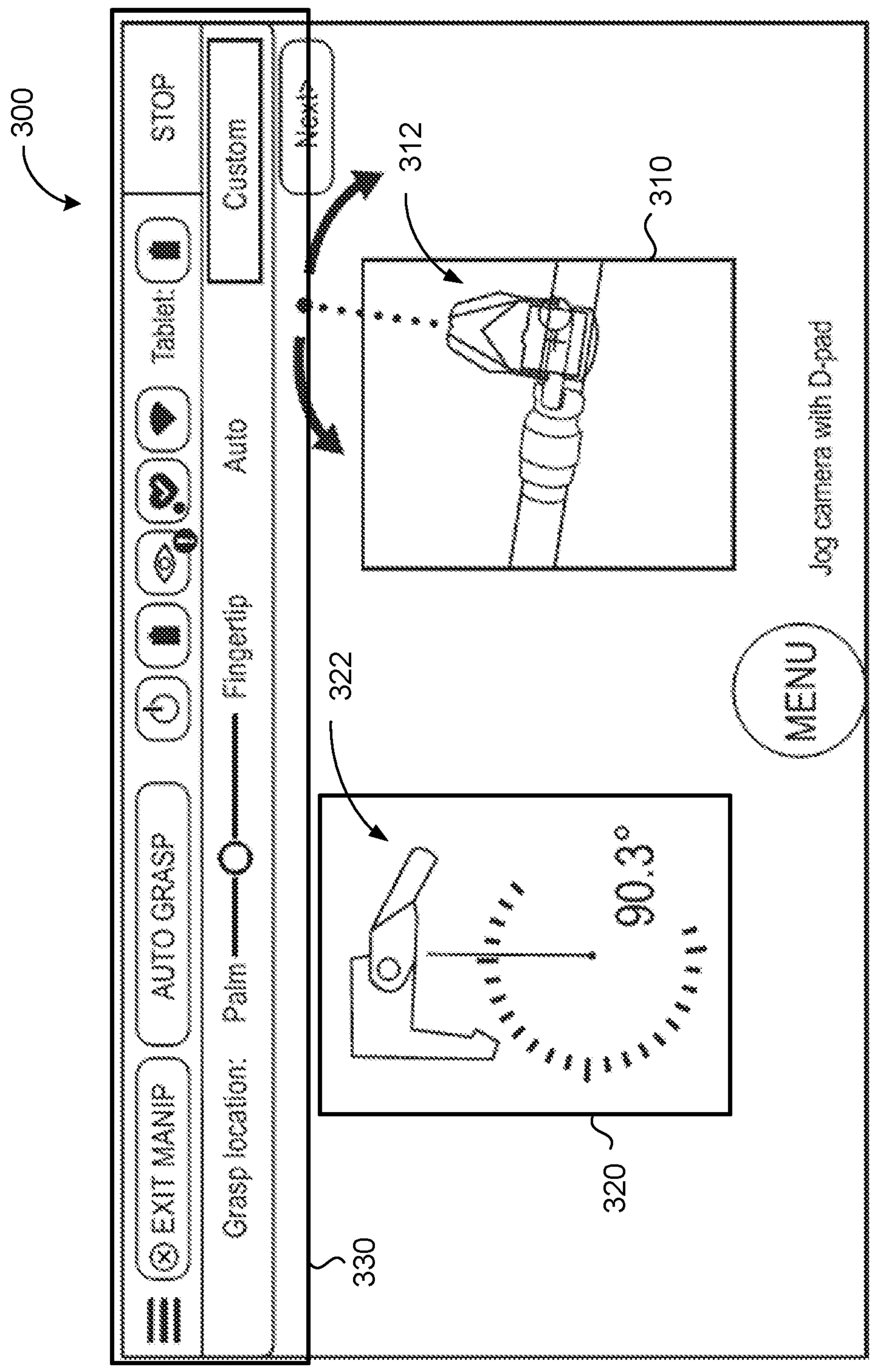

300
STOP
Custom
Next
Tablet:
Auto
Fingertip
Palm
Grasp location:
AUTO GRASP
EXIT MANIP
312
310
322
90.3°
MENU
Jog camera with D-pad
320
330

FIG. 3E

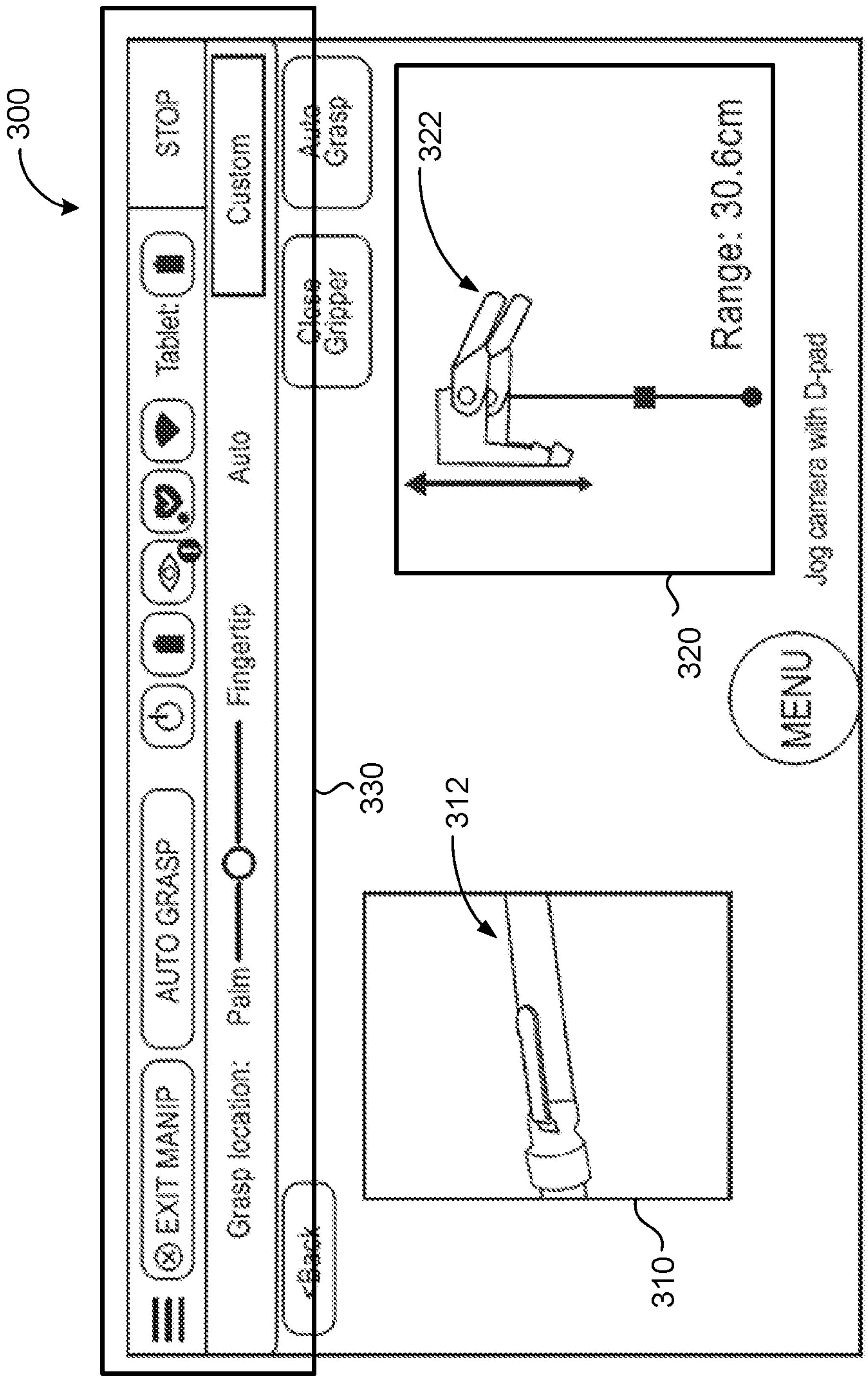

300
EXIT MANIP
AUTO GRASP
Tablet
STOP
Grasp location:
Palm
Fingertip
Auto
Custom
Back
Close Gripper
Auto Grasp
330
322
Range: 30.6cm
320
312
310
MENU
Jog camera with D-pad

FIG. 3F

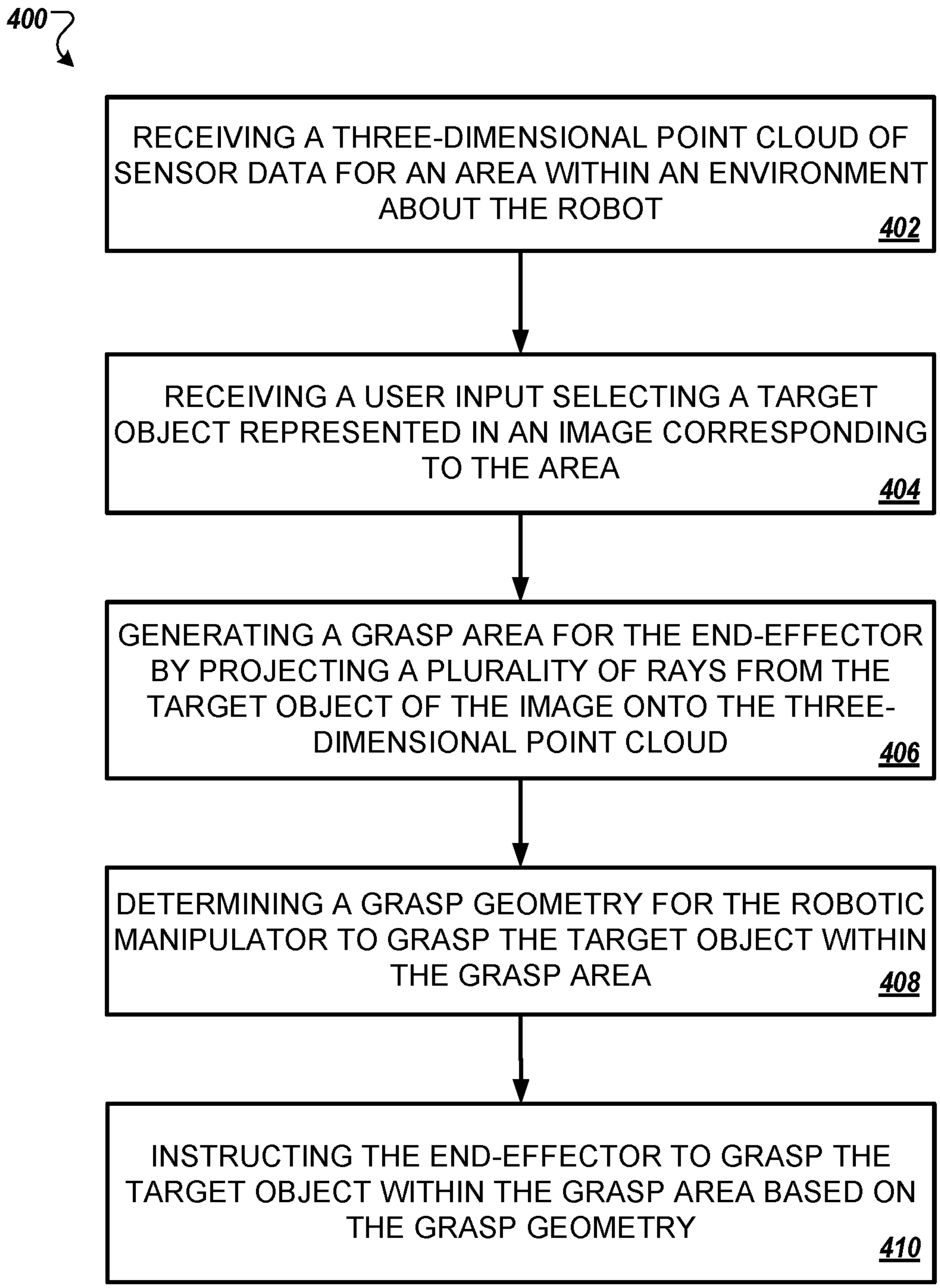

400
RECEIVING A THREE-DIMENSIONAL POINT CLOUD OF SENSOR DATA FOR AN AREA WITHIN AN ENVIRONMENT ABOUT THE ROBOT
402
RECEIVING A USER INPUT SELECTING A TARGET OBJECT REPRESENTED IN AN IMAGE CORRESPONDING TO THE AREA
404
GENERATING A GRASP AREA FOR THE END-EFFECTOR BY PROJECTING A PLURALITY OF RAYS FROM THE TARGET OBJECT OF THE IMAGE ONTO THE THREE-DIMENSIONAL POINT CLOUD
406
DETERMINING A GRASP GEOMETRY FOR THE ROBOTIC MANIPULATOR TO GRASP THE TARGET OBJECT WITHIN THE GRASP AREA
408
INSTRUCTING THE END-EFFECTOR TO GRASP THE TARGET OBJECT WITHIN THE GRASP AREA BASED ON THE GRASP GEOMETRY
410

FIG. 4

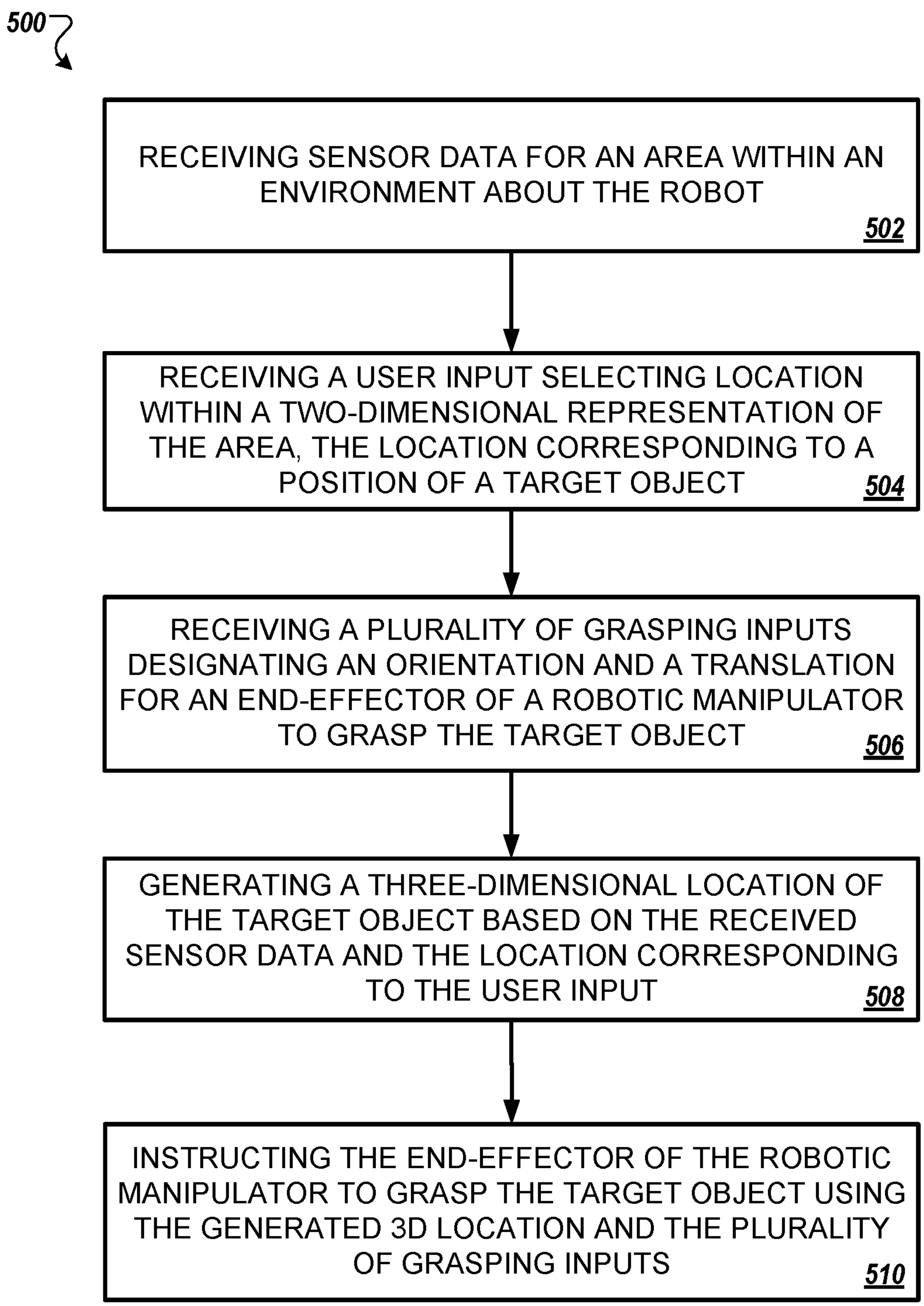

500
RECEIVING SENSOR DATA FOR AN AREA WITHIN AN ENVIRONMENT ABOUT THE ROBOT
502
RECEIVING A USER INPUT SELECTING LOCATION WITHIN A TWO-DIMENSIONAL REPRESENTATION OF THE AREA, THE LOCATION CORRESPONDING TO A POSITION OF A TARGET OBJECT
504
RECEIVING A PLURALITY OF GRASPING INPUTS DESIGNATING AN ORIENTATION AND A TRANSLATION FOR AN END-EFFECTOR OF A ROBOTIC MANIPULATOR TO GRASP THE TARGET OBJECT
506
GENERATING A THREE-DIMENSIONAL LOCATION OF THE TARGET OBJECT BASED ON THE RECEIVED SENSOR DATA AND THE LOCATION CORRESPONDING TO THE USER INPUT
508
INSTRUCTING THE END-EFFECTOR OF THE ROBOTIC MANIPULATOR TO GRASP THE TARGET OBJECT USING THE GENERATED 3D LOCATION AND THE PLURALITY OF GRASPING INPUTS
510

FIG. 5

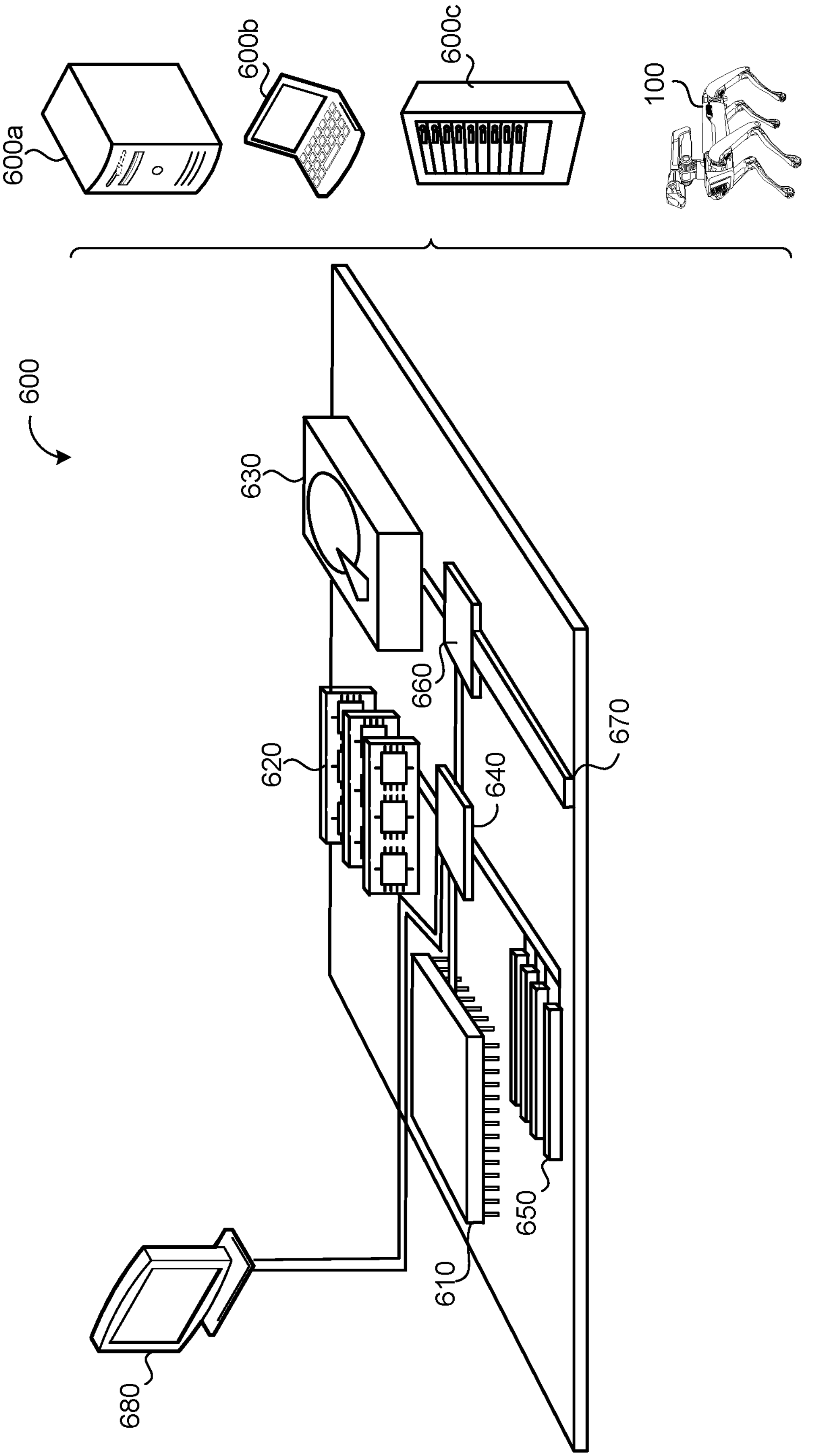


FIG. 6

USER INTERFACE FOR SUPERVISED AUTONOMOUS GRASPING

CROSS REFERENCE TO RELATED APPLICATIONS

[0001] This U.S. patent application claims priority under 35 U.S.C. § 119(e) to U.S. Provisional Application 63/128,768, filed on Dec. 21, 2020. The disclosure of this prior application is considered part of the disclosure of this application and is hereby incorporated by reference in its entirety.

TECHNICAL FIELD

[0002] This disclosure relates to a user interface for supervised autonomous grasping.

BACKGROUND

[0003] A robot is generally defined as a reprogrammable and multifunctional manipulator designed to move material, parts, tools, or specialized devices through variable programmed motions for a performance of tasks. Robots may be manipulators that are physically anchored (e.g., industrial robotic arms), mobile robots that move throughout an environment (e.g., using legs, wheels, or traction based mechanisms), or some combination of a manipulator and a mobile robot. Robots are utilized in a variety of industries including, for example, manufacturing, transportation, hazardous environments, exploration, and healthcare. As such, the ability to program robots in a quick and an efficient manner for various behaviors provides additional benefits to such industries.

SUMMARY

[0004] One aspect of the disclosure provides a computer-implemented method that, when executed by data processing hardware of a robot causes the data processing hardware to perform operations. The operations include receiving sensor data for a space within an environment about the robot. The operations further include receiving, from a user interface (UI) in communication with the data processing hardware, a user input indicating a user-selection of a location within a two-dimensional (2D) representation of the space. The location corresponds to a position of a target object within the space. The operations also include receiving, from the UI, a plurality of grasping inputs designating an orientation and a translation for an end-effector of a robotic manipulator to grasp the target object. Furthermore, the operations include generating, a three-dimensional (3D) location of the target object based on the received sensor data and the location corresponding to the user input. Additionally, the operations include instructing the end-effector of the robotic manipulator to grasp the target object using the generated 3D location and the plurality of grasping inputs designating the orientation and the translation of the end-effector of the robotic manipulator.

[0005] Aspects of the disclosure may include one or more of the following optional features. In some implementations, the operations further include grasping, by the end-effector of the robotic manipulator, the target object. In some embodiments, the plurality of grasping inputs corresponds to a plurality of constraints on one or more degrees of freedom for the end-effector of the robotic manipulator. In further embodiments, the one or more degrees of freedom include a pitch of the end-effector, a roll of the end-effector, a first translation in an x-direction, and a second translation in a y-direction. In even further embodiments, the one or more degrees of freedom further includes a third translation in a z-direction.

[0006] In some examples, receiving the plurality of grasping inputs designating the orientation and the translation for the end-effector of the robotic manipulator to grasp the target object includes receiving a first grasping input designating a first orientation for the end-effector of the robotic manipulator to grasp the target object, and instructing modification of a viewport image including the target object at the UI based on the designed first orientation for the end-effector of the robotic manipulator. In further examples, the first orientation includes one of a pitch or a roll for the end-effector of the robotic manipulator to grasp the target object. In other further examples, the UI includes a first window and a second window separate from the first window. The first window includes the viewport image displaying the sensor data for the space within the environment about the robot that includes the target object. The second window includes a graphical icon representing the end-effector. The graphical icon is capable of being user-manipulated to indicate the first grasping input designating the first orientation for the end-effector of the robotic manipulator to grasp the target object. In even further examples, the graphical icon includes a wire-frame representation of the end-effector and a radial dial to designate a pitch as the first orientation for the end-effector of the robotic manipulator to grasp the target object. In other even further examples, the operations further include overlaying, on the viewport image, a representation of the end-effector at the first orientation designated by the first grasping input, and receiving, from the UI, a second grasping input designating a second orientation for the end-effector of the robotic manipulator to grasp the target object.

[0007] In additional even further examples, the second orientation corresponds to a roll for the end-effector of the robotic manipulator to grasp the target object. In other additional even further examples, receiving the second grasping input designating the second orientation includes receiving another user input indicating another user-selection of the graphical icon indicating the roll for the end-effector of the robotic manipulator to grasp the target object.

[0008] Another aspect of the disclosure provides a robot. The robot includes a body, a robotic manipulator coupled to the body, data processing hardware in communication with the robotic manipulator, and memory hardware in communication with the data processing hardware. The robotic manipulator includes an end-effector configured to grasp objects within an environment about the robot. The memory hardware stores instructions that, when executed on the data processing hardware, cause the data processing hardware to perform operations. The operations include receiving sensor data for a space within an environment about the robot. The operations further include receiving, from a user interface (UI) in communication with the data processing hardware, a user input indicating a user-selection of a location within a two-dimensional (2D) representation of the space. The location corresponds to a position of a target object within the space. The operations also include receiving, from the UI, a plurality of grasping inputs designating an orientation and a translation for the end-effector of the robotic manipulator to grasp the target object. Furthermore, the operations include generating a three-dimensional (3D) location of the target object based on the received sensor data and the location corresponding to the user input. Additionally, the operations include instructing the end-effector of the robotic manipulator to grasp the target object using the generated 3D location and the plurality of grasping inputs designating the orientation and the translation of the end-effector of the robotic manipulator.

[0009] Aspects of the disclosure may include one or more of the following optional features. In some implementations, the operations further include grasping, by the end-effector of the robotic manipulator, the target object. In some embodiments, the plurality of grasping inputs corresponds to a plurality of constraints on one or more degrees of freedom for the end-effector of the robotic manipulator. In further embodiments, the one or more degrees of freedom include a pitch of the end-effector, a roll of the end-effector, a first translation in an x-direction, and a second translation in a y-direction. In even further embodiments, the one or more degrees of freedom further includes a third translation in a z-direction.

[0010] In some examples, receiving the plurality of grasping inputs designating the orientation and the translation for the end-effector of the robotic manipulator to grasp the target object includes receiving a first grasping input designating a first orientation for the end-effector of the robotic manipulator to grasp the target object, and instructing modification of a viewport image including the target object at the UI based on the designed first orientation for the end-effector of the robotic manipulator. In further examples, the first orientation includes one of a pitch or a roll for the end-effector of the robotic manipulator to grasp the target object. In other further examples, the UI includes a first window and a second window separate from the first window. The first window includes the viewport image displaying the sensor data for the space within the environment about the robot that includes the target object, the second window includes a graphical icon representing the end-effector. The graphical icon is capable of being user-manipulated to indicate the first grasping input designating the first orientation for the end-effector of the robotic manipulator to grasp the target object. In even further examples, the graphical icon comprises a wire-frame representation of the end-effector and a radial dial to designate a pitch as the first orientation for the end-effector of the robotic manipulator to grasp the target object. In other even further examples, the operations further include overlaying, on the viewport image, a representation of the end-effector at the first orientation designated by the first grasping input and receiving, from the UI, a second grasping input designating a second orientation for the end-effector of the robotic manipulator to grasp the target object.

[0011] In additional even further examples, the second orientation corresponds to a roll for the end-effector of the robotic manipulator to grasp the target object. In other additional even further examples, receiving the second grasping input designating the second orientation includes receiving another user input indicating another user-selection of the graphical icon indicating the roll for the end-effector of the robotic manipulator to grasp the target object.

[0012] The details of one or more implementations of the disclosure are set forth in the accompanying drawings and the description below. Other aspects, features, and advantages will be apparent from the description and drawings, and from the claims.

DESCRIPTION OF DRAWINGS

[0013] FIG. **1**A is a perspective view of an example robot capable of grasping an object.

[0014] FIG. **1**B is a perspective view of the robot of FIG. **1**A with a remote controller in communication with the robot.

[0015] FIG. **1**C is a schematic view of example systems of the robot of FIG. **1**A.

[0016] FIGS. **2**A-**2**C are schematic views of example grasping systems for the robot of FIG. **1**A.

[0017] FIG. **3**A is a schematic view of an example environment of a user interface for grasping an object using the robot of FIG. **1**A.

[0018] FIGS. **3**B-**3**F are schematic views of example user interfaces for coordinating with the robot of FIG. **1**A to grasp an object.

[0019] FIG. **4** is a flowchart of an example arrangement of operations for a method of supervised autonomous grasping.

[0020] FIG. **5** is a flowchart of an example arrangement of operations for a method of using a user interface for supervised autonomous grasping.

[0021] FIG. **6** is a schematic view of an example computing device that may be used to implement the systems and methods described herein.

[0022] Like reference symbols in the various drawings indicate like elements.

DETAILED DESCRIPTION

[0023] Referring to FIGS. **1**A-**1**C, the robot **100** includes a body **110** with locomotion based structures such as legs **120***a-d* coupled to the body **110** that enable the robot **100** to move about the environment **10**. In some examples, each leg **120** is an articulable structure such that one or more joints J permit members **122** of the leg **120** to move. For instance, each leg **120** includes a hip joint JH coupling an upper member **122**, $\mathbf{122}_U$ of the leg **120** to the body **110** and a knee joint JK coupling the upper member $\mathbf{122}_U$ of the leg **120** to a lower member $\mathbf{122}_L$ of the leg **120**. Although FIG. **1**A depicts a quadruped robot with four legs **120***a-d*, the robot **100** may include any number of legs or locomotive based structures (e.g., a biped or humanoid robot with two legs, or other arrangements of one or more legs) that provide a means to traverse the terrain within the environment **10**.

[0024] In order to traverse the terrain, each leg **120** has a distal end **124** that contacts a surface of the terrain (i.e., a traction surface). In other words, the distal end **124** of the leg **120** is the end of the leg **120** used by the robot **100** to pivot, plant, or generally provide traction during movement of the robot **100**. For example, the distal end **124** of a leg **120** corresponds to a foot of the robot **100**. In some examples, though not shown, the distal end **124** of the leg **120** includes an ankle joint JA such that the distal end **124** is articulable with respect to the lower member $\mathbf{122}_L$ of the leg **120**.

[0025] In the examples shown, the robot **100** includes an arm **126** that functions as a robotic manipulator. The arm **126** may be configured to move about multiple degrees of freedom in order to engage elements of the environment **10** (e.g., objects within the environment **10**). In some examples, the arm **126** includes one or more members **128**, where the members **128** are coupled by joints J such that the arm **126** may pivot or rotate about the joint(s) J. For instance, with more than one member **128**, the arm **126** may be configured to extend or to retract. To illustrate an example, FIG. **1**A depicts the arm **126** with three members **128** corresponding to a lower member $\mathbf{128}_L$, an upper member $\mathbf{128}_U$, and a hand member $\mathbf{128}_H$ (e.g., shown as an end-effector **150**). Here, the lower member $\mathbf{128}_L$ may rotate or pivot about a first arm joint J_{A1} located adjacent to the body **110** (e.g., where the arm **126** connects to the body **110** of the robot **100**). The lower member $\mathbf{128}_L$ is coupled to the upper member $\mathbf{128}_U$ at a second arm joint J_{A2} and the upper member $\mathbf{128}_U$ is coupled to the hand member $\mathbf{128}_H$ at a third arm joint J_{A3}. In some examples, such as FIGS. **1**A and **1**B, the hand member $\mathbf{128}_H$ or end-effector **150** is a mechanical gripper that includes a moveable jaw and a fixed jaw configured to perform different types of grasping of elements within the environment **10**. The moveable jaw is configured to move relative to the fixed jaw in order to move between an open position for the gripper and a closed position for the gripper (e.g., closed around an object). In some implementations, the arm **126** additionally includes a fourth joint J_{A4}. The fourth joint J_{A4} may be located near the coupling of the lower member $\mathbf{128}_L$ to the upper member $\mathbf{128}_U$ and function to allow the upper member $\mathbf{128}_U$ to twist or rotate relative to the lower member $\mathbf{128}_L$. In other words, the fourth joint J_{A4} may function as a twist joint similarly to the third joint J_{A3} or wrist joint of the arm **126** adjacent the hand member $\mathbf{128}_H$. For instance, as a twist joint, one member coupled at the joint J may move or rotate relative to another member coupled at the joint J (e.g., a first member coupled at the twist joint is fixed while the second member coupled at the twist joint rotates). In some implementations, the arm **126** connects to the robot **100** at a socket on the body **110** of the robot **100**. In some configurations, the socket is configured as a connector such that the arm **126** may attach or detach from the robot **100** depending on whether the arm **126** is needed for operation.

[0026] The robot **100** has a vertical gravitational axis (e.g., shown as a Z-direction axis Az) along a direction of gravity, and a center of mass CM, which is a position that corresponds to an average position of all parts of the robot **100** where the parts are weighted according to their masses (i.e., a point where the weighted relative position of the distributed mass of the robot **100** sums to zero). The robot **100** further has a pose P based on the CM relative to the vertical gravitational axis Az (i.e., the fixed reference frame with respect to gravity) to define a particular attitude or stance assumed by the robot **100**. The attitude of the robot **100** can be defined by an orientation or an angular position of the robot **100** in space. Movement by the legs **120** relative to the body **110** alters the pose P of the robot **100** (i.e., the combination of the position of the CM of the robot and the attitude or orientation of the robot **100**). Here, a height generally refers to a distance along the z-direction (e.g., along a z-direction axis Az). The sagittal plane of the robot **100** corresponds to the Y-Z plane extending in directions of a y-direction axis AY and the z-direction axis Az. In other words, the sagittal plane bisects the robot **100** into a left and a right side. Generally perpendicular to the sagittal plane, a ground plane (also referred to as a transverse plane) spans the X-Y plane by extending in directions of the x-direction axis Ax and the y-direction axis AY. The ground plane refers to a ground surface **14** where distal ends **124** of the legs **120** of the robot **100** may generate traction to help the robot **100** move about the environment **30**. Another anatomical plane of the robot **100** is the frontal plane that extends across the body **110** of the robot **100** (e.g., from a left side of the robot **100** with a first leg **120***a* to a right side of the robot **100** with a second leg **120***b*). The frontal plane spans the X-Z plane by extending in directions of the x-direction axis Ax and the z-direction axis Az.

[0027] In order to maneuver about the environment **10** or to perform tasks using the arm **126**, the robot **100** includes a sensor system **130** with one or more sensors **132**, **132***a-n* (e.g., shown as a first sensor **132**, **132***a* and a second sensor **132**, **132***b*). The sensors **132** may include vision/image sensors, inertial sensors (e.g., an inertial measurement unit (IMU)), force sensors, and/or kinematic sensors. Some examples of sensors **132** include a camera such as a stereo camera, a time-of-flight (TOF) sensor, a scanning light-detection and ranging (LIDAR) sensor, or a scanning laser-detection and ranging (LADAR) sensor. In some examples, the sensor **132** has a corresponding field(s) of view Fv defining a sensing range or region corresponding to the sensor **132**. For instance, FIG. **1**A depicts a field of a view Fv for the robot **100**. Each sensor **132** may be pivotable and/or rotatable such that the sensor **132** may, for example, change the field of view Fv about one or more axis (e.g., an x-axis, a y-axis, or a z-axis in relation to a ground plane).

[0028] When surveying a field of view Fv with a sensor **132**, the sensor system **130** generates sensor data **134** (also referred to as image data) corresponding to the field of view Fv. The sensor system **130** may generate the field of view Fv with a sensor **132** mounted on or near the body **110** of the robot **100** (e.g., sensor(s) **132***a*, **132***b*). The sensor system may additionally and/or alternatively generate the field of view Fv with a sensor **132** mounted at or near the end-effector **150** of the arm **126** (e.g., sensor(s) **132***c*). The one or more sensors **132** may capture sensor data **134** that defines the three-dimensional point cloud for the area within the environment **10** about the robot **100**. In some examples, the sensor data **134** is image data that corresponds to a three-dimensional volumetric point cloud generated by a three-dimensional volumetric image sensor **132**. Additionally or alternatively, when the robot **100** is maneuvering about the environment **10**, the sensor system **130** gathers pose data for the robot **100** that includes inertial measurement data (e.g., measured by an IMU). In some examples, the pose data includes kinematic data and/or orientation data about the robot **100**, for instance, kinematic data and/or orientation data about joints J or other portions of a leg **120** or arm **126** of the robot **100**. With the sensor data **134**, various systems of the robot **100** may use the sensor data **134** to define a current state of the robot **100** (e.g., of the kinematics of the robot **100**) and/or a current state of the environment **30** about the robot **100**.

[0029] In some implementations, the sensor system **130** includes sensor(s) **132** coupled to a joint J. Moreover, these sensors **132** may couple to a motor M that operates a joint J of the robot **100** (e.g., sensors **132**, **132***a-b*). Here, these sensors **132** generate joint dynamics in the form of joint-based sensor data **134**. Joint dynamics collected as joint-based sensor data **134** may include joint angles (e.g., an upper member $\mathbf{122}_U$ relative to a lower member $\mathbf{122}_L$ or hand member $\mathbf{126}_H$ relative to another member of the arm **126** or robot **100**), joint speed (e.g., joint angular velocity or joint angular acceleration), and/or forces experienced at a joint J (also referred to as joint forces). Joint-based sensor data generated by one or more sensors **132** may be raw sensor data, data that is further processed to form different types of joint dynamics, or some combination of both. For instance, a sensor **132** measures joint position (or a position of member(s) **122** coupled at a joint J) and systems of the robot **100** perform further processing to derive velocity and/or acceleration from the positional data. In other examples, a sensor **132** is configured to measure velocity and/or acceleration directly.

[0030] As the sensor system **130** gathers sensor data **134**, a computing system **140** stores, processes, and/or to communicates the sensor data **134** to various systems of the robot **100** (e.g., the control system **170**, grasping system **200**, and/or remote controller **20**). In order to perform computing tasks related to the sensor data **134**, the computing system **140** of the robot **100** includes data processing hardware **142** and memory hardware **144**. The data processing hardware **142** is configured to execute instructions stored in the memory hardware **144** to perform computing tasks related to activities (e.g., movement and/or movement based activities) for the robot **100**. Generally speaking, the computing system **140** refers to one or more locations of data processing hardware **142** and/or memory hardware **144**.

[0031] In some examples, the computing system **140** is a local system located on the robot **100**. When located on the robot **100**, the computing system **140** may be centralized (i.e., in a single location/area on the robot **100**, for example, the body **110** of the robot **100**), decentralized (i.e., located at various locations about the robot **100**), or a hybrid combination of both (e.g., where a majority of centralized hardware and a minority of decentralized hardware). To illustrate some differences, a decentralized computing system **140** may allow processing to occur at an activity location (e.g., at motor that moves a joint of a leg **120**) while a centralized computing system **140** may allow for a central processing hub that communicates to systems located at various positions on the robot **100** (e.g., communicate to the motor that moves the joint of the leg **120**).

[0032] Additionally or alternatively, the computing system **140** includes computing resources that are located remotely from the robot **100**. For instance, the computing system **140** communicates via a network **180** with a remote system **160** (e.g., a remote server or a cloud-based environment). Much like the computing system **140**, the remote system **160** includes remote computing resources, such as remote data processing hardware **162** and remote memory hardware **164**. Here, sensor data **134** or other processed data (e.g., data processing locally by the computing system **140**) may be stored in the remote system **160** and may be accessible to the computing system **140**. In additional examples, the computing system **140** is configured to utilize the remote resources **162**, **164** as extensions of the computing resources **142**, **144** such that resources of the computing system **140** may reside on resources of the remote system **160**.

[0033] In some implementations, as shown in FIGS. **1A** and **1B**, the robot **100** includes a control system **170**. The control system **170** may be configured to communicate with systems of the robot **100**, such as the at least one sensor system **130**. The control system **170** may perform operations and other functions using hardware **140**. The control system **170** includes at least one controller **172** that is configured to control the robot **100**. For example, the controller **172** controls movement of the robot **100** to traverse about the environment **10** based on input or feedback from the systems of the robot **100** (e.g., the sensor system **130**, the control system **170**, and/or the grasping system **200**). In additional examples, the controller **172** controls movement between poses and/or behaviors of the robot **100**. At least one the controller **172** may be responsible for controlling movement of the arm **126** of the robot **100** in order for the arm **126** to perform various tasks using the end-effector **150**. For instance, at least one controller **172** controls the end-effector **150** (e.g., gripper) to manipulate an object or element in the environment **10**. For example, the controller **172** actuates the movable jaw in a direction towards the fixed jaw to close the gripper. In other examples, the controller **172** actuates the movable jaw in a direction away from the fixed jaw to open the gripper.

[0034] A given controller **172** may control the robot **100** by controlling movement about one or more joints J of the robot **100**. In some configurations, the given controller **172** is software with programming logic that controls at least one joint J or a motor M which operates, or is coupled to, a joint J. For instance, the controller **172** controls an amount of force that is applied to a joint J (e.g., torque at a joint J). As programmable controllers **172**, the number of joints J that a controller **172** controls is scalable and/or customizable for a particular control purpose. A controller **172** may control a single joint J (e.g., control a torque at a single joint J), multiple joints J, or actuation of one or more members **128** (e.g., actuation of the hand member $\mathbf{128}_H$) of the robot **100**. By controlling one or more joints J, actuators or motors M, the controller **172** may coordinate movement for all different parts of the robot **100** (e.g., the body **110**, one or more legs **120**, the arm **126**). For example, to perform some movements or tasks, a controller **172** may be configured to control movement of multiple parts of the robot **100** such as, for example, two legs **120***a-b*, four legs **120***a-d*, or two legs **120***a-b* combined with the arm **126**.

[0035] Referring now to FIG. **1B**, the sensor system **130** of the robot **100** generates a three-dimensional point cloud of sensor data **134** for an area or space or volume within the environment **10** about the robot **100**. Although referred to as a three-dimensional point cloud of sensor data **134**, it should be understood that the sensor data **134** may represent a three-dimensional portion of the environment **10** or a two-dimensional portion (such as a surface or plane) of the environment **10**. In other words, the sensor data **134** may be a three-dimensional point cloud or a two-dimensional collection of points. The sensor data **134** corresponds to the current field of view Fv of the one or more sensors **132** mounted on the robot **100**. In some examples, the sensor system **130** generates the field of view Fv with the one or more sensors **132***c* mounted at or near the end-effector **150**. In other examples, the sensor system **130** additionally and/or alternatively generates the field of view Fv based on the one or more sensors **132***a*, **132***b* mounted at or near the body **110** of the robot **100**. The sensor data **134** updates as the robot **100** maneuvers within the environment **10** and the one or more sensors **132** are subject to different field of views Fv. The sensor system **130** sends the sensor data **134** to the control system **170**, grasping system **200**, and/or remote controller **20**.

[0036] A user **12** may interact with the robot **100** via the remote controller **20** that communicates with the robot **100** to perform actions. Additionally, the robot **100** may communicate with the remote controller **20** to display an image on a user interface **300** (e.g., UI **300**) of the remote controller **20**. The UI **300** is configured to display the image that corresponds to three-dimensional field of view Fv of the one or more sensors **132** or to toggle between sensors **132** in order to display different images corresponding to a respective field of views Fv for a given sensor **132**. The image displayed on the UI **300** of the remote controller **20** is a two-dimensional image that corresponds to the three-dimensional point cloud of sensor data **134** (e.g., field of view Fv) for the area within the environment **10** about the robot **100**. That is, the image displayed on the UI **300** is a two-dimensional image representation that corresponds to the three-dimensional field of view Fv of the one or more sensors **132**.

[0037] The image displayed on the UI **300** may include one or more objects that are present in the environment **10** (e.g., within a field of view Fv for a sensor **132** of the robot **100**). In some examples, the grasping system **200** or some other system of the robot **100** may be configured to classify an image in order to identify one or more objects within the image (e.g., to identify one or more graspable objects). In some implementations, the image is classified by a machine learning algorithm in order to identify the presence of one or more graspable objects in the image that correspond to one or more graspable objects within a portion of the environment **10** corresponding to the image. In particular, the sensor system **130** receives the image that corresponds to the area (e.g., environment **10**) and sends the image (e.g., sensor data **134**) to the grasping system **200**. The grasping system **200** classifies graspable objects within the received image (e.g., sensor data **134**) using a machine learning object classification algorithm. For example, the grasping system **200** may classify a piece of clothing on the ground as "laundry," or a piece of trash on the ground as "trash." The classification of the objects in the image may display to the user **12** on the UI **300**. The UI **300** may further calibrate the received image to display for the user **12**. The UI **300** allows the user **12** to select an object displayed in the two-dimensional image as a target object in order to instruct the robot **100** to perform an action upon the selected target object in the three-dimensional environment **10**.

[0038] In some implementations, the target object selected by the user corresponds to a respective object for an end-effector **150** of a robotic manipulator of the robot **100** to grasp. For example, the sensor system **130** of a robot **100** in a manufacturing environment **10** generates a three-dimensional point cloud of sensor data **134** for an area within the manufacturing environment **10**. The UI **300** displays the two-dimensional image that corresponds to the three-dimensional point cloud of sensor data **134** within the manufacturing environment **10**. The user **12** may instruct the robot **100** to grasp a target object (e.g., a valve) within the manufacturing environment **10** by selecting the target object (e.g., valve) on the UI **300**. The remote controller **20** sends the selected target object to the robot **100** to execute the grasp on the target object.

[0039] The grasping system **200** receives the user-selected target object and sensor data **134**. From the user-selected target object and sensor data **134**, the grasping system **200** identifies an area within the three-dimensional environment **10** where the target object is located. For instance, the grasping system **200** generates a grasp area corresponding to the area within the three-dimensional environment **10** where the target object is actually located in to order designate where the end-effector **150** is to grasp the target object. In particular, the grasping system **200** transforms the user-selected target object from the two-dimensional image to the grasp area on the three-dimensional point cloud of sensor data **134**. By generating the grasp area, the grasping system **200** allows the selected target object from the two-dimensional image to instruct the robot **100** to grasp the target object in the three-dimensional environment **10**. In some configurations, the grasping system **200** generates the grasp area by projecting a plurality of rays from the selected target object of the image onto the three-dimensional point cloud of sensor data **134**, as discussed in more detail below in FIG. **2**C. After determining the grasp area, the grasping system **200** determines a grasp geometry **212** for the robotic manipulator (i.e., the arm **126** of the robot **100**) to grasp the target object with. The grasp geometry **212** indicates the pose of the end-effector **150** of the robotic manipulator, where the pose represents the translation (e.g., x-coordinate, y-coordinate, and z-coordinate) and orientation (e.g., pitch, yaw, and roll) of the end-effector **150**. That is, the grasp geometry **212** indicates the pose (e.g., orientation and translation) that the end-effector **150** of the robotic manipulator uses to grasp the target object.

[0040] The grasping system **200** sends an initial grasp geometry **212**I to one or more controllers **172** that instruct the robot **100** to execute the grasp geometry **212** on the target object. In some implementations, the grasping system **200** includes one or more dedicated controllers **172** to instruct the robot **100** to execute the grasp geometry **212**. In other implementations, the grasping system **200** sends the grasp geometry **212** to one or more controllers **172** of the control system **170** that instruct the robot **100** to execute the grasp geometry **212**.

[0041] Referring now to FIG. **2**A, in some implementations, the grasping system **200** determines the grasp geometry **212** for the end-effector **150** of the robotic manipulator to grasp the targeted object selected by the user **12**. That is, the grasping system **200** determines the pose (e.g., orientation and translation) of the end-effector **150** of the robotic manipulator to grasp the target object. The grasping system **200** may include a grasp geometry generator **210** and a selector **220** to determine the grasp geometry **212**. The grasp geometry generator **210** receives sensor data **134** from the sensor system **130**. The grasp geometry generator **210** is configured to generate the grasp geometry **212** for the end-effector **150** of the robotic manipulator to grasp the selected target object based on the grasp area and sensor data **134**. In particular, the grasp geometry generator **210** receives the selected target object and the sensor data **134** to generate the grasp area. Based on the grasp area, the grasp geometry generator **210** determines the grasp geometry **212** (e.g., orientation and translation) of the end-effector **150** to grasp the target object. The grasp geometry generator **210** sends the grasp geometry **212** to the selector **220**. The selector **220** is configured to implement the grasp geometry **212** received from the grasp geometry generator **210**. In particular, the selector **220** sends the initial grasp geometry **212**I to the control system **170**. The control system **170** instructs the robot **100** to begin execution of the initial grasp geometry **212**I to grasp the selected target object.

[0042] In some implementations, the user **12** may input an end-effector constraint at the remote controller **20** where the end-effector constraint constrains one or more degrees of freedom of the end-effector **150**. The degrees of freedom may include translation (e.g., x-coordinate, y-coordinate, and z-coordinate) and/or orientation (e.g., pitch, roll, and yaw) of the end-effector **150**. In other words, the end-effector **150** may have six degrees of freedom where three of the degrees relate to translation and three relate to orientation. The user **12** may instruct the end-effector **150** to grasp the target object with a grasp geometry **212** that includes the end-effector constraint in order to constrain a degree of freedom for the end-effector **150**. For example, the user **12** may instruct the robot **100** to grasp the target object with a pitch of ninety degrees. In this example, the grasping system **200** can generate any grasp geometry that includes a pitch of ninety degrees. In another example, the user **12** instructs the robot **100** to grasp the target object with a grasp geometry **212** that includes a specific height (e.g., z-coordinate). Thus, the grasp geometry generator **210** can generate a grasp geometry **212** that includes the user-selected z-coordinate. The user **12** may include any number of end-effector constraints to constrain the end-effector **150** when grasping the target object. For instance, combining both examples, the user **12** may input end-effector **150** constraints for both pitch and the z-coordinate (e.g., when assigning the target object for the end-effector **150** to grasp). The end-effector constraint allows the user **12** to customize any number of degrees of freedom for the end-effector **150** to grasp the target object.

[0043] In some implementations, after the robot **100** begins to execute the initial grasp geometry **212**I, the grasping system **200** may determine a new grasp geometry **212**N to grasp the target object. The grasping system **200** may determine, after the robot **100** begins execution of the initial grasp geometry **212**I, a new grasp geometry **212**N that improves and/or refines the grasp geometry **212** being executed. Here, an improvement or refinement in the grasp geometry **212** may correspond to a grasp geometry **212** that is more efficient (e.g., a more cost effective grasp in terms of energy or motion), has a higher likelihood of success, has a more optimal execution time (e.g., faster or slower), etc., to grasp the target object when compared to the initial grasp geometry **212**I. The grasping system **200** may generate the new grasp geometry **212**N based on updated sensor data **134**U that represents the changing field of view Fv for one or more sensors **132** as the robot **100** maneuvers within the environment **30** to grasp the target object. That is, as the robot **100** maneuvers within the environment **30** to execute the initial grasp geometry **212**I to grasp the target object, the one or more sensors **132** capture the changing the field of view Fv within the environment **10**. Based on the changing field of view Fv (e.g., updated sensor data **134**U) the grasping system determines the new grasp geometry **212**N. For example, a sensor **132** of the robot **100** (e.g., a sensor **132** mounted on or near the end-effector **150**) may generate sensor data **134** at some sensing frequency. Thus, while the robot **100** moves to execute the initial grasp geometry **212**I, the sensor **132** may move and may generate new sensor data **134** (referred to as "updated sensor data **134**U") at the sensing frequency that inherently may include new information that is capable of improving or refining the initial grasp geometry **212**I. The grasping system **200** may therefore leverage this updated sensor data **134**U as the grasp by the end-effector **150** is being performed according to the initial grasp geometry **212**I to update or to modify the initial grasp geometry **212**I; thus leading to a continuous or periodic feedback loop that ensures that the target object is optimally grasped.

[0044] As an example, while the end-effector **150** of the robotic manipulator moves to execute the initial grasp geometry **212**I, the sensor system **130** receives updated sensor data **134**U that indicates a foreign object near the target object. In particular, as the end-effector **150** maneuvers within the environment **10**, the sensor **132***c* has a field of view Fv within the environment **10** that is different than the field of view Fv before the robot **100** began execution of the initial grasp geometry **212**I (i.e., an initial field of view Fv when the initial grasp geometry **212**I was generated). In this example, the foreign object was outside the field of view Fv of the sensor system **130** before the robot **100** began execution of the initial grasp geometry **212**I. Because the foreign object was outside the field of view Fv, the sensor system **130** did not represent the foreign object in the sensor data **134** sent to the grasp geometry generator **210**. Thus, the grasp geometry generator **210** may generate an initial grasp geometry **212**I that failed to account for the foreign object (e.g., an obstruction by the foreign object) because the sensor data **134** sent to the grasp geometry generator **210** did not indicate any foreign objects near the target object. Without any knowledge of the foreign object, if the robot **100** executed the initial grasp geometry **212**I, the foreign object may prevent the end-effector **150** from successfully grasping the target object. In this example, the robot **100** may modify the initial grasp geometry **212**I based on the updated sensor data **134**U (e.g., the sensor data **134**U that includes the foreign object) to successfully grasp the target object.

[0045] In some implementations, during the time period between when the end-effector **150** of the robotic manipulator starts executing the grasp geometry **212** and before completing the execution of the grasp geometry **212** on the target object, the sensor system **130** receives updated sensor data **134**U. That is, while the end-effector **150** of the robotic manipulator moves to execute the initial grasp geometry **212**I on the target object, the sensor system **130** receives updated sensor data **134**U. The updated sensor data **134**U represents the updated field of view Fv as the robot **100** moves within the environment **30** to grasp the target object. In particular, the updated sensor data **134**U may provide additional information (e.g., a foreign object at or near the target object) to the grasping system **200** that was not available before the grasping system **200** determined the initial grasp geometry **212**I. For example, the sensor system **130** of the robot **100** receives sensor data **134** that represents the current field of view Fv of the robot **100**, after the robot **100** begins to execute the grasp geometry **212** the sensor system **130** of the robot **100** receives updated sensor data **134**U as the robot **100** moves to execute the grasp. In some examples, the grasping system **200** may modify the grasp geometry **212** based on the updated sensor data **134**U (e.g., the updated sensor data **134**U indicates a foreign object that prevents the robot **100** from grasping the target object). In other examples, the grasping system **200** may continue to execute the initial grasp geometry **212**I after receiving the updated sensor data **134**U (e.g., the updated sensor data **134**U indicates the same or substantially similar data as the initial sensor data **134**). In this sense, the grasping system **200** may review the validity of the initial grasp geometry **212**I using sensor data **134** provided to the grasping system

200 after the grasping system **200** generates the initial grasp geometry **212**I. Upon review of the initial grasp geometry **212**I based on the received updated sensor data **134**U, the robot **100** may continue to execute the initial grasp geometry **212**I (e.g., the initial grasp geometry **212**I is still optimal when compared to other candidate grasp geometries **212** generated using the updated sensor data **134**U), modify the initial grasp geometry **212**I, or completely switch to an alternative grasp geometry **212**.

[0046] Optionally, the grasping system **200** may include an adjuster **230**. The adjuster **230** is indicated by dashed lines because the adjuster **230** is an optional component of the grasping system **200**. The adjuster **230** is configured to determine whether to adjust the initial grasp geometry **212**I after the end-effector **150** of the robotic manipulator begins to execute the initial grasp geometry **212**I. As the robot **100** executes the initial grasp geometry **212**I, the grasp geometry generator **210** receives updated sensor data **134**U from the one or more sensors **132**. Based on the updated sensor data **134**U the grasp geometry generator **210** generates a new candidate grasp geometry **212**N. The grasp geometry generator **210** sends the new candidate grasp geometry **212**N to the adjuster **230**. The adjuster **230** may also receive the initial grasp geometry **212**I from the selector **220**. The adjuster **230** determines whether to modify the initial grasp geometry **212**I based on the new grasp geometry **212**N and updated sensor data **134**U. That is, after beginning execution of the initial grasp geometry **212**I, the adjuster **230** receives the new candidate grasp geometry **212**N and the updated sensor data **134**U. In other words, the grasping system **200** generated the initial grasp geometry **212**I using sensor data **134** at a first instance of time (e.g., when the user **12** selects the target object for the end-effector **150** to grasp) and then, the grasping system **200** generates one or more new candidate grasp geometries **212**N using the updated sensor data **134**U at a second instance of time subsequent to the first instance of time (e.g., when the robotic manipulator and/or end-effector **150** is executing a grasp of the target object). Based on the updated sensor data **134**U, the adjuster **230** determines whether to continue execution of the initial grasp geometry **212**I or modify the initial grasp geometry **212**I.

[0047] In some examples, the adjuster **230** determines to continue execution of the initial grasp geometry **212**I. In other examples, the adjuster **230** determines to modify the initial grasp geometry **212**I to generate a modified grasp geometry **212**M. That is, after receiving the updated sensor data **134**U, the adjuster **230** compares the initial grasp geometry **212**I and the new candidate grasp geometry **212**N and determines that it should modify the initial grasp geometry **212**I. For example, when the updated sensor data **134**U indicates a foreign object at or near the target object, the adjuster **230** determines the new candidate grasp geometry **212**N includes a higher likelihood of success to grasp the target object than the initial grasp geometry **212**I. In another example, based on the updated sensor data **134**U, the adjuster **230** determines the new candidate grasp geometry **212**N includes a shorter grasp execution time than the initial grasp geometry **212**I. The adjuster **230** may modify the initial grasp geometry **212**I by adjusting one or more degrees of freedom to match or more closely match characteristics of the new candidate grasp geometry **212**N. In some implementations, the adjuster **230** modifies the initial grasp geometry **212**I by discarding the initial grasp geometry **212**I and executing the new candidate grasp geometry **212**N. After modifying the initial grasp geometry **212**I, the adjuster **230** sends the modified grasp geometry **212**M to the control system **170** to instruct the robot **100** to execute the modified grasp geometry **212**M. When the adjuster **230** determines that the initial grasp geometry **212**I should continue being executed, the adjuster **230** does not send the modified grasp geometry **212**M to the control system **170**.

[0048] Referring now to FIG. 2B, in some implementations, the grasp geometry generator **210** generates a plurality of candidate grasp geometries **212**, **212*a-n*** based on the selected target object within the grasp area. In particular, the grasp geometry generator **210** generates multiple candidate grasp geometries **212** and the grasping system **200** determines which of the multiple candidate grasp geometries **212** the robot **100** should use to grasp the target object. In these implementations, the grasping system **200** includes a scorer **240** that assigns a grasping score **242** to each of the plurality of candidate grasp geometries **212**. The grasping score **242** indicates a likelihood of success that the candidate grasp geometry **212** will successfully grasp the target object. That is, based on the selected target object, sensor data **134**, and the grasp area, the grasp geometry generator **210** generates a plurality of grasp geometries **212** to grasp the target object. Here, the grasp geometry generator **210** sends each of the plurality of candidate grasp geometries **212** to the scorer **240**. For each candidate grasp geometry **212** of the plurality of candidate grasp geometries **212**, the scorer **240** determines a grasping score **242** that represents the candidate grasp geometry's capability to grasp the target object. The scorer **240** sends each grasping score **242** that corresponds to the respective candidate grasp geometry **212** of the plurality of candidate grasp geometries **212** to the selector **220**. The generator **210** may generate a plurality of grasp geometries **212** because there are a number of pose permutations possible that enable the end-effector **150** to grasp some portion of the target object. For instance, the end-effector **150** may approach and/or grasp the target object from a particular direction or movement vector in 3D space or at a particular orientation (e.g., pitch, roll, or yaw). In other words, since the end-effector **150** may have multiple degrees of freedom at its disposal to affect the manner in which the end-effector **150** grasps the target object, the generator **210** may generate some number of these permutations as candidate grasp geometries **212**.

[0049] In some configurations, there may be such a large number of potential candidate grasp geometries **212** that the generator **210** may work in conjunction with the selector **220** to generate an N-best number of grasp geometries **212** at a particular instance of time. In some implementations, the generator **210** is preconfigured to generate a maximum number of candidate grasp geometries **212** at any particular instant in time. In some examples, the number of grasp geometries **212** may be reduced, discounted, or decayed based on the relative timing of when the generator **210** generates the grasp geometries **212**. For example, the generator **210** may generate a large number of grasp geometries **212** to form the initial grasp geometry **212**I at a first instance of time, but then, at a second instance of time, the generator **210** may be configured to generate a smaller number of grasp geometries **212** while the robotic manipulator is executing the initial grasp geometry **212**I.

[0050] The selector **220** is configured to select the respective candidate grasp geometry **212** with a greatest grasping score **242** as a grasp geometry **212** for the robot **100** to use to grasp the target object. The grasping score **242** may be generated by a scoring algorithm that accounts for different factors that identify an overall performance for a given grasping geometry **212**. These factors may be preconfigured or designed by the user **12** of the robot **100**. Some examples of factors that may contribute to the grasping score **242** include a speed to grasp the target object (e.g., a time to grasp the object), a degree of complication for the particular grasp, the degree of change from the current pose of the end-effector **150** to the grasping pose of the end-effector **150**, the engagement of the grasp geometry **212** with the target object (e.g., engagement location relative to the centroid of the target object), the amount of torque the target object may be estimated to contribute, the amount of force or direction of force that the end-effector **150** imparts on the target object, etc. When determining the grasping score **242**, the factors that influence the score **242** may also be weighted to stress an importance of one factor over another factor. For instance, if the target object has been classified as a fragile object, the scoring algorithm may discount the speed of the grasp to ensure the fragile object is less likely to be damaged. Based on some number of these factors, the grasping score **242** may generally indicate an efficiency, execution time, likelihood of success, etc. of a grasp geometry. In some examples, the selector **220** selects the candidate grasp geometry **212** from the plurality of candidate grasp geometries **212** when the grasping score **242** satisfies a grasping score threshold (e.g., when the grasping score **242** exceeds a value set as the grasping score threshold). As an example, the selector **220** receives three candidate grasp geometries **212** that include grasping scores **242** of 0.6, 0.4, and 0.8. In this example, the selector **220** determines the candidate grasp geometry **212** with the grasping score 0.8 has the highest likelihood to successfully grasp the target object. The selector **220** sends the selected candidate grasp geometry **212** (e.g., initial grasp geometry **212**I) from the plurality of candidate grasp geometries **212** to the control system **170**. The control system **170** instructs the robot **100** to execute the candidate grasp geometry **212** with the grasping score **242** of 0.8 as initial grasp geometry **212**I.

[0051] The grasping system **200** sends the initial grasp geometry **212**I to the control system **170** to initiate a sequence of movements to grasp the target object according to the initial grasp geometry **212**I. In other words, to execute the initial grasp geometry **212**I, the control system **170** instructs the arm **126** to move from an initial pose of the arm **126** to a grasping pose designated by the initial grasping geometry **212**I. Here, the initial pose of the arm **126** refers to the pose or state of the arm **126** when the controller **20** received the input from the user **12** selecting the target object to be grasped by the end-effector **150** of the arm **126**. In this respect, the initial grasp geometry **212**I may be based on the initial pose for the end-effector **150** of the robotic manipulator. For instance, when the sensor **132** providing the image to the user **12** at the controller **20** is from a sensor **132** at the end-effector **150**, the field of view Fv of the sensor **132** associated with the end-effector **150** would be used to define the initial grasp geometry **212**I and that field of view Fv is based on the initial pose of the arm **126**.

[0052] In some implementations, the grasping system **200** determines a plurality of new candidate grasp geometries **212**N after the robot **100** begins execution on the initial grasp geometry **212**I. That is, while the end-effector **150** of the robotic manipulator moves to grasp the target object based on the initial grasp geometry **212**I the sensor system **130** receives updated sensor data **134**U for a second pose of the end-effector **150** of the robotic manipulator. The sensor system **130** sends the updated sensor data **134**U to the grasping system **200**. The grasp geometry generator **210** determines a new set of candidate grasp geometries **212**N based on the updated sensor data **134**. The new set of candidate grasp geometries **212**N may include any number of new candidate grasp geometries **212**N. The grasp geometry generator **210** sends each new candidate grasp geometry **212**N to the scorer **240**.

[0053] The scorer **240** that scores the new candidate grasp geometry **212**N may be the same scorer **240** used to score the candidate grasp geometries **212** that resulted in the initial grasp geometry **212**I or a different scorer **240** dedicated to scoring new candidate grasp geometries **212**N. In either case, the scorer **240** assigns a grasping score **242** to each new candidate grasp geometry **212**N of the new set of candidate grasp geometries **212**N. That is, the grasp geometry generator **210** sends the plurality of new candidate grasp geometries **212**N to the scorer **240** that determines the grasping score **242** for each of the plurality of new candidate grasp geometries **212**N. The scorer **240** sends the grasping score **242** for each respective new candidate grasp geometry **212**N to the adjuster **230**. In some examples, the scorer **240** sends only the highest grasping score **242** from the plurality of new candidate grasp geometries **212**N. The adjuster **230** determines whether a respective grasp geometry **212** from the new set of candidate grasp geometries **212**N includes a corresponding grasping score **242** that exceeds the grasping score **242** of the initial grasp geometry **212**I (i.e., a score **242** that indicates a candidate grasp geometry **212**N is better than the initial grasp geometry **212**I). That is, the adjuster **230** receives the updated sensor data **134**U and the respective grasping score **242** for the initial grasp geometry **212**I and for each new candidate grasp geometry **212**N.

[0054] In some implementations, when the corresponding grasping score **242** of the new candidate grasp geometries **212**N exceeds the grasping score **242** of the initial grasp geometry **212**I, the adjuster **230** modifies the initial grasp geometry **212**I based on the respective candidate grasp geometry **212**N from the new set of candidate grasp geometries **212**N. For example, the robot **100** begins execution of the initial grasp geometry **212**I with a grasping score of 0.8. After the robot **100** begins execution of the initial grasp geometry **212**I, the grasp geometry generator **210** receives updated sensor data **134**U that corresponds to the current field of view Fv of the one or more sensors **132**. The grasp geometry generator **210** generates a plurality of new candidate grasp geometries **212**N based on the updated sensor data **134**. In this example, the adjuster **230** receives the initial grasp geometry **212**I with the grasping score **242** of 0.8 and receives a new candidate grasp geometry **212**N with a grasping score **242** of 0.85. Here, the adjuster **230** determines the grasping score **242** (e.g., grasping score **242** of 0.85) for the new candidate grasp geometry **212**N exceeds the grasping score **242** (e.g., grasping score **242** of 0.8) of the initial grasp geometry **212**I and modifies the initial grasp geometry **212**I. As state previously, this modification may some form of adjustment to the initial grasp geometry **212**I or complete replacement of the initial grasp geometry **212**I with the new candidate grasp geometry **212**N.

[0055] In some implementations, the adjuster **230** only modifies the initial grasp geometry **212**I when the grasping score **242** of the new candidate grasp geometry **212**N exceeds the score **242** of the initial grasp geometry **212**I by a threshold. For example, the adjuster **230** only modifies the initial grasp geometry **212**I when the grasping score **242** of the new candidate grasp geometry **212**N exceeds the grasping score **242** of the initial grasp geometry **212**I by a margin of 0.1. In this example, when the grasping score **242** of the initial grasp geometry **212**I is 0.6 and the grasping score **242** of the new candidate grasp geometry **212**N is 0.65, the adjuster **230** determines the grasping score **242** of the new candidate grasp geometry **212**N does not exceed the grasping score **242** of the initial grasp geometry **212**I by the threshold (e.g., **0.1**). Here, even though the grasping score **242** of the new candidate grasp geometry **212**N exceeds the grasping score **242** of the initial grasp geometry **212**I, the robot **100** continues execution of the initial grasp geometry **212**I. Stated differently, the margin of difference between grasping scores **242** may not justify the change in grasp geometries **212** even though a newer grasp geometry **212** has a higher score **242**.

[0056] Referring now to FIG. **2**C, in some examples, the grasp geometry generator **210** generates the grasp area **216**. By generating the grasp area **216**, the grasp geometry generator **210** translates the user selected two-dimensional area of interest (e.g., selected target object) into the grasp area **216** in the three-dimensional point cloud of sensor data **134**. Specifically, the generation of the grasp area **216** allows the user **12** to interact with the two-dimensional image to instruct the robot **100** to perform an action in the three-dimensional environment **30**. The grasp geometry generator **210** receives the user-selected target object from the UI **300** and sensor data **134** (e.g., three-dimensional point cloud). The user **12** selects the target object on the two-dimensional image on the UI **300** that corresponds to the three-dimensional point cloud of data **134** for the field of view Fv of the robot **100**. The grasp geometry generator **210** projects a plurality of rays from the selected target object from the two-dimensional image onto the three-dimensional point cloud of sensor data **134**. The grasp area **216** therefore corresponds to the area formed by the intersection of the projected rays and the three-dimensional point cloud of sensor data **134**

[0057] In particular, the grasp geometry generator **210** projects the plurality of rays from one or more pixels of the selected target object. Each ray of the plurality of rays projected from the two-dimensional image to the three-dimensional point cloud represents a pixel of the selected target object. The collection of the plurality of rays in the three-dimensional point cloud represents the grasp area **216**. By projecting a ray for each pixel from the selected target object, the grasp geometry generator **210** translates the two-dimensional area of interest for the user **12** (e.g., selected target object) to the three-dimensional grasp area **216**. Stated differently, the grasp area **216** designates a three-dimensional area that includes the target object such that the grasping system **200** may generate a grasp geometry **212** to grasp the three-dimensional target object within the grasp area **216**. This means that the grasp area **216** designates an area of interest for the robotic manipulator to grasp. From this identified grasp area **216**, the grasp geometry generator **210** may use the sensor data **134** within the boundaries of the identified grasp area **216** to understand the target object (e.g., the contour of the target object represented by the 3D point cloud sensor data **134**) and to determine the grasp geometry **212**.

[0058] In some examples, instructing the end-effector **150** of the robotic manipulator to grasp the target object within the grasp area **216** based on the grasp geometry **212** includes the one or more controllers **172** instructing the body **110** of the robot **100** to pitch toward the target object. That is, the one or more controllers **172** may instruct both the end-effector **150** of the robot **100** to maneuver towards the target object and the body **110** of the robot **100** to pitch towards the target object. By instructing both the end-effector **150** and the body **110**, the robot **100** may generate more degrees of freedom that the end-effector **150** of the robotic manipulator can access.

[0059] In other examples, the one or more controllers **172** instruct a first leg **120** of the robot **100** to rotate an upper member **122**U of the first leg **120** about a knee joint J_k towards a lower member **122**L of the first leg **120**. For example, the one or more controllers **172** instructs each leg **120** of the robot **100** to rotate the upper member **122**U of the leg about the knee joint J_k towards the lower member $\mathbf{122}_L$ to lower the body **110** of the robot **100**. In this example, when the one or more controllers **172** instruct each leg **120** of the robot **100**, the body **110** of the robot **100** lowers while the pitch of the body **110** remains constant. In another example, the one or more controllers **172** instruct a subset of the legs **120** of the robot **100** to rotate the upper member **122**U of the leg **120** about the knee joint J_k towards the lower member **122**L. Here, the body **110** of the robot **100** may pitch towards the target object while the body **110** of the robot lowers towards the ground surface **14**.

[0060] Although the grasping system **200** of the robot **100** may be an efficient way to automatically grasp an object selected by a user **12**. This ease of use feature may have limitations if the user **12** desires a very particular grasp geometry **212** to grasp the target object. For instance, the user **12** may instruct the robot **100** to perform subsequent actions on the selected object after performing an initial action. For example, the user **12** first instructs the robot **100** to grasp a valve and then subsequently instructs the robot **100** to turn the valve. In another example, the user **12** first instructs the robot **100** to grasp a switch and then subsequently instructs the robot **100** to flip the switch.

[0061] In these subsequent action examples, the user **12** may prefer to not be at the whim of an automatic grasping system. That is, with an automatic system the position and orientation that the automatic system of the robot **100** determines to grasp the object may be unable to perform subsequent actions that the user **12** desires the robot **100** to perform. For example, the automatic system of the robot **100** determines a position and orientation to grasp a valve that is unable to perform the subsequent action of turning the valve. Here, the limited range of motion of the robot **100** prevents the robot **100** from performing the subsequent action of turning the valve with the grasping position and orientation that the automatic system generated. The automatic system of the robot **100** may not grasp the valve in a position and orientation that allows the robot **100** to subsequently turn the valve because the robot **100** is unaware of the subsequent action the user **12** intends to perform when the automatic system generates the valve-grasping maneuver. The scenarios highlight the fact that the automated system may have its setbacks when the user **12** wants the robotic manipulator to behave in a particular way when grasping the target object.

[0062] To address these setbacks, implementations herein are directed towards a user interface (UI) for autonomous grasping that allows users **12** to instruct a robot **100** to grasp objects with a specific position and orientation. The user interface presents the position and orientation for an end-effector **150** of a robotic manipulator to grasp objects in an intuitive manner. Here, a sensor system **130** of the robot **100** receives sensor data **134** that corresponds to the environment **10** about the robot **100**. The sensor data **134** is displayed for a user **12** of the robot **100** on a user interface in a two-dimensional representation that allows the user **12** to select a target object within the environment **10** of the robot **100**. Additionally, the user **12** may provide grasping inputs to the user interface that constrain the pose for an end-effector **150** of a robotic manipulator. The pose for the end-effector **150** of the robotic manipulator represents both the position (e.g., x-direction, y-direction, and z-direction) and orientation (e.g., pitch, roll, and yaw) of the end effector **150**. The robot **100** generates a three-dimensional location of the target object based on the received sensor data **134** and location that corresponds to the selected target object and grasping inputs. A control system **170** of the robot **100** instructs the end-effector **150** of the robotic manipulator to grasp the target object with the user **12** provided position and orientation based on the three-dimensional location of the target object.

[0063] Referring now to FIG. **3**A, in some implementations, the sensor system **130** of the robot **100** receives sensor data **134** for an area within an environment **10** about the robot **100**. The robot **100** sends the sensor data **134** from the sensor system **130** to a remote controller **20** that displays an image that corresponds to the sensor data **134** on the UI **300**. The imaged displayed on the UI **300** is a two-dimensional (2D) image that corresponds to the area within the environment **10** about the robot **100**. In particular, the image is a 2D representation of the three-dimensional (3D) environment **10** about the robot **100**.

[0064] The user **12** interacts with the UI **300** by providing a user input to the UI **300** that selects a location within the 2D representation of the area. The location selected by the user **12** corresponds to a position of a target object **302** within the area. Additionally, the user **12** interacts with the UI **300** by providing a plurality of grasping inputs **304** for an end-effector **150** of the robot **100**. The grasping inputs **304** define the translation and orientation (e.g., pose) for the end-effector **150** of the robotic manipulator to grasp the target object **302**. In some implementations, the plurality of grasping inputs **304** correspond to a plurality of constraints on one or more degrees of freedom for the end-effector **150** of the robotic manipulator. The one or more degrees of freedom may include a pitch of the end-effector **150**, a roll of the end-effector **150**, a yaw of the end-effector **150**, a first translation in an x-direction, and a second translation in a y-direction. The one or more degrees of freedom may further include a third translation in a z-direction. Here, the translation (e.g., in the x-direction, y-direction, and/or z-direction) and the orientation (the pitch, yaw, and/or roll) of the end-effector **150** may correspond to a coordinate system local to the end-effector **150** (e.g., shown in FIG. **1**A). The remote controller **20** communicates the selected target object **302** and plurality of grasping inputs **304** to the robot **100**.

[0065] The sensor system **130** of the robot **100** generates a 3D location of the target object **302** based on the received sensor data **134**, location that corresponds to the user-selected target object **302**, and the grasping inputs **304**. That is, the robot **100** generates the 3D location of the target object **302** based on the user **12** selecting the target object **302** on the 2D image representation of the sensor data **134** displayed on the UI **300**. For example, the robot **100** receives the user-selected target object **302** from the 2D image and generates the 3D location that corresponds to the location of the selected target object **302** within the environment **10**. The one or more controllers **172** of the robot **100** instruct the end-effector **150** of the robotic manipulator to grasp the target object **302** at the generated 3D location based on the plurality of grasping inputs **304** that designate the orientation and the translation (e.g., pose) for the end-effector **150** of the robotic manipulator.

[0066] Referring now to FIGS. **3**A-**3**F, in some examples, the UI **300** includes a first window **310** and a second window **320**. The first window **310** of the UI **300** includes a viewport that displays a 2D image **312** corresponding to the sensor data **134** for the area within the environment **10** about the robot **100** that includes the target object **302**. The second window **320** includes a graphical icon **322** that represents the end-effector **150** of the robotic manipulator. Although FIG. **3**C illustrates the second window **320** as being separate from the first window **310**, in some examples, the content of the second window **320** may be included within the first window **310** (e.g., configured to be overlain on the 2D image **312** displayed in the first window **310**). In some implementations, the graphical icon **322** represents a means to designate a first orientation for the end-effector **150**. In the specific example of FIG. **3**B, the graphical icon **322** includes a wire-frame representation of the end-effector **150** as the means to designate the first orientation for the end-effector **150**. Here, the graphical icon **322** also includes a radial dial associated with the wire-frame representation of the end-effector **150** such that the user **12** may generate the first orientation by moving the wire-frame representation to a particular location on the radial dial. For example, where the first orientation represents the pitch of the end-effector **150**, the radial dial designates the pitch for the end-effector **150** of the robotic manipulator. The graphical icon **322** is capable of being manipulated by the user **12** (e.g., rotated along the radial dial to a particular degree) to indicate the first grasping input **304** that designates the first orientation for the end-effector **150** of the robotic manipulator. That is, the user **12** may manipulate the radial dial to the desired pitch for the end-effector **150** to input the first grasping input **304** into the UI **300**. In this respect, the first grasping input **304** identifies a first orientation at which the end-effector **150** should grasp the target object **302**.

[0067] In some examples, the UI **300** also includes a third window **330** with a menu of options that may influence some portion of the functionality of the end-effector **150** of the robotic manipulator (e.g., influences how the end-effector **150** grasps the target object **302**). For example, these menu options may be used by the user **12** to toggle through different types of grasping modes or features of the various grasping modes at the controller **20**. In some configurations, such as FIG. **3**C, the third window **330** is a completely separate window from both the first window **310** and the second window **320**. In some implementations, the menu includes a plurality of user-selectable options. The user-selectable options may include a first option (e.g., a first selectable button) to initiate a grasping mode, a second option (e.g., a second selectable button) to initiate a custom grasp mode for the end-effector **150**, and/or a third option (e.g., a third selectable button) to initiate an automatic grasp for the target object **302**. Here, the selectable-option for the automatic grasp mode allows the user **12** to select a target object **302** and the robot **100** automatically grasps the selected target object **302** (e.g., using the automatic grasping process of the grasping system **200**). In contrast, the option for the manual grasp mode of the target object **302** allows the user **12** to initiate a custom grasping process that enables the user **12** to select (or designate) the grasping inputs **304** that control how the end-effector **150** of the robotic manipulator grasps the target object **302**.

[0068] In some examples, the UI **300** updates the 2D image **312** displayed to the user **12** at the controller **20** after receiving each grasping input **304**. For instance, after the user **12** inputs a grasping input **304**, the end-effector **150** may move according to the grasping input **304**. This move by the end-effector **150** may, in turn, generate new or updated sensor data **134** (e.g., especially when the sensor **132** generating the sensor data **134** is located on the end-effector **150**) which is displayed at the UI **300** as a new or updated 2D image **312**. Here, when the 2D image representing the sensor data **134** is displayed in the viewport of the first window **310**, user **12** will be able to visualize the new or updated 2D image **312** at the viewport. By updating the viewport image **312** after receiving each grasping input **304**, the UI **300** provides the user **12** with visual feedback after the end-effector **150** of the robotic manipulator maneuvers to each grasping input **304** (e.g., pitches, rolls, yaws, or translates in a particular direction). Moreover, allowing the user **12** to select or to input each grasping input **304** in 2D images **312** at the UI **300** (e.g., at the two-dimensional viewport image **312**) may allow the user **12** to avoid interacting with a more complicated 3D space to designate the grasping inputs **304**. In particular, selecting the grasping inputs **304** from three-dimensional representations is often difficult for users **12** because changing one of the grasping inputs **304** may invalidate the previously provided grasping inputs **304**. In 3D space, this becomes less intuitive for an user **12**, especially a user **12** who may not be accustom to thinking or inputting constraints in a three-dimensional manner. For example, the position of a grasp (e.g., x-direction, y-direction, and z-direction) that instructs a robot **100** to grasp a target object **302** from a top orientation is different than a position of a grasp that instructs the robot **100** to grasp the target object **302** from a side orientation. Thus, if the user **12** first provides the position to the end-effector **150**, a subsequent change of the orientation of the end-effector **150** may invalidate the previously provided position for the end-effector **150**. In contrast, by sequentially prompting the user **12** to provide each grasping input **304** while having visual feedback in the two-dimensional viewport image **312**, the UI **300** is able to prevent the user **12** from inadvertently invalidating any previously provided grasping inputs **304**. Moreover, the user **12** may be able to quickly and/or to efficiently recognize if grasping inputs **304** are constraining the manual grasp of the target object **302** in the manner that he or she expected.

[0069] In some implementations, the user **12** provides the plurality of grasping inputs **304** by providing a first grasping input **304** that designates a first orientation for the end-effector **150** of the robotic manipulator to grasp the target object **302**. Here, the first orientation may include one of a pitch or a roll for the end-effector **150** of the robotic manipulator to grasp the target object **302**. In response, the end-effector **150** maneuvers to the first orientation and the one or more sensors **132** of the robot **100** generate sensor data **134** that corresponds to the field of view Fv at the first orientation. The robot **100** sends the sensor data **134** that corresponds to the field of view Fv at the first orientation to the UI **300** that displays the two-dimensional viewport image **312** corresponding to the first of view Fv at the first orientation. The user **12** may then provide a second grasping input **304** that designates a second orientation for the end-effector **150** of the robotic manipulator based on the modified viewport image **312** at the first orientation.

[0070] For example, a user **12** provides a first grasping input **304** to the UI **300** that designates a first orientation for a twenty degree pitch of the end-effector **150**. The control system **170** of the robot **100** instructs the end-effector **150** to maneuver to the twenty-degree pitch as the first orientation. As the end-effector **150** of the robotic manipulator maneuvers to the first orientation (e.g., twenty degree pitch), the one or more sensors **132** generate sensor data **134** that corresponds to the field of view Fv of the end-effector **150** at the first orientation. The robot **100** sends the sensor data to the UI **300** that displays the viewport image **312** that corresponds with the field of view Fv of the end-effector **150** at the first orientation. The user **12** may then provide the second grasping input **304** that designates the second orientation to the UI **300** based on the viewport image **312** that displays the field of view Fv at the first orientation. For example, the user **12** provides a second grasping input **304** that designates a second orientation for a sixty-five degree roll of the end-effector **150** from the viewport image **312** that is displaying the twenty degree pitch. The control system **170** of the robot **100** instructs the end-effector **150** to maneuver to the second orientation (e.g., sixty-five degree roll) while maintaining the first orientation (e.g., twenty degree pitch). That is, the control system **170** executes the second grasping input **304** without invalidating the previously provided first grasping input **304**.

[0071] In some implementations, the UI **300** overlays, on the viewport image **312**, a representation of the end-effector **150** (e.g., wire frame representation of the end-effector **150**) at the first orientation designated by the first grasping input **304**. For example, after the end-effector **150** maneuvers to the first orientation and the UI **300** displays the sensor data **134** that corresponds to the field of view Fv at the first orientation, the UI **300** overlays the wire frame representation of the end-effector **150** on the viewport image **312**. The overlain representation of the end-effector **150** corresponds to the current pose (e.g., at the first orientation) of the end-effector **150** in relation to the target object **302**. The user **12** may manipulate the overlain representation of the end-effector **150** at the first window **310** to provide the second grasping input **304**. In particular, the user **12** can manipulate the overlain representation to provide a second grasping input **304** for the end-effector **150**. By manipulating the representation of the end-effector **150** at the first window **310**, the user **12** gets a 2D visual representation of the end-effector **150** in relation to the target object **302** for the second grasping input **304**.

[0072] The UI **300** and/or grasping system **200** may derive one or more grasping inputs **304** without explicit input as to that particular grasping input **304** from the user **12**. In some implementations, the robot **100** derives one or more grasping inputs **304** based on the position of the robot **100**. In particular, the robot **100** derives the grasping inputs **304** based on the position of the robot **100** relative to the target object **302**. In some examples, the robot **100** derives the grasping inputs **304** based on a prior position of the robot **100** relative to the target object **302** before the user **12** selects the target object **302**. In other examples, the robot **100** derives the one or more grasping inputs **304** based on a position of the robot **100** relative to the target object **302** after the user **12** selects the target object **302**. That is, the robot **100** moves to a new position relative to the target object **302** after the user **12** selects the target object **302**, and the robot **100** uses the new position to derive the grasping inputs **304**. For example, the user **12** selects the target object **302** on the UI **300** and the robot **100** moves to a new position relative to the target object **302**. In this example, once the robot **100** moves to the new position relative to the target object **302**, the UI **300** and/or grasping system **200** may use the new position to derive a grasping input **304** that designates a yaw orientation of the end-effector **150**. In either case, based on the position of the robot **100** relative to the target object **302**, the robot **100** derives the yaw orientation of the end-effector **150** of the robotic manipulator to grasp the target object **302**. The derived yaw orientation may therefore form a constraint for the degree of the freedom corresponding to yaw when the end-effector **150** grasps the target object **302**. The user **12** may provide the remaining grasping inputs **304** either before or after the robot **100** (e.g., the UI **300** and/or grasping system **200**) derives the yaw orientation. The derived orientation of the end-effector **150** is a non-limiting example, the robot **100** may derive any of the plurality of grasping inputs **304** (e.g., any position or orientation of the end-effector **150**) based on the position of the robot **100** relative to the target object **302**.

[0073] Referring to FIG. **3**B, the sensor system **130** of the robot **100** receives sensor data **134** for the area within the environment **10** of the robot **100**. The robot **100** sends the sensor data **134** to the remote controller **20** that displays the sensor data **134** as a two-dimensional representation. The user **12** selects the target object **302** from the two-dimensional representation displayed on the UI **300** at the remote controller **20**. Specifically, the user **12** provides a user input to the 2D representation that selects the location corresponding to the position of the target object **302**. The remote controller **20** sends the selected target object **302** to the robot **100** (e.g., to the grasping system **200** of the robot **100**). The robot **100** derives the yaw orientation of the end-effector **150** based on the position of the robot **100** in relation to the selected target object **302**. The user **12** then provides the plurality of grasping inputs **304** that corresponds to one or more degrees of freedom for the end-effector **150** of the robotic manipulator.

[0074] Referring to FIG. **3**C, the user **12** provides the first grasping input **304** that designates the first orientation for the pitch of the end-effector **150**. For example, the user **12** manipulates the radial dial of the graphical icon **322** in the second window **320** to designate the first orientation that corresponds to the pitch of the end-effector **150** (e.g., shown as a pitch of 87.7 degrees). The remote controller **20** sends the first grasping input **304** (e.g., first orientation) to the control system **170** that instructs the robot **100** to maneuver the end-effector **150** to a position (or pose) corresponding to the first grasping input **304**. After the end-effector **150** maneuvers to a position (or pose) corresponding to the first grasping input **304**, the robot **100** sends the sensor data **134** from the one or more sensors **132** that corresponds to the field of view Fv of the end-effector **150** at the first orientation to the remote controller **20**. The UI **300** displays the viewport image **312** in the first window **310** that corresponds to the sensor data **134** at the first orientation to the user **12**.

[0075] Referring to FIG. **3**D, in some examples, the user **12** provides the second grasping input **304** that designates a first translation that corresponds to an x-direction and a y-direction of the end-effector **150**. In other examples, the second grasping input **304** designates a first translation that corresponds only to the x-direction or only to the y-direction. The user **12** may provide the second grasping input **304** by manipulating the representation of the end-effector **150** at the first window **310** to the designated first translation (e.g., x-direction and y-direction). The representation of the end-effector **150** moves relative to the viewport image **312** at the first window **310** to assist the user **12** in visualizing the first translation position of the end-effector **150** relative to the target object **302**. The remote controller **20** sends the second grasping input **304** to the control system **170**, which, in turn, instructs the robot **100** to maneuver the end-effector **150** to the first translation of the x-direction and y-direction. The control system **170** instructs the end-effector **150** of the robot **100** to maneuver to the first translation while maintaining the first orientation of the end-effector **150**. That is, after the end-effector **150** of the robotic manipulator maneuvers to the first translation, the end-effector **150** is at a pose that includes the first orientation (e.g., pitch of the end-effector **150**) and the first translation (e.g., x-direction and y-direction of the end-effector **150**). Specifically, the control system **170** instructs the end-effector **150** of the robotic manipulator to maneuver to the first translation (e.g., second grasping input **304**) while the first orientation (e.g., first grasping input **304**) of the end-effector **150** remains valid. The robot **100** sends the sensor data **134** from the one or more sensors **132** that corresponds to the field of view Fv of the end-effector **150** at the first orientation and first translation to the remote controller **20**. The UI **300** displays the viewport image **312** that corresponds to the sensor data **134** at the first orientation and first translation to the user **12**. When comparing FIGS. **3**C and **3**D, the combination of these figures indicates the sequence described where the user **12** first sets the pitch of the end-effector **150** using the radial dial of the graphical icon **322** in FIG. **3**C and then the user **12** dictates the x and y translation of the end-effector **150** at the particular pitch using a selectable graphical representation of the end-effector **150** overlain on the viewport image **312** in FIG. **3**D.

[0076] Referring to FIG. **3**E, in some implementations, the user **12** provides a third grasping input **304** that designates a second orientation that corresponds to the rotation of the end-effector **150**. The user **12** provides the third grasping input **304** that designates the second orientation by manipulating the overlain graphical representation of the end-effector **150** at the first window **310**. The overlain representation of the end-effector **150** moves relative to the viewport image **312** as the user **12** manipulates the representation of the end-effector **150** to assist the user **12** in visualizing the second orientation of the end-effector **150** relative to the target object **302**. The remote controller **20** sends the third grasping input **304** to the control system **170** that instructs the robot **100** to maneuver the end-effector **150** to a position (or pose) that integrates the third grasping input **304** that designates the second orientation for the end-effector **150** (e.g., the roll of the end-effector **150**). The control system **170** instructs the end-effector **150** of the robot **100** to maneuver to a position (or pose) that integrates the third grasping input **304** while maintaining the first orientation and the first translation of the end-effector **150**. That is, after the end-effector **150** of the robotic manipulator maneuvers to a position incorporating the third grasping input **304**, the end-effector **150** is at a pose that includes the first orientation (e.g., pitch of the end-effector **150**), the first translation (e.g., x-direction and y-direction of the end-effector **150**), and second orientation (e.g., roll of the end-effector **150**). The robot **100** sends the sensor data **134** from the one or more sensors **132** that corresponds to the field of view Fv of the end-effector **150** at the pose that includes the first orientation, the first translation, and the second orientation. The UI **300** displays the viewport image **312** that corresponds to the sensor data **134** at the first orientation, first translation, and second orientation to the user **12** at the controller **20**.

[0077] Referring to FIG. **3**F, the user **12** may provide a fourth grasping input **304** that designates a second translation that corresponds to the z-direction of the end-effector **150**. In some examples, the user **12** chooses to manually provide the second translation that corresponds to the z-direction by selecting an option (e.g., button or icon) in the third window **330** of the UI **300**. When the user **12** selects the manual mode by selecting the manual option, the user **12** provides the second translation that corresponds to the z-direction by manipulating the graphical icon **322** in the second window **320** of the UI **300**. That is, the user **12** may interact with the graphical icon **322** of the end-effector **150** to provide the designated z-direction of the end-effector **150** to grasp the target object **302**. As can be seen comparing the second window **320** of FIG. **3**F with the second window **320** of FIG. **3**C, the second window **320** may display different graphical icons **322** that assist the user **12** to input a particular orientation or translation for the end-effector **150**. When the user **12** inputs the fourth grasping input **304** (e.g., the z-direction of translation), the remote controller **20** sends the fourth grasping input **304** (e.g., z-direction) to the control system **170** that instructs the robot **100** to maneuver the end-effector **150** to a position (or pose) that incorporates the fourth grasping input **304**. The remote controller **20** sends the fourth grasping input **304** to the control system **170** that instructs the robot **100** to maneuver the end-effector **150** to a position (or pose) integrating the fourth grasping input **304**, which designated the z-direction translation for the end-effector **150**. The control system **170** instructs the end-effector **150** of the robot to maneuver to a position or pose incorporating the fourth grasping input **304** while maintaining the first orientation, the first translation, the second orientation, and the second translation of the end-effector **150**. That is, after the end-effector **150** of the robotic manipulator maneuvers to a position embodying the fourth grasping input **304**, the end-effector **150** is at a pose that includes the first orientation (e.g., pitch of the end-effector **150**), the first translation (e.g., x-direction and y-direction of the end-effector **150**), and second orientation (e.g., roll of the end-effector **150**). When the end-effector **150** assumes this pose, the robot **100** sends the sensor data **134** from the one or more sensors **132** that corresponds to the field of view Fv of the end-effector **150** to the remote controller **20** for the user **12** to visualize. For example, the UI **300** displays the sensor data **134** for the field of view Fv at the assumed pose in the viewport image **312** of the first window **310**. In other words, the viewport image **312** would display the sensor data **134** corresponding to the first orientation, first translation, second orientation, and second translation of the end-effector **150**.

[0078] The control system **170** instructs the end-effector **150** of the robotic manipulator to grasp the target object **302** after the plurality of grasping inputs **304** are received or the sequence designed by the manual mode of the UI **300** is complete. In particular, after robot **100** derives the yaw of the end-effector **150** and receives the selected target object **302**, the first orientation (e.g., pitch of the end-effector **150**), the first translation (e.g., x-direction and y-direction of the end-effector **150**), the second orientation (e.g., roll of the end-effector **150**), and second translation (e.g., z-direction of the end-effector **150**), the end-effector **150** of the robotic manipulator should be positioned in a grasping pose desired by the user **12**. Thus, the control system **170** of the robot **100** instructs the end-effector **150** to grasp the target object **302** using this grasping pose.

[0079] In some examples, the user **12** selects for the UI **300** and/or grasping system **200** to automatically provide the second translation that corresponds to the z-direction for the end-effector **150**. In the depicted UI **300**, the user **12** selects the "auto grasp" icon or button located in the third window **330** of the UI **300** to indicate that the user **12** wants the grasping system **200** to automatically provide the second translation that corresponds to the z-direction for the end-effector **150**. In some examples, the automatic option is restricted (i.e., the user **12** cannot select this option) until the UI **300** has received a particular set of grasping inputs **304** from the user **12**. For instance, in the automatic option, the UI **300** requires that the user **12** has already provided the selected target object **302**, the yaw orientation (may or may not be derived), the pitch orientation of the end-effector **150**, the roll orientation of the end-effector **150**, and the x-direction and y-direction translation for the end-effector **150**. Given the plurality of these grasping inputs **304** already received or derived, the robot **100** (e.g., the grasping system **200** and/or the UI **300**) may automatically generate the z-direction required to grasp the selected target object **302**.

[0080] In some implementations, the user **12** requires the end-effector **150** of the robotic manipulator to grasp the target object **302** at a specific location of the end-effector **150**. In particular, the user **12** instructs the end-effector **150** to grasp the target object **302** at an end (e.g., fingertips) of the end-effector **150**, at the center (e.g., palm) of the end-effector **150**, or at any point between the fingertips of the end-effector **150** and the palm of the end-effector **150**. To designate the specific grasping or contact location on the end-effector **150**, the user **12** may use a graphical icon included in the third window **330** of the UI **300**. For example, FIG. **3**F depicts the third window **330** including a graphical icon that the user **12** may select to adjust the grasp location on the end-effector **150**. Here, the third window **330** includes a slidable icon that the user **12** may slide between a palm location on the end-effector **150** to a fingertip location on the end-effector in order to designate a precise contact location for the end-effector **150** to engage with the target object **302**. For example, the user **12** adjusts the grasp location adjuster towards the fingertip grasp location such that the grasping inputs **304** (e.g., orientation and position) correspond to the fingertips of the end-effector **150**. In another example, the user **12** adjusts the grasp location adjuster towards the palm grasp location such that the grasping inputs **304** correspond to the palm of the end-effector **150**. Specifically, the grasp location adjuster allows the user **12** to provide which portion of the end-effector **150** (e.g., palm or fingertip) engages with the target object at the user provided orientation and position.

[0081] FIG. **4** is a flowchart of an example arrangement of operations for a method **400** of supervised autonomous grasping. The method **400** may be a computer-implemented method executed by data processing hardware **142** of the robot **100**, which causes the data processing hardware **142** to perform operations. The method **400**, at operation **402**, includes receiving a three-dimensional point cloud of sensor data **134** for an area within an environment **30** about the robot **100**. The method **400**, at operation **404**, includes receiving, from a user **12** of the robot **100**, a user input selecting a target object represented in an image that corresponds to the area. The target object selected by the user input corresponds to a respective object for an end-effector **150** of a robotic manipulator of the robot **100** to grasp. The method, at operation **406**, includes generating a grasp area **216** for the end-effector **150** of the robotic manipulator by projecting a plurality of rays **218** from the selected target object of the image onto the three-dimensional point cloud of sensor data **134**. The method **400**, at operation **408**, includes determining a grasp geometry **212** for the robotic manipulator to grasp the target object within the grasp area **216**. The method **400**, at operation **410**, includes instructing the end-effector **150** of the robotic manipulator to grasp the target object within the grasp area **216** based on the grasp geometry **212**.

[0082] FIG. **5** is a flowchart of an example arrangement of operations for a method **500** for using a user interface **300** for supervised autonomous grasping. The method **500** may be a computer-implemented method executed by data processing hardware **142** of the robot **100**, which causes the data processing hardware **142** to perform operations. The method **500**, at operation **502**, includes receiving sensor data **134** for an area within an environment **30** about the robot **100**. The method **500**, at operation **504**, includes receiving, from a user **12** of the robot **100** at a user interface (UI) **300** in communication with the data processing hardware **142**, a user input selecting a location within a two-dimensional (2D) representation of the area. The location corresponding to a position of a target object **302** within the area. The method **500**, at operation **506**, includes receiving, at the user interface **300** in communication with the data processing hardware **142**, a plurality of grasping inputs **304** designating an orientation and a translation for an end-effector **150** of a robotic manipulator to grasp the target object **302**. The method **500**, at operation **508**, includes generating a three-dimensional (3D) location of the target object **302** based on the received sensor data **134** and the location corresponding to the user input. The method **500**, at operation **510**, includes instructing the end-effector **150** of the robotic manipulator to grasp the target object **302** using the generated 3D location and the plurality of grasping inputs **304** designating the orientation and the translation of the end-effector **150** of the robotic manipulator.

[0083] FIG. **6** is schematic view of an example computing device **600** that may be used to implement the systems and methods described in this document. The computing device **600** is intended to represent various forms of digital computers, such as laptops, desktops, workstations, personal digital assistants, servers, blade servers, mainframes, and other appropriate computers. The components shown here, their connections and relationships, and their functions, are meant to be exemplary only, and are not meant to limit implementations of the inventions described and/or claimed in this document.

[0084] The computing device **600** includes a processor **610** (e.g., data processing hardware), memory **620** (e.g., memory hardware), a storage device **630**, a high-speed interface/controller **640** connecting to the memory **620** and high-speed expansion ports **650**, and a low speed interface/controller **660** connecting to a low speed bus **670** and a storage device **630**. Each of the components **610**, **620**, **630**, **640**, **660**, and **660**, are interconnected using various busses, and may be mounted on a common motherboard or in other manners as appropriate. The processor **610** can process instructions for execution within the computing device **600**, including instructions stored in the memory **620** or on the storage device **630** to display graphical information for a graphical user interface (GUI) on an external input/output device, such as display **680** coupled to high speed interface **640**. In other implementations, multiple processors and/or multiple buses may be used, as appropriate, along with multiple memories and types of memory. Also, multiple computing devices **600** may be connected, with each device providing portions of the necessary operations (e.g., as a server bank, a group of blade servers, or a multi-processor system).

[0085] The memory **620** stores information non-transitorily within the computing device **600**. The memory **620** may be a computer-readable medium, a volatile memory unit(s), or non-volatile memory unit(s). The non-transitory memory **620** may be physical devices used to store programs (e.g., sequences of instructions) or data (e.g., program state information) on a temporary or permanent basis for use by the computing device **600**. Examples of non-volatile memory include, but are not limited to, flash memory and read-only memory (ROM)/programmable read-only memory (PROM)/erasable programmable read-only memory (EPROM)/electronically erasable programmable read-only memory (EEPROM) (e.g., typically used for firmware, such as boot programs). Examples of volatile memory include, but are not limited to, random access memory (RAM), dynamic random access memory (DRAM), static random access memory (SRAM), phase change memory (PCM) as well as disks or tapes.

[0086] The storage device **630** is capable of providing mass storage for the computing device **600**. In some implementations, the storage device **630** is a computer-readable medium. In various different implementations, the storage device **630** may be a floppy disk device, a hard disk device, an optical disk device, or a tape device, a flash memory or other similar solid state memory device, or an array of devices, including devices in a storage area network or other configurations. In additional implementations, a computer program product is tangibly embodied in an information carrier. The computer program product contains instructions that, when executed, perform one or more methods, such as those described above. The information carrier is a computer- or machine-readable medium, such as the memory **620**, the storage device **630**, or memory on processor **610**.

[0087] The high speed controller **640** manages bandwidth-intensive operations for the computing device **600**, while the low speed controller **660** manages lower bandwidth-intensive operations. Such allocation of duties is exemplary only. In some implementations, the high-speed controller **640** is coupled to the memory **620**, the display **680** (e.g., through a graphics processor or accelerator), and to the high-speed expansion ports **650**, which may accept various expansion cards (not shown). In some implementations, the low-speed controller **660** is coupled to the storage device **630** and a low-speed expansion port **670**. The low-speed expansion port **670**, which may include various communication ports (e.g., USB, Bluetooth, Ethernet, wireless Ethernet), may be coupled to one or more input/output devices, such as a keyboard, a pointing device, a scanner, or a networking device such as a switch or router, e.g., through a network adapter.

[0088] The computing device **600** may be implemented in a number of different forms, as shown in the figure. For example, it may be implemented as a standard server **600***a* or multiple times in a group of such servers **600***a*, as a laptop computer **600***b*, or as part of a rack server system **600***c*.

[0089] Various implementations of the systems and techniques described herein can be realized in digital electronic and/or optical circuitry, integrated circuitry, specially designed ASICs (application specific integrated circuits), computer hardware, firmware, software, and/or combinations thereof. These various implementations can include implementation in one or more computer programs that are executable and/or interpretable on a programmable system including at least one programmable processor, which may be special or general purpose, coupled to receive data and instructions from, and to transmit data and instructions to, a storage system, at least one input device, and at least one output device.

[0090] These computer programs (also known as programs, software, software applications or code) include machine instructions for a programmable processor, and can be implemented in a high-level procedural and/or object-oriented programming language, and/or in assembly/machine language. As used herein, the terms “machine-readable medium” and “computer-readable medium” refer to any computer program product, non-transitory computer readable medium, apparatus and/or device (e.g., magnetic discs, optical disks, memory, Programmable Logic Devices (PLDs)) used to provide machine instructions and/or data to a programmable processor, including a machine-readable medium that receives machine instructions as a machine-readable signal. The term “machine-readable signal” refers to any signal used to provide machine instructions and/or data to a programmable processor.

[0091] The processes and logic flows described in this specification can be performed by one or more programmable processors executing one or more computer programs to perform functions by operating on input data and generating output. The processes and logic flows can also be performed by special purpose logic circuitry, e.g., an FPGA (field programmable gate array) or an ASIC (application specific integrated circuit). Processors suitable for the execution of a computer program include, by way of example, both general and special purpose microprocessors, and any one or more processors of any kind of digital computer. Generally, a processor will receive instructions and data from a read only memory or a random access memory or both. The essential elements of a computer are a processor for performing instructions and one or more memory devices for storing instructions and data. Generally, a computer will also include, or be operatively coupled to receive data from or transfer data to, or both, one or more mass storage devices for storing data, e.g., magnetic, magneto optical disks, or optical disks. However, a computer need not have such devices. Computer readable media suitable for storing computer program instructions and data include all forms of non-volatile memory, media and memory devices, including by way of example semiconductor memory devices, e.g., EPROM, EEPROM, and flash memory devices; magnetic disks, e.g., internal hard disks or removable disks; magneto optical disks; and CD ROM and DVD-ROM disks. The processor and the memory can be supplemented by, or incorporated in, special purpose logic circuitry.

[0092] To provide for interaction with a user, one or more aspects of the disclosure can be implemented on a computer having a display device, e.g., a CRT (cathode ray tube), LCD (liquid crystal display) monitor, or touch screen for displaying information to the user and optionally a keyboard and a pointing device, e.g., a mouse or a trackball, by which the user can provide input to the computer. Other kinds of devices can be used to provide interaction with a user as well; for example, feedback provided to the user can be any form of sensory feedback, e.g., visual feedback, auditory feedback, or tactile feedback; and input from the user can be received in any form, including acoustic, speech, or tactile input. In addition, a computer can interact with a user by sending documents to and receiving documents from a device that is used by the user; for example, by sending web pages to a web browser on a user’s client device in response to requests received from the web browser.

[0093] A number of implementations have been described. Nevertheless, it will be understood that various modifications may be made without departing from the spirit and scope of the disclosure. Accordingly, other implementations are within the scope of the following claims.

What is claimed is:

1. A computer-implemented method when executed by data processing hardware of a robot causes the data processing hardware to perform operations comprising:

receiving sensor data for a space within an environment about the robot;

receiving, from a user interface (UI) in communication with the data processing hardware, a user input indicating a user-selection of a location within a two-dimensional (2D) representation of the space, the location corresponding to a position of a target object within the space;

receiving, from the UI, a plurality of grasping inputs designating an orientation and a translation for an end-effector of a robotic manipulator to grasp the target object;

generating a three-dimensional (3D) location of the target object based on the received sensor data and the location corresponding to the user input; and

instructing the end-effector of the robotic manipulator to grasp the target object using the generated 3D location and the plurality of grasping inputs designating the orientation and the translation of the end-effector of the robotic manipulator.

2. The method of claim **1**, further comprising grasping, by the end-effector of the robotic manipulator, the target object.

3. The method of claim **1**, wherein the plurality of grasping inputs corresponds to a plurality of constraints on one or more degrees of freedom for the end-effector of the robotic manipulator.

4. The method of claim **3**, wherein the one or more degrees of freedom comprise a pitch of the end-effector, a roll of the end-effector, a first translation in an x-direction, and a second translation in a y-direction.

5. The method of claim **4**, wherein the one or more degrees of freedom further comprises a third translation in a z-direction.

6. The method of claim **1**, wherein receiving the plurality of grasping inputs designating the orientation and the translation for the end-effector of the robotic manipulator to grasp the target object comprises:

receiving a first grasping input designating a first orientation for the end-effector of the robotic manipulator to grasp the target object; and

instructing modification of a viewport image comprising the target object at the UI based on the designed first orientation for the end-effector of the robotic manipulator.

7. The method of claim **6**, wherein the first orientation comprises one of a pitch or a roll for the end-effector of the robotic manipulator to grasp the target object.

8. The method of claim **6**, wherein the UI comprises a first window and a second window separate from the first window, the first window comprising the viewport image displaying the sensor data for the space within the environment about the robot that includes the target object, the second window comprising a graphical icon representing the end-effector, the graphical icon capable of being user-manipulated to indicate the first grasping input designating the first orientation for the end-effector of the robotic manipulator to grasp the target object.

9. The method of claim **8**, wherein the graphical icon comprises a wire-frame representation of the end-effector and a radial dial to designate a pitch as the first orientation for the end-effector of the robotic manipulator to grasp the target object.

10. The method of claim **8**, further comprising:

overlaying, on the viewport image, a representation of the end-effector at the first orientation designated by the first grasping input; and

receiving, from the UI, a second grasping input designating a second orientation for the end-effector of the robotic manipulator to grasp the target object.

11. The method of claim **10**, wherein the second orientation corresponds to a roll for the end-effector of the robotic manipulator to grasp the target object.

12. The method of claim **10**, wherein receiving the second grasping input designating the second orientation comprises receiving another user input indicating another user-selection of the graphical icon indicating a roll for the end-effector of the robotic manipulator to grasp the target object.

13. A robot comprising:

a body;

a robotic manipulator coupled to the body, the robotic manipulator comprising an end-effector configured to grasp objects within an environment about the robot;

data processing hardware in communication with the robotic manipulator; and

memory hardware in communication with the data processing hardware, the memory hardware storing instructions that when executed on the data processing hardware cause the data processing hardware to perform operations comprising:

receiving sensor data for a space within an environment about the robot;

receiving, from a user interface (UI) in communication with the data processing hardware, a user input indicating a user-selection of a location within a two-dimensional (2D) representation of the space, the location corresponding to a position of a target object within the space;

receiving, from the UI, a plurality of grasping inputs designating an orientation and a translation for the end-effector of the robotic manipulator to grasp the target object;

generating a three-dimensional (3D) location of the target object based on the received sensor data and the location corresponding to the user input; and

instructing the end-effector of the robotic manipulator to grasp the target object using the generated 3D location and the plurality of grasping inputs designating the orientation and the translation of the end-effector of the robotic manipulator.

14. The robot of claim **13**, wherein the operations further comprise grasping, by the end-effector of the robotic manipulator, the target object.

15. The robot of claim **13**, wherein the plurality of grasping inputs corresponds to a plurality of constraints on one or more degrees of freedom for the end-effector of the robotic manipulator.

16. The robot of claim **15**, wherein the one or more degrees of freedom comprise a pitch of the end-effector, a roll of the end-effector, a first translation in an x-direction, and a second translation in a y-direction.

17. The robot of claim **16**, wherein the one or more degrees of freedom further comprises a third translation in a z-direction.

18. The robot of claim **13**, wherein receiving the plurality of grasping inputs designating the orientation and the translation for the end-effector of the robotic manipulator to grasp the target object comprises:

receiving a first grasping input designating a first orientation for the end-effector of the robotic manipulator to grasp the target object; and

instructing modification of a viewport image comprising the target object at the UI based on the designed first orientation for the end-effector of the robotic manipulator.

19. The robot of claim **18**, wherein the first orientation comprises one of a pitch or a roll for the end-effector of the robotic manipulator to grasp the target object.

20. The robot of claim **18**, wherein the UI comprises a first window and a second window separate from the first window, the first window comprising the viewport image displaying the sensor data for the space within the environment about the robot that includes the target object, the second window comprising a graphical icon representing the end-effector, the graphical icon capable of being user-manipulated to indicate the first grasping input designating the first orientation for the end-effector of the robotic manipulator to grasp the target object.

21. The robot of claim **20**, wherein the graphical icon comprises a wire-frame representation of the end-effector and a radial dial to designate a pitch as the first orientation for the end-effector of the robotic manipulator to grasp the target object.

22. The robot of claim **20**, wherein the operations further comprise:

overlaying, on the viewport image, a representation of the end-effector at the first orientation designated by the first grasping input; and

receiving, from the UI, a second grasping input designating a second orientation for the end-effector of the robotic manipulator to grasp the target object.

23. The robot of claim **22**, wherein the second orientation corresponds to a roll for the end-effector of the robotic manipulator to grasp the target object.

24. The robot of claim **22**, wherein receiving the second grasping input designating the second orientation comprises receiving another user input indicating another user-selection of the graphical icon indicating a roll for the end-effector of the robotic manipulator to grasp the target object.

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