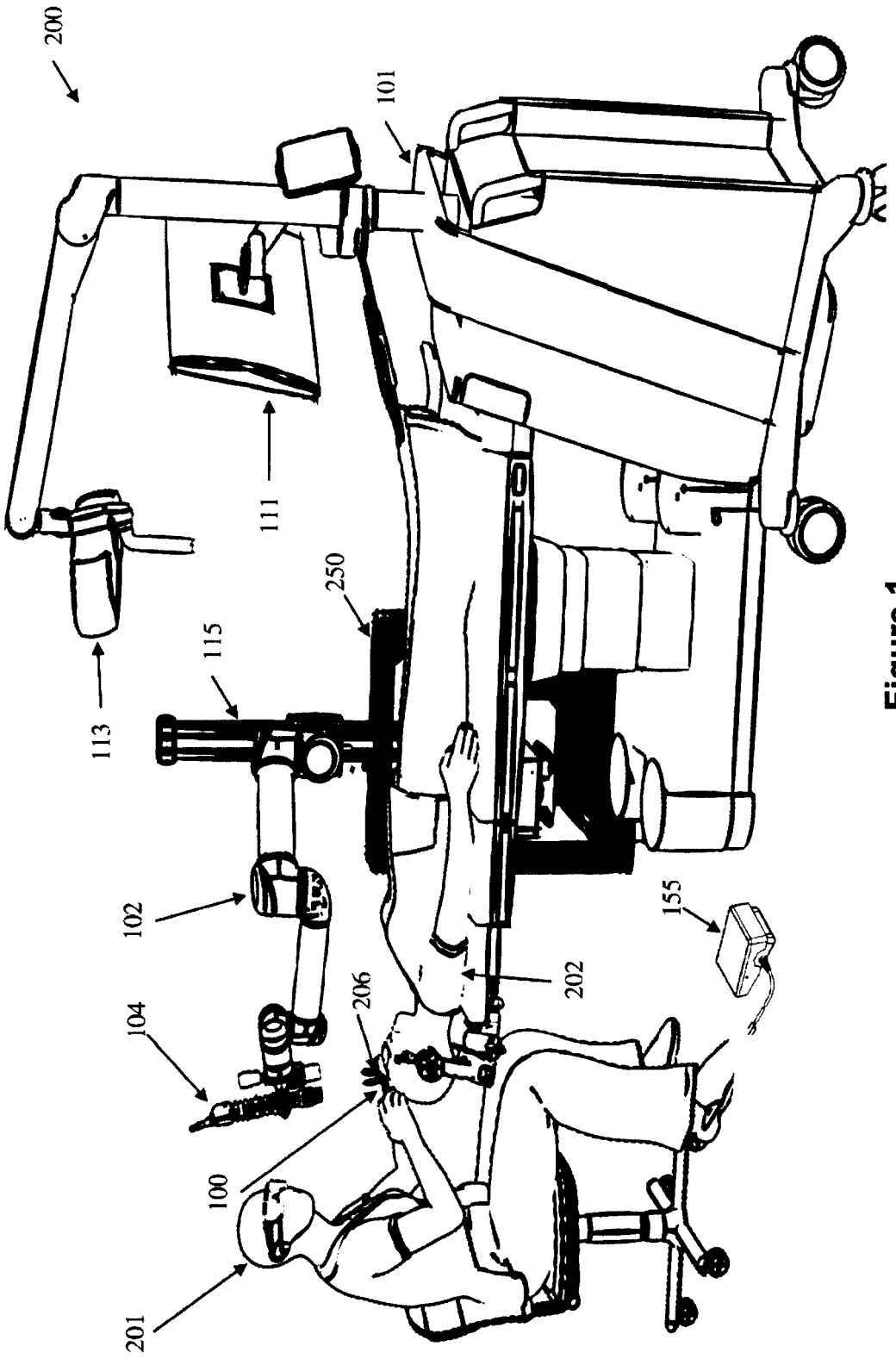


Figure 1

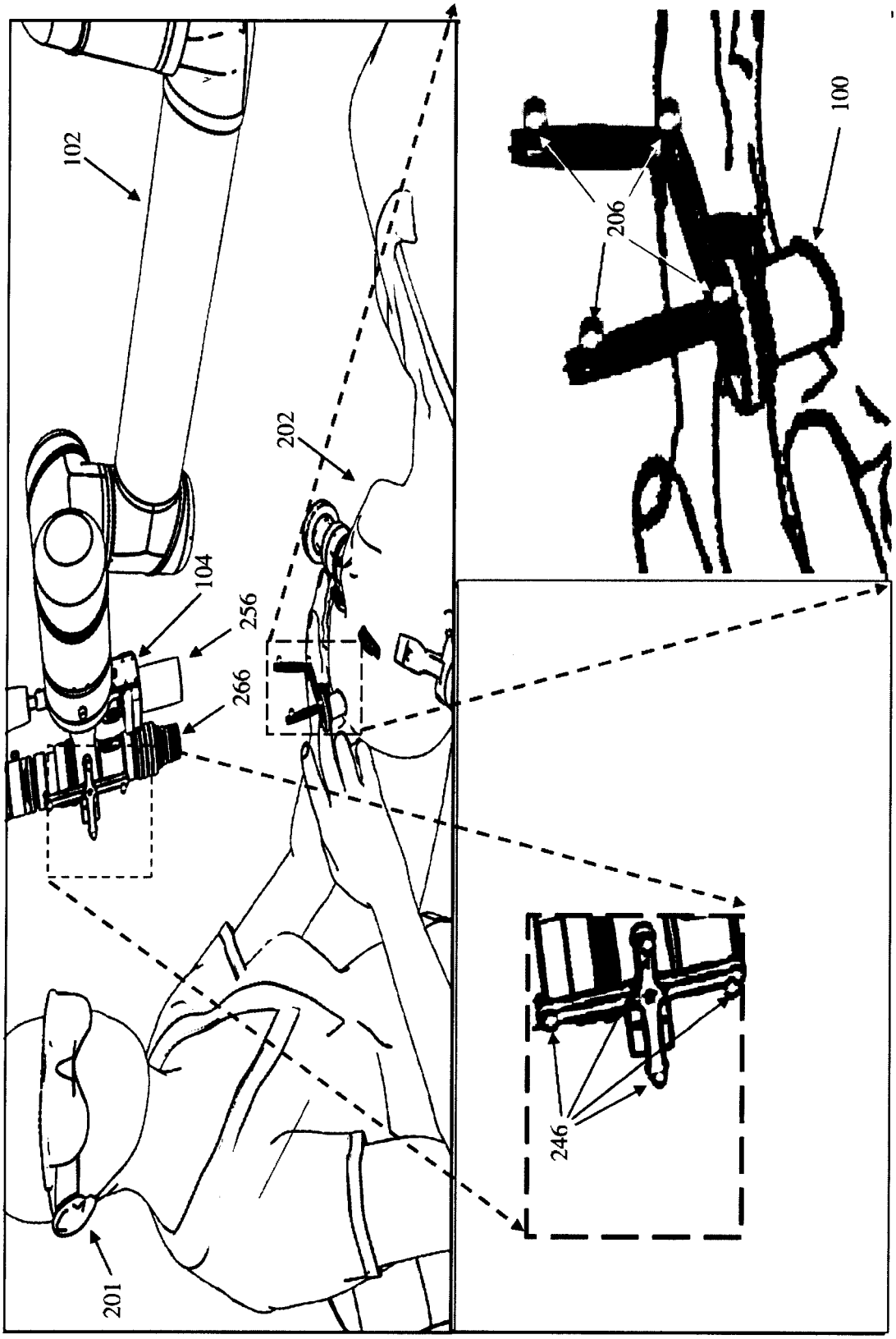


Figure 2

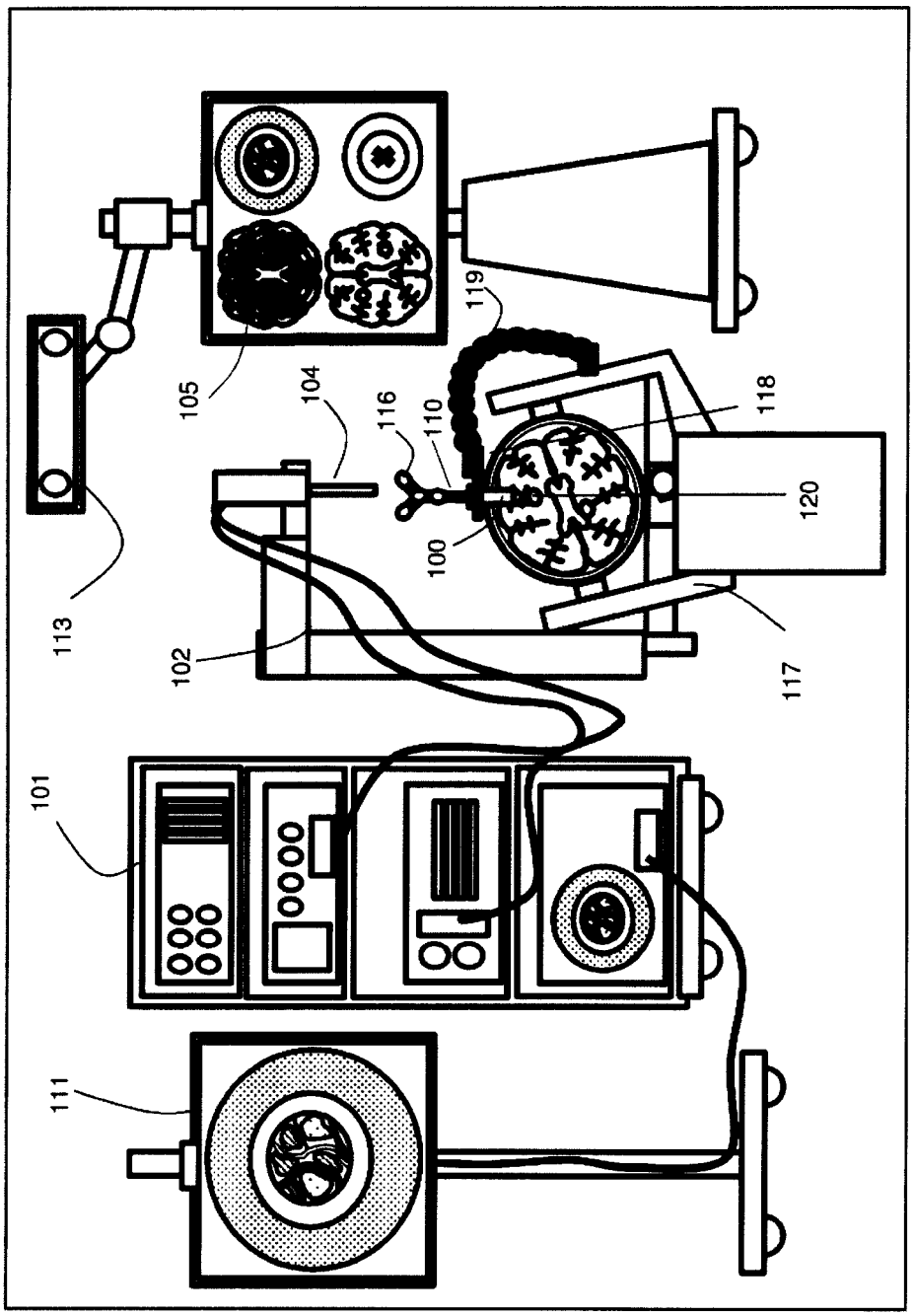


Figure 3

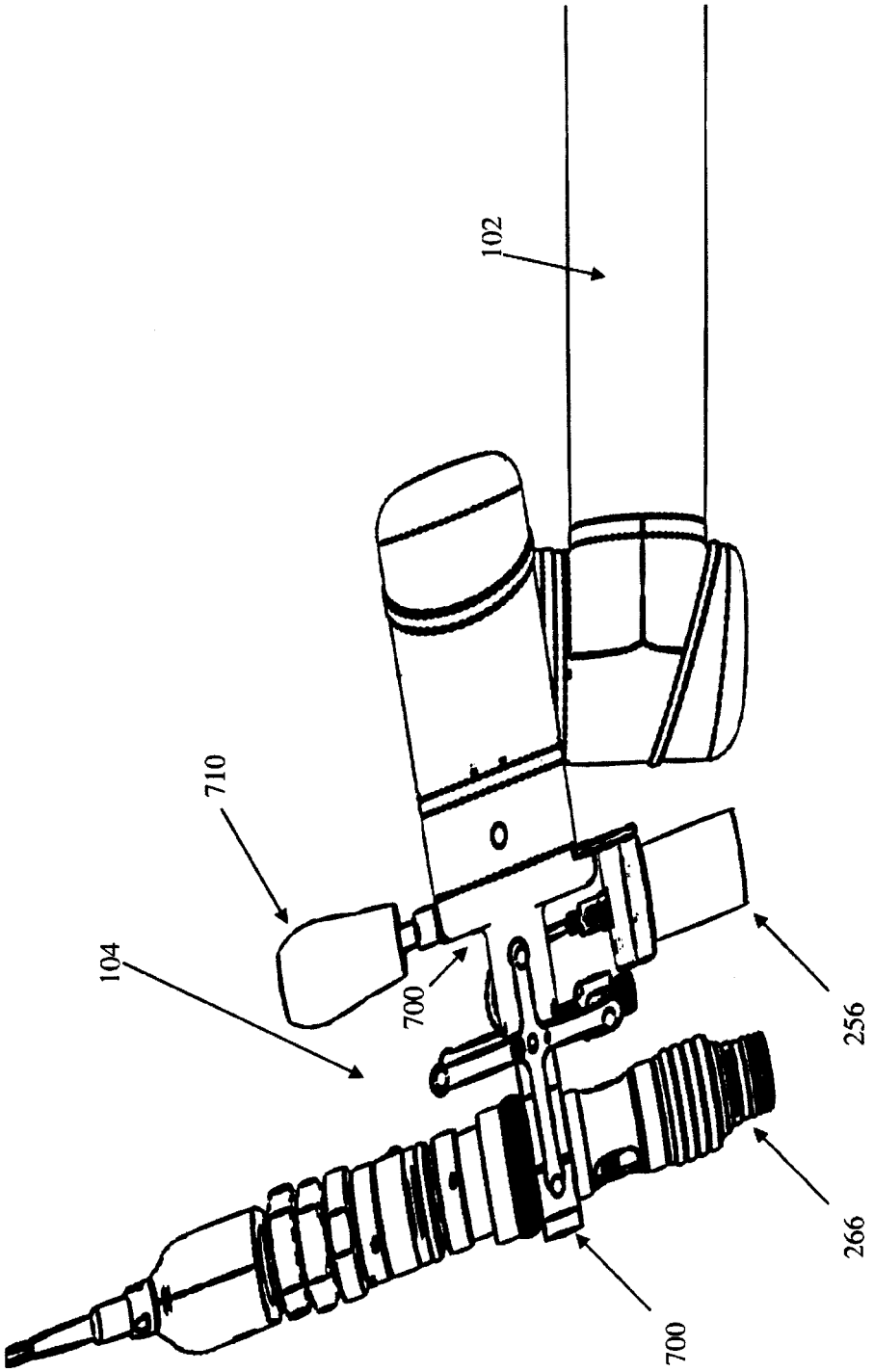
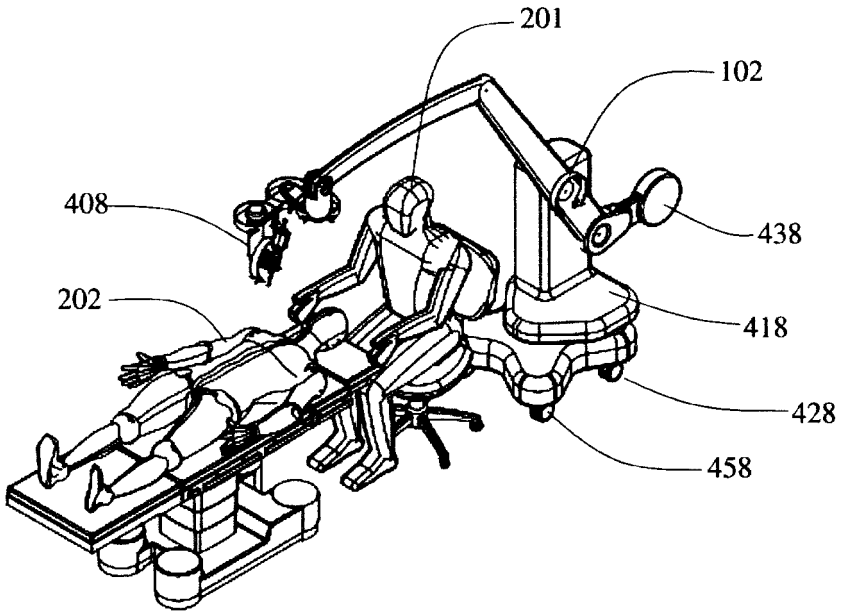
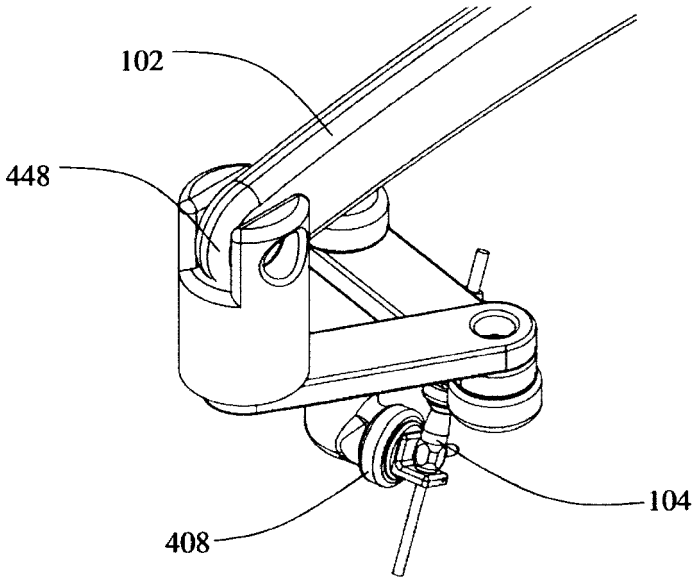


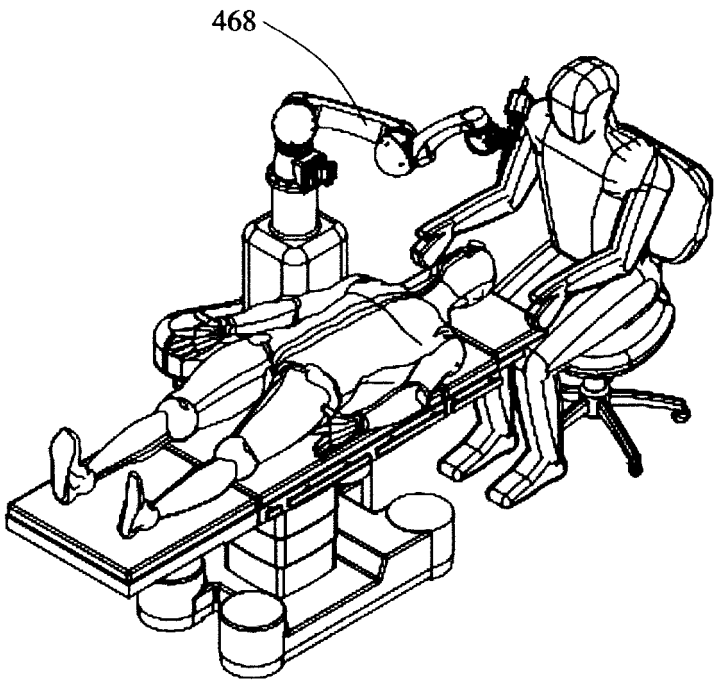
Figure 4A

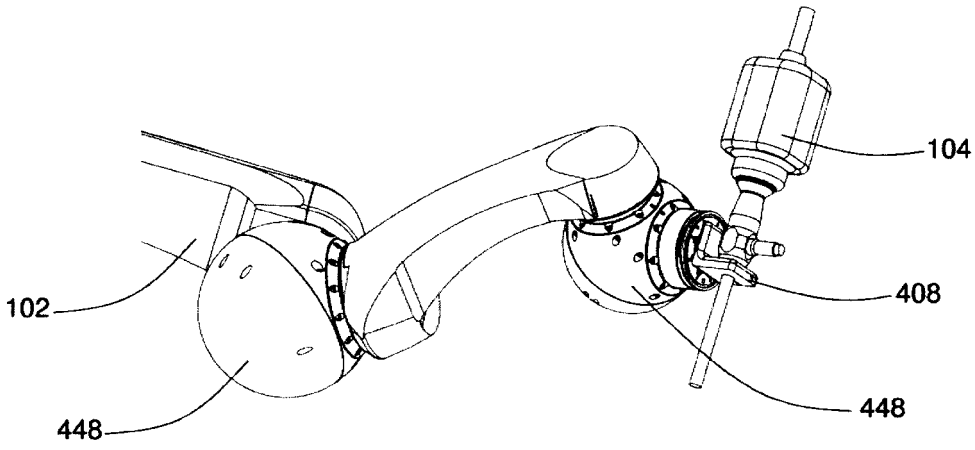




End Effector

Figure 4B





End Effector

Figure 4C

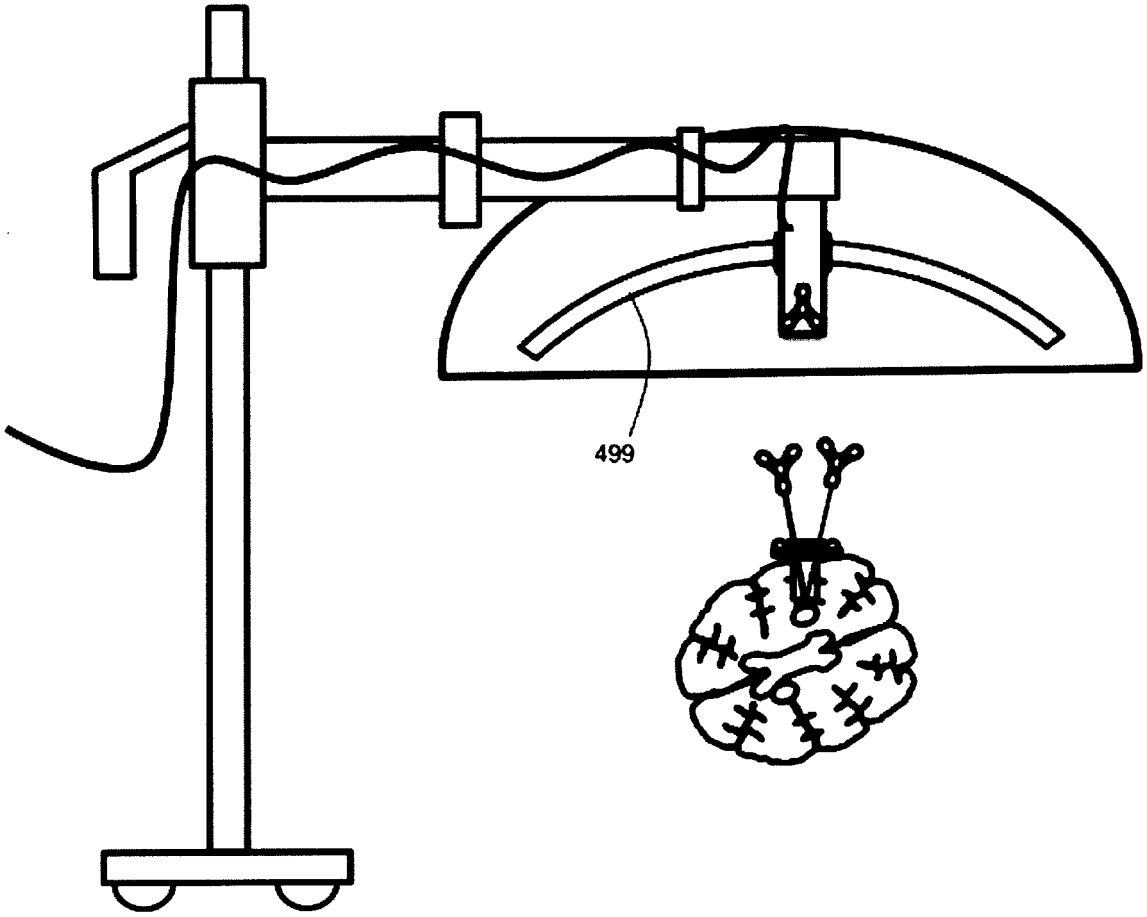


Figure 4D

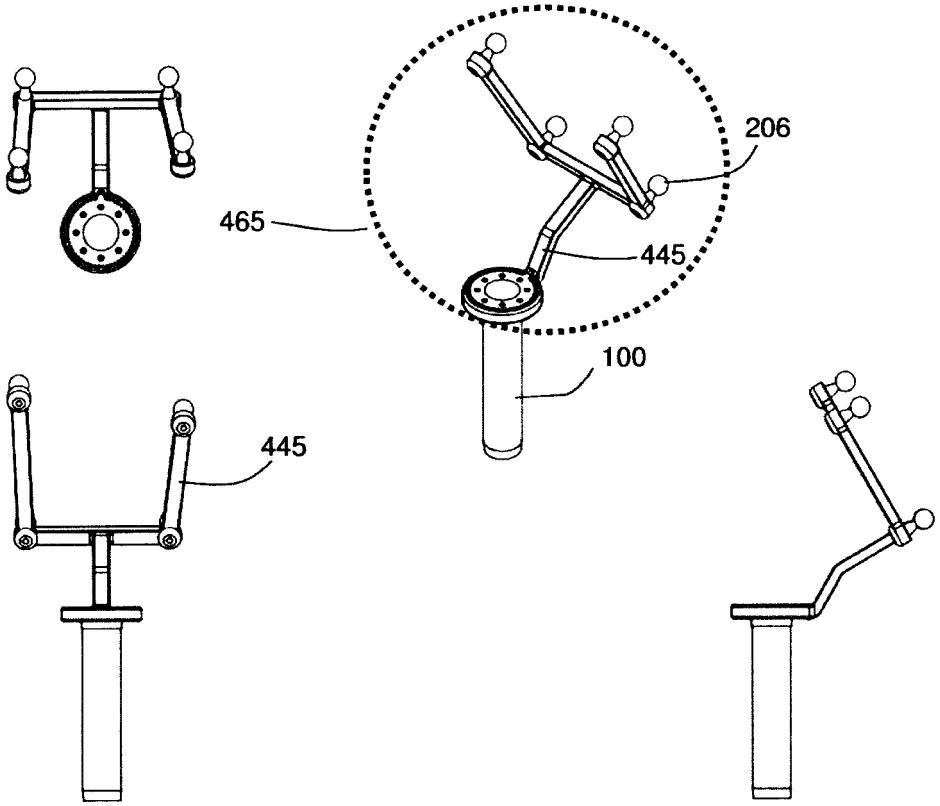


Figure 4E

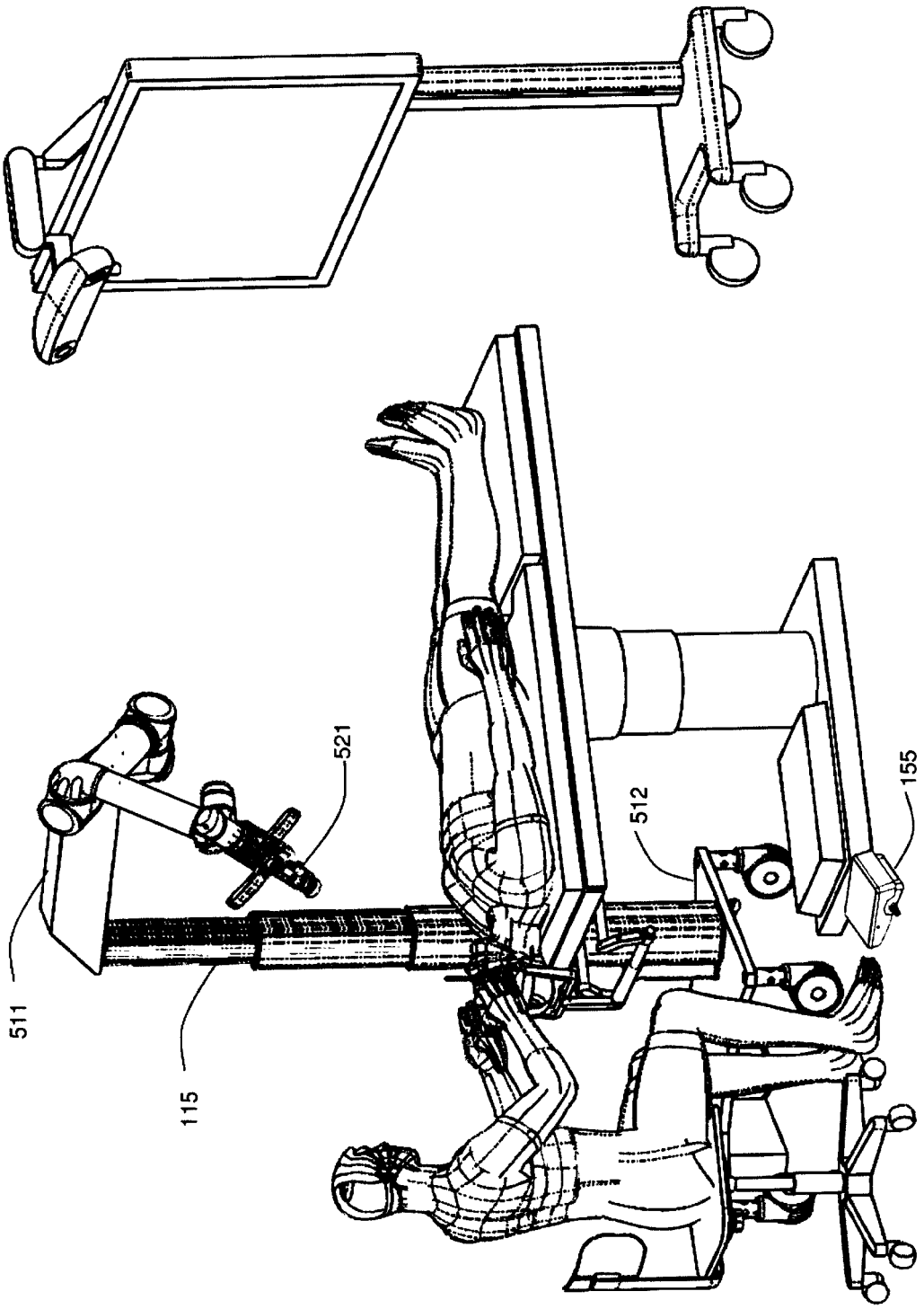


Figure 5A

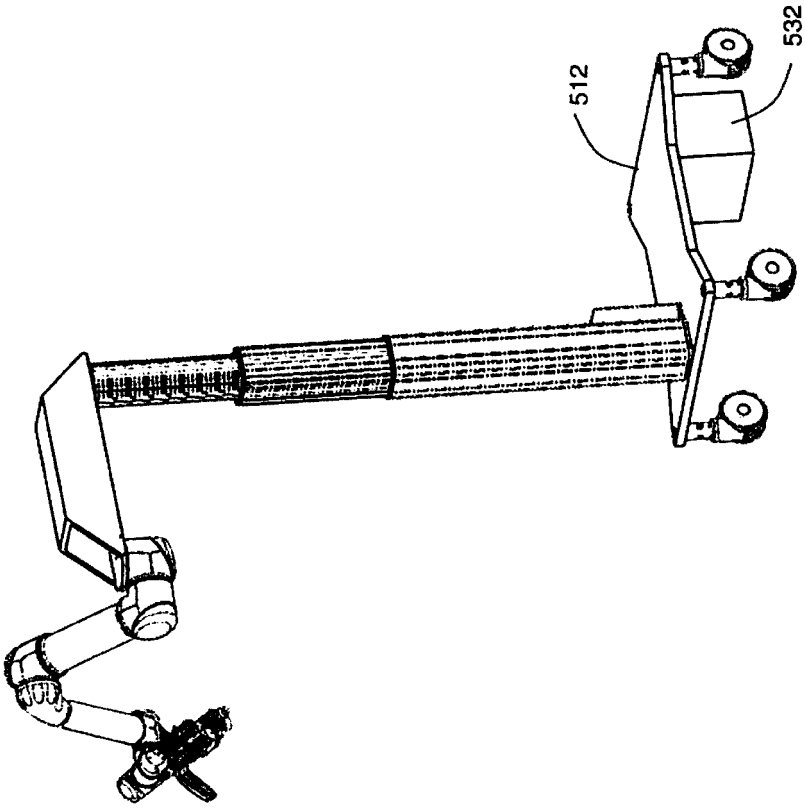


Figure 5B

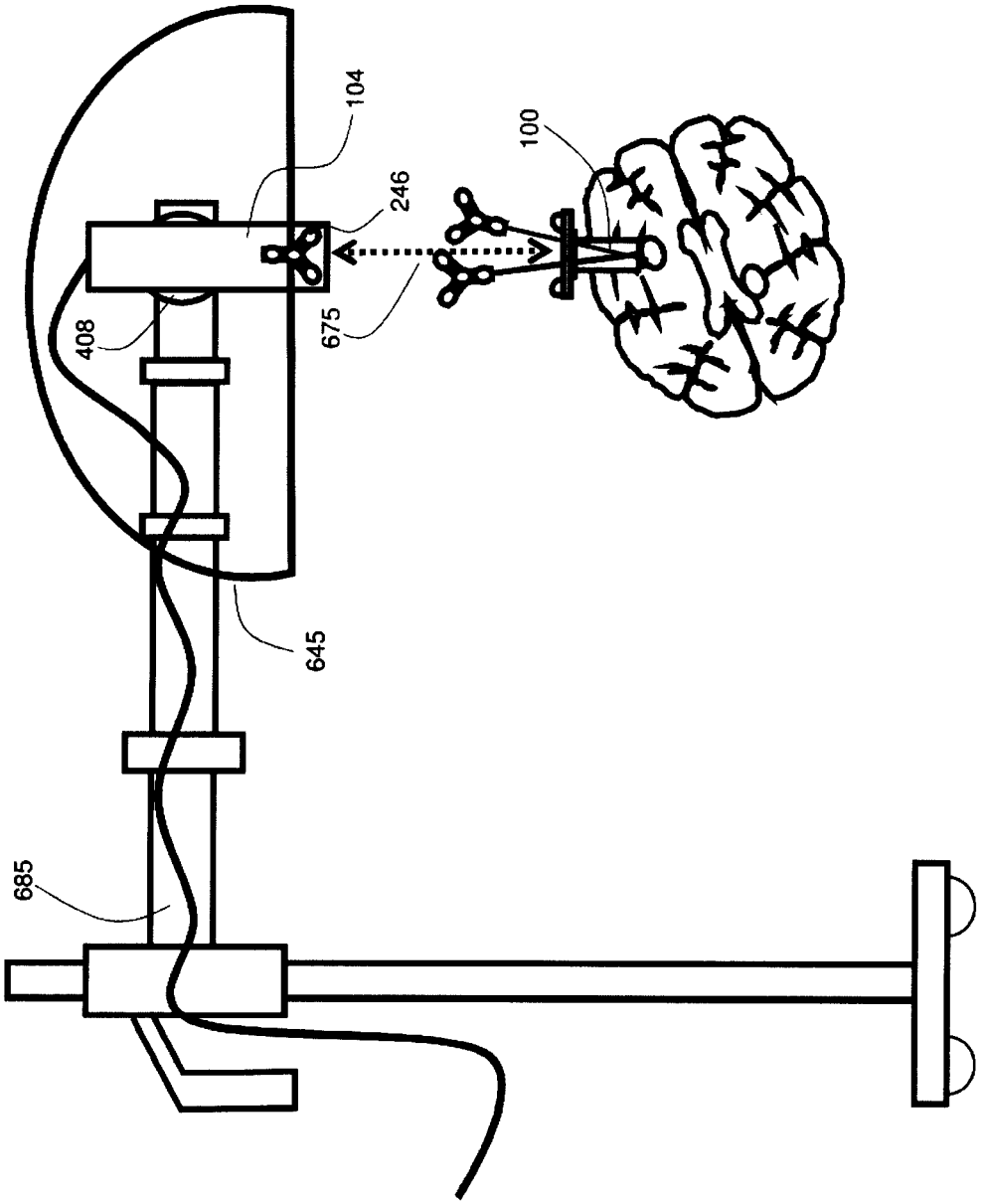


Figure 6A

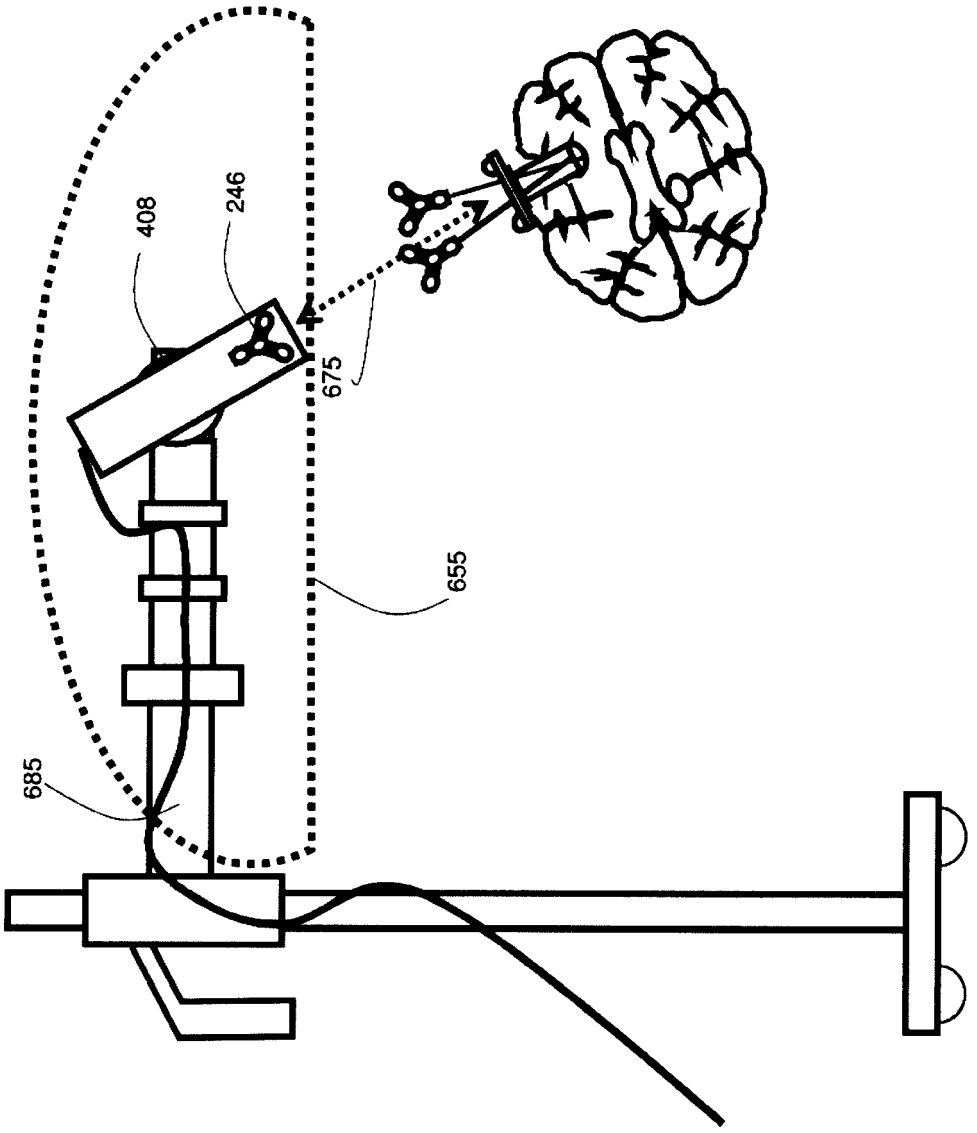


Figure 6B

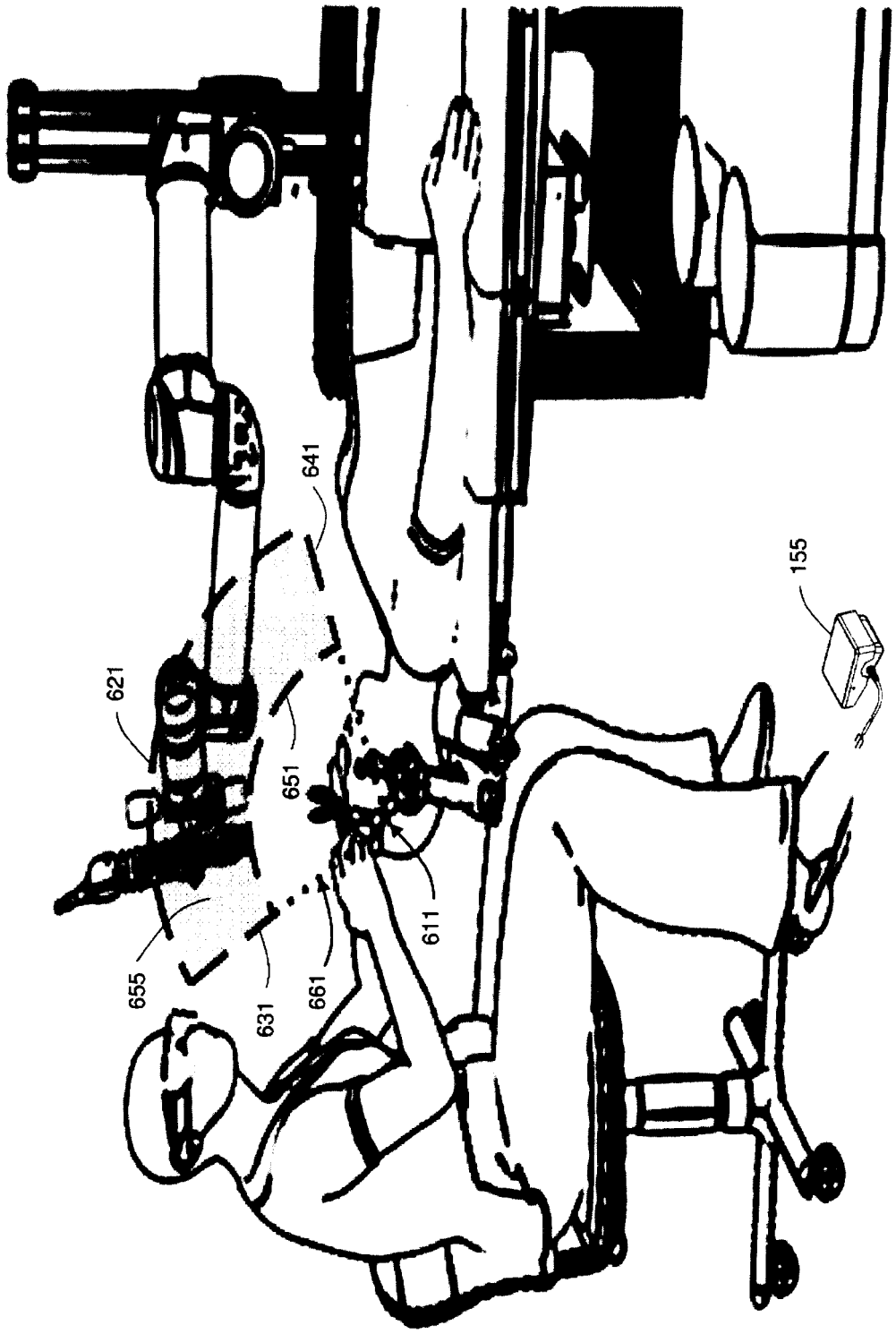


Figure 6C

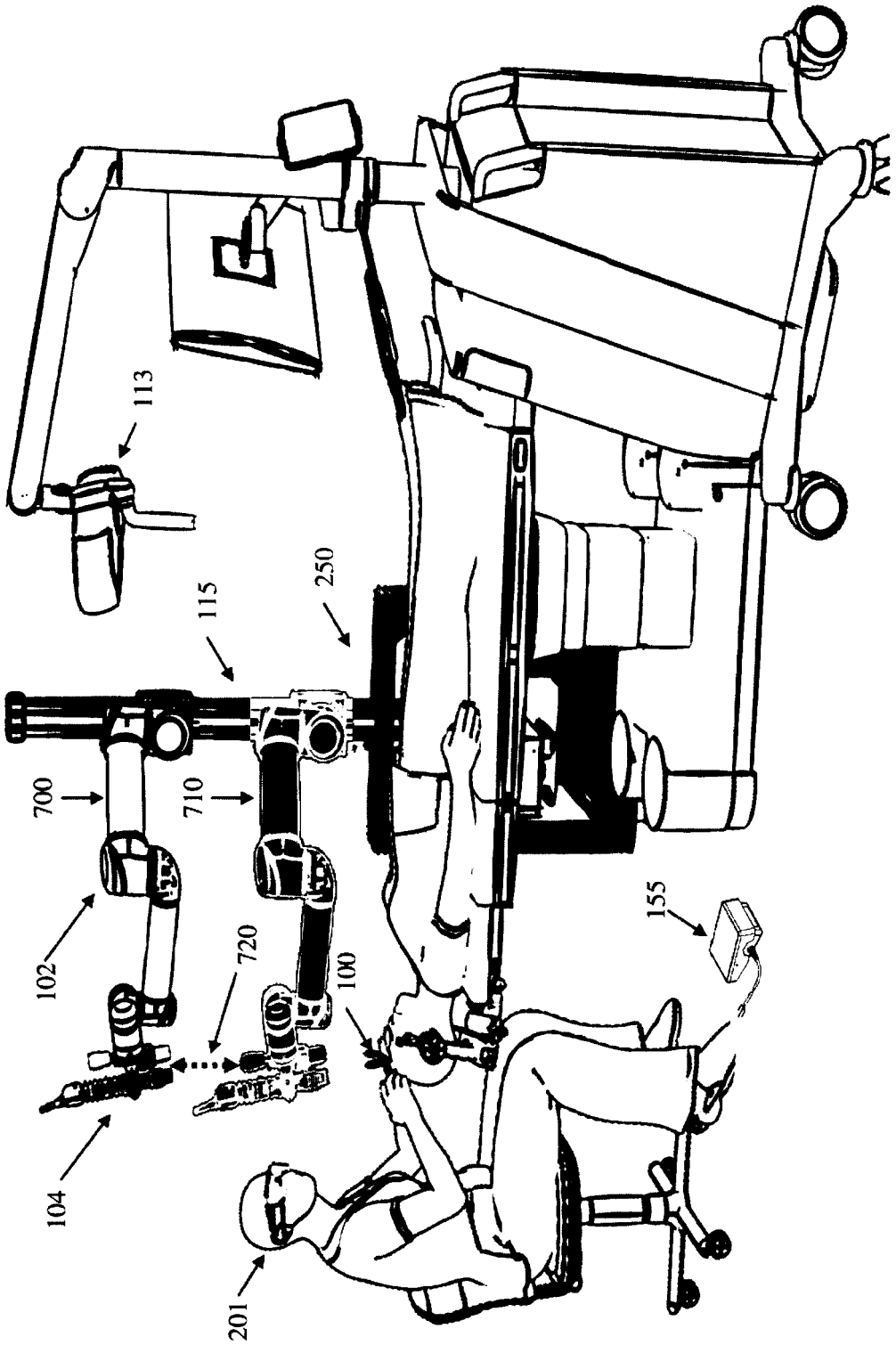


Figure 7

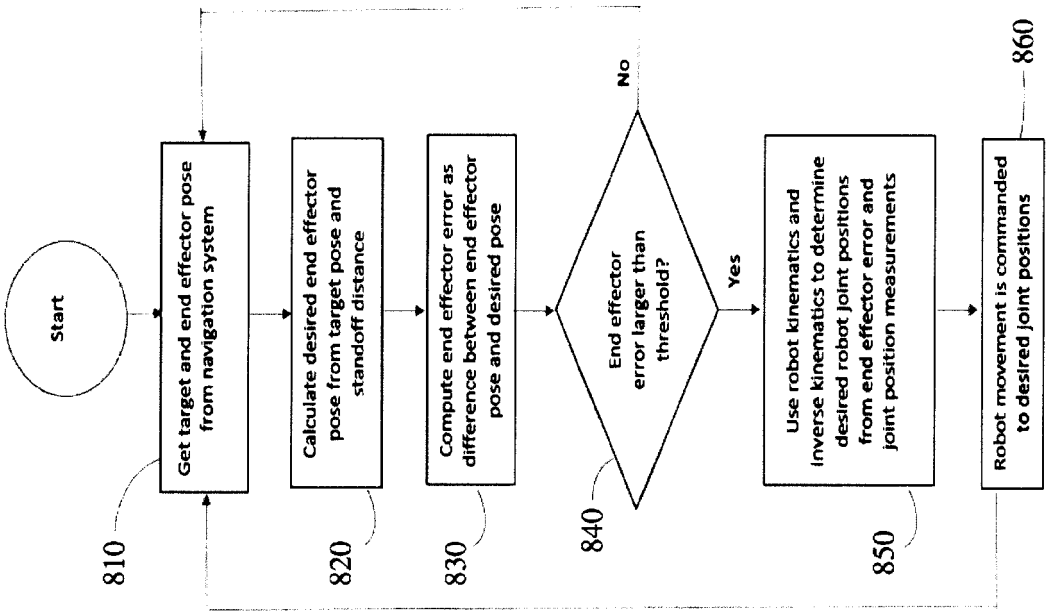

Start
Get target and end effector pose from navigation system
Calculate desired end effector pose from target pose and standoff distance
Compute end effector error as difference between end effector pose and desired pose
End effector error larger than threshold?
No
Yes
Use robot kinematics and inverse kinematics to determine desired robot joint positions from end effector error and joint position measurements
Robot movement is commanded to desired joint positions
810
820
830
840
850
860

Figure 8A

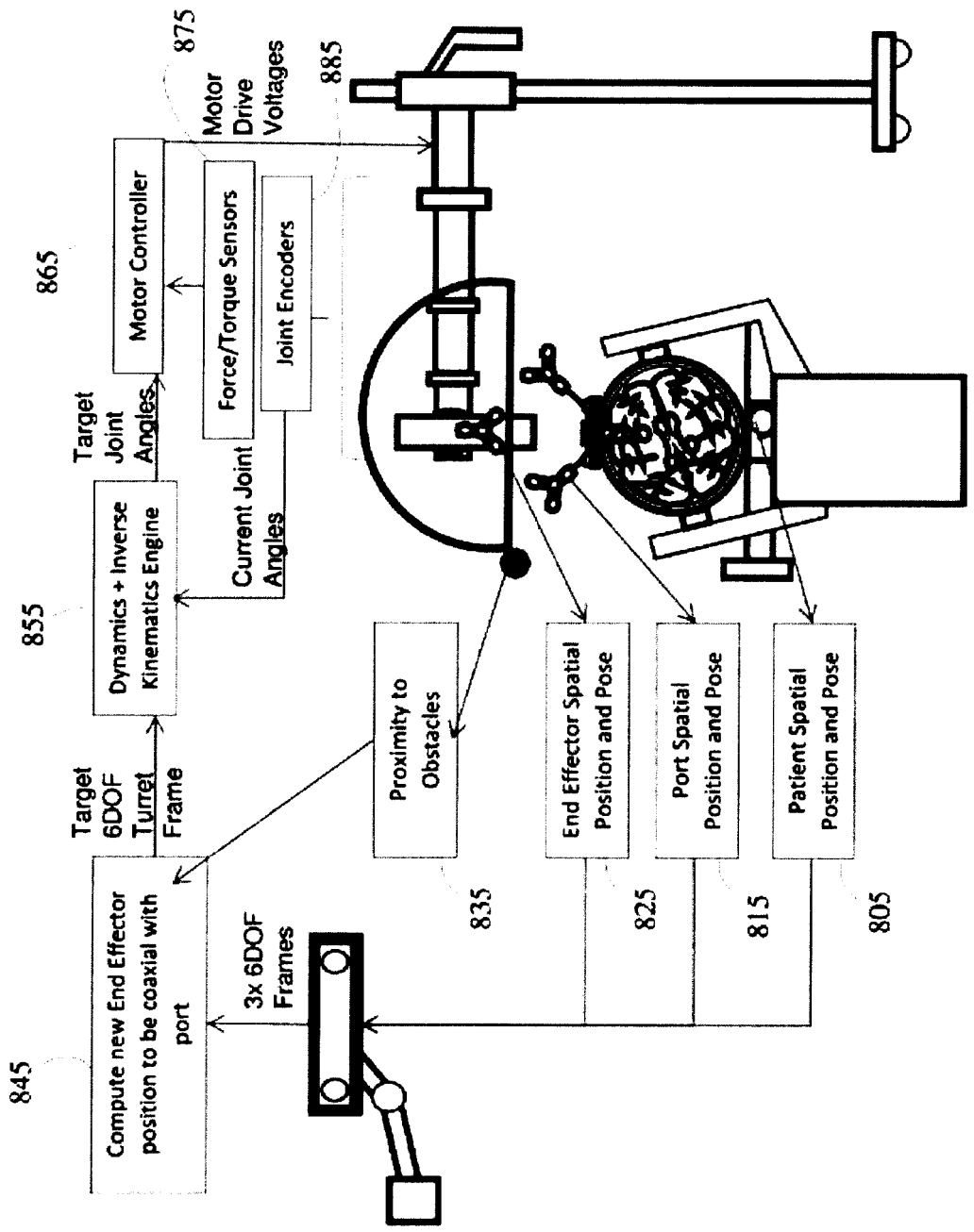

875
Motor Drive Voltages
885
Motor Controller
Force/Torque Sensors
Joint Encoders
865
Target Joint Angles
Current Joint Angles
Dynamics + Inverse Kinematics Engine
855
Target 6DOF Turret Frame
Proximity to Obstacles
End Effector Spatial Position and Pose
Port Spatial Position and Pose
Patient Spatial Position and Pose
835
825
815
805
3x 6DOF Frames
Compute new End Effector position to be coaxial with port
845

Figure 8B

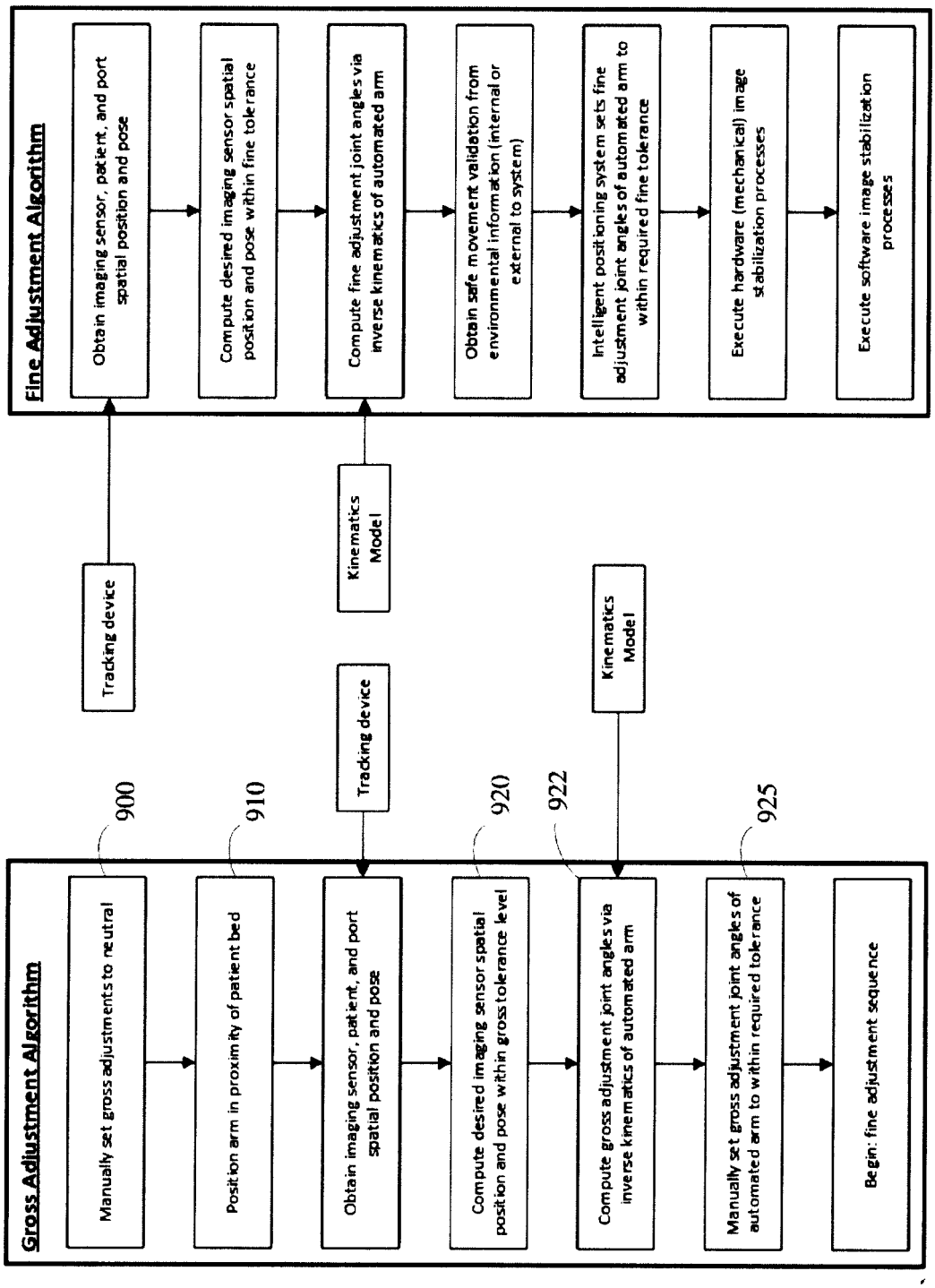

Gross Adjustment Algorithm
Manually set gross adjustments to neutral
Position arm in proximity of patient bed
Obtain imaging sensor, patient, and port spatial position and pose
Compute desired imaging sensor spatial position and pose within gross tolerance level
Compute gross adjustment joint angles via inverse kinematics of automated arm
Manually set gross adjustment joint angles of automated arm to within required tolerance
Begin: fine adjustment sequence
900
910
920
922
925
Tracking device
Kinematics Model
Tracking device
Kinematics Model
Fine Adjustment Algorithm
Obtain imaging sensor, patient, and port spatial position and pose
Compute desired imaging sensor spatial position and pose within fine tolerance
Compute fine adjustment joint angles via inverse kinematics of automated arm
Obtain safe movement validation from environmental information (internal or external to system)
Intelligent positioning system sets fine adjustment joint angles of automated arm to within required fine tolerance
Execute hardware (mechanical) image stabilization processes
Execute software image stabilization processes

Figure 9A

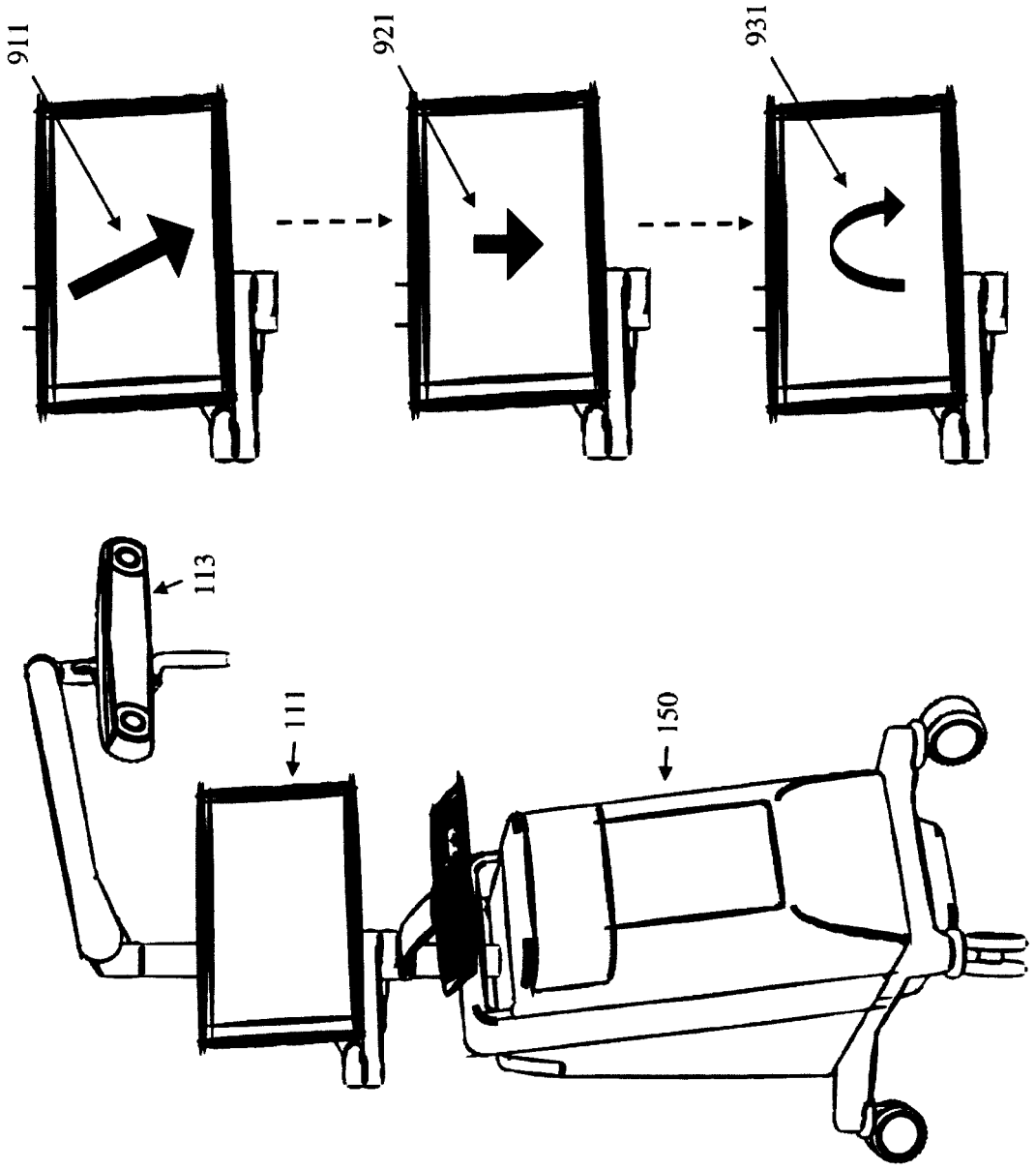


Figure 9B

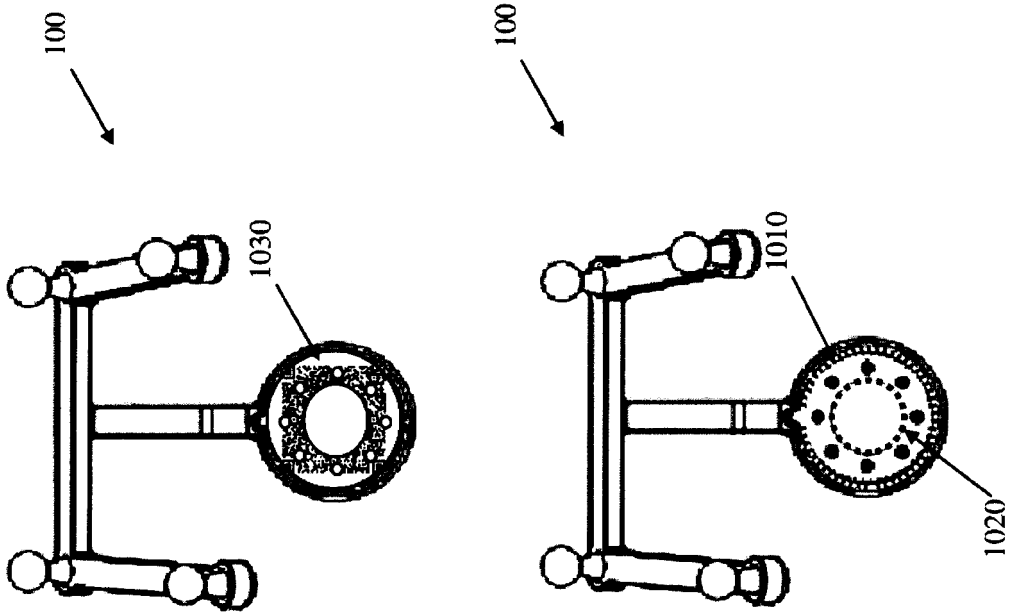


Figure 10A

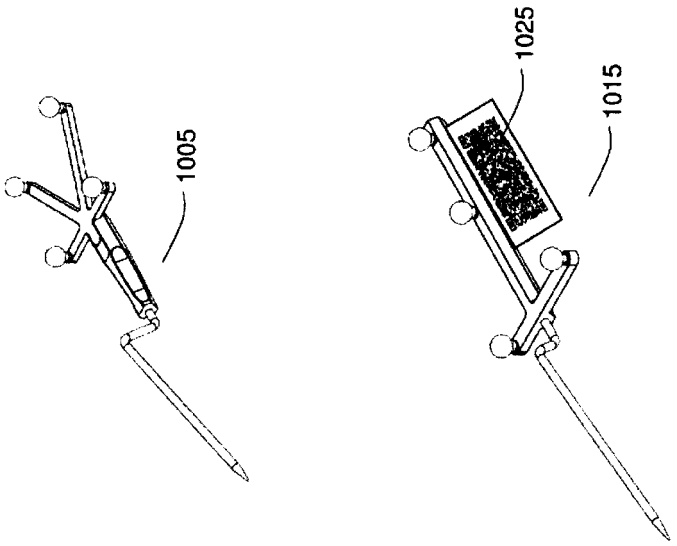


Figure 10B

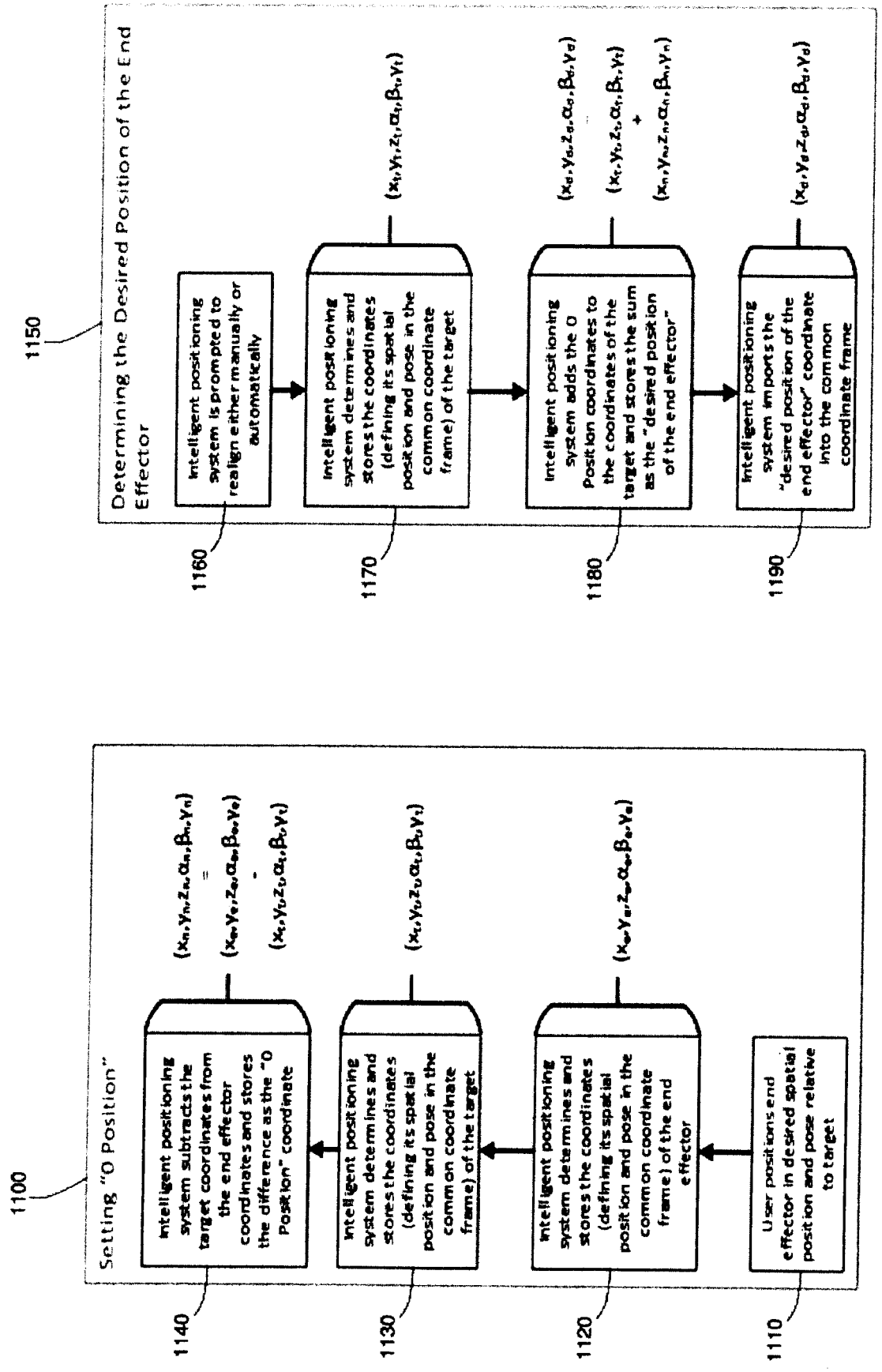

1100
Setting "0 Position"
User positions end effector in desired spatial position and pose relative to target
1110
Intelligent positioning system determines and stores the coordinates (defining its spatial position and pose in the common coordinate frame) of the end effector
1120
$(x_e, y_e, z_e, \alpha_e, \beta_e, \gamma_e)$
Intelligent positioning system determines and stores the coordinates (defining its spatial position and pose in the common coordinate frame) of the target
1130
$(x_t, y_t, z_t, \alpha_t, \beta_t, \gamma_t)$
Intelligent positioning system subtracts the target coordinates from the end effector coordinates and stores the difference as the "0 Position" coordinate
1140
$(x_n, y_n, z_n, \alpha_n, \beta_n, \gamma_n)$ = $(x_e, y_e, z_e, \alpha_e, \beta_e, \gamma_e)$ - $(x_t, y_t, z_t, \alpha_t, \beta_t, \gamma_t)$
1150
Determining the Desired Position of the End Effector
Intelligent positioning system is prompted to realign either manually or automatically
1160
Intelligent positioning system determines and stores the coordinates (defining its spatial position and pose in the common coordinate frame) of the target
1170
$(x_t, y_t, z_t, \alpha_t, \beta_t, \gamma_t)$
Intelligent positioning system adds the 0 Position coordinates to the coordinates of the target and stores the sum as the "desired position of the end effector"
1180
$(x_d, y_d, z_d, \alpha_d, \beta_d, \gamma_d)$ = $(x_t, y_t, z_t, \alpha_t, \beta_t, \gamma_t)$ + $(x_n, y_n, z_n, \alpha_n, \beta_n, \gamma_n)$
Intelligent positioning system imports the "desired position of the end effector" coordinate into the common coordinate frame
1190
$(x_d, y_d, z_d, \alpha_d, \beta_d, \gamma_d)$

Figure 11

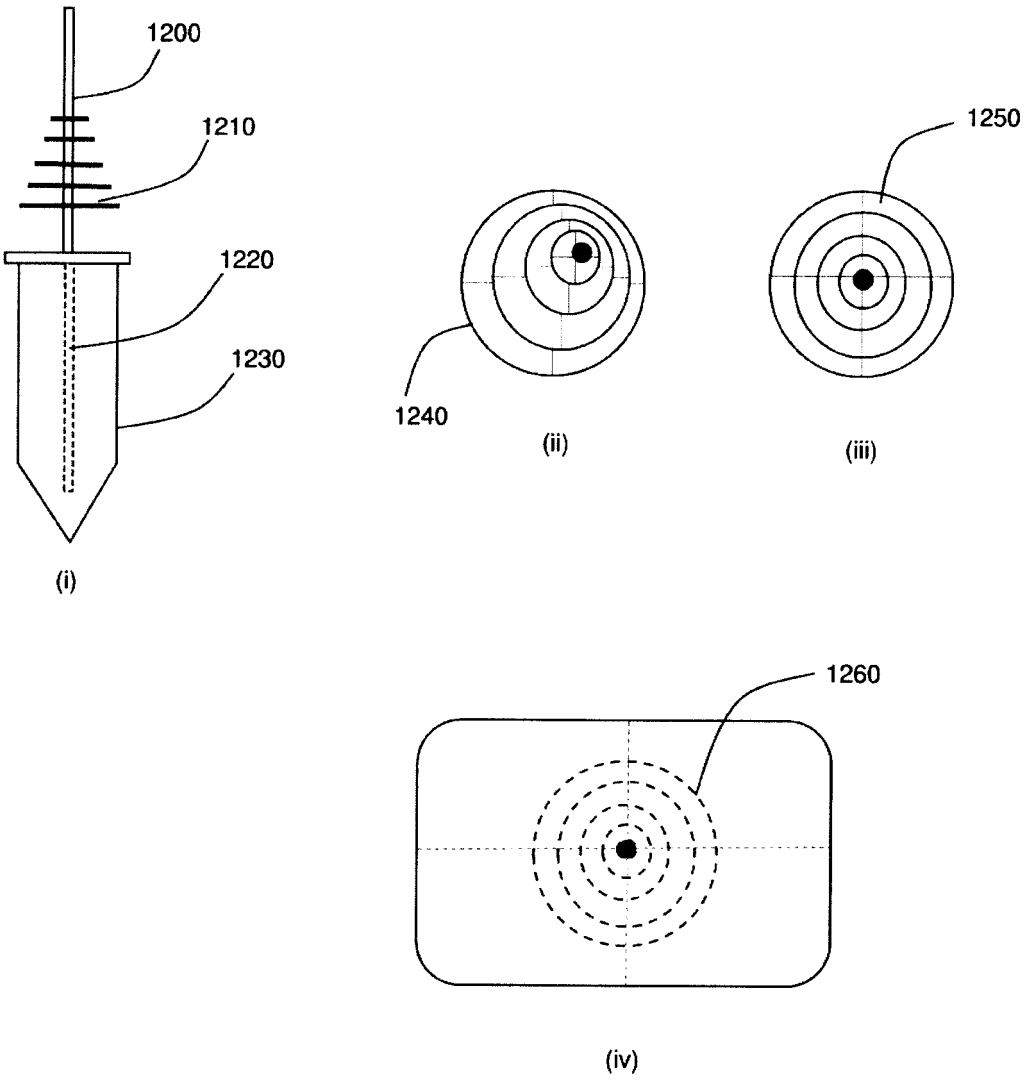


Figure 12A

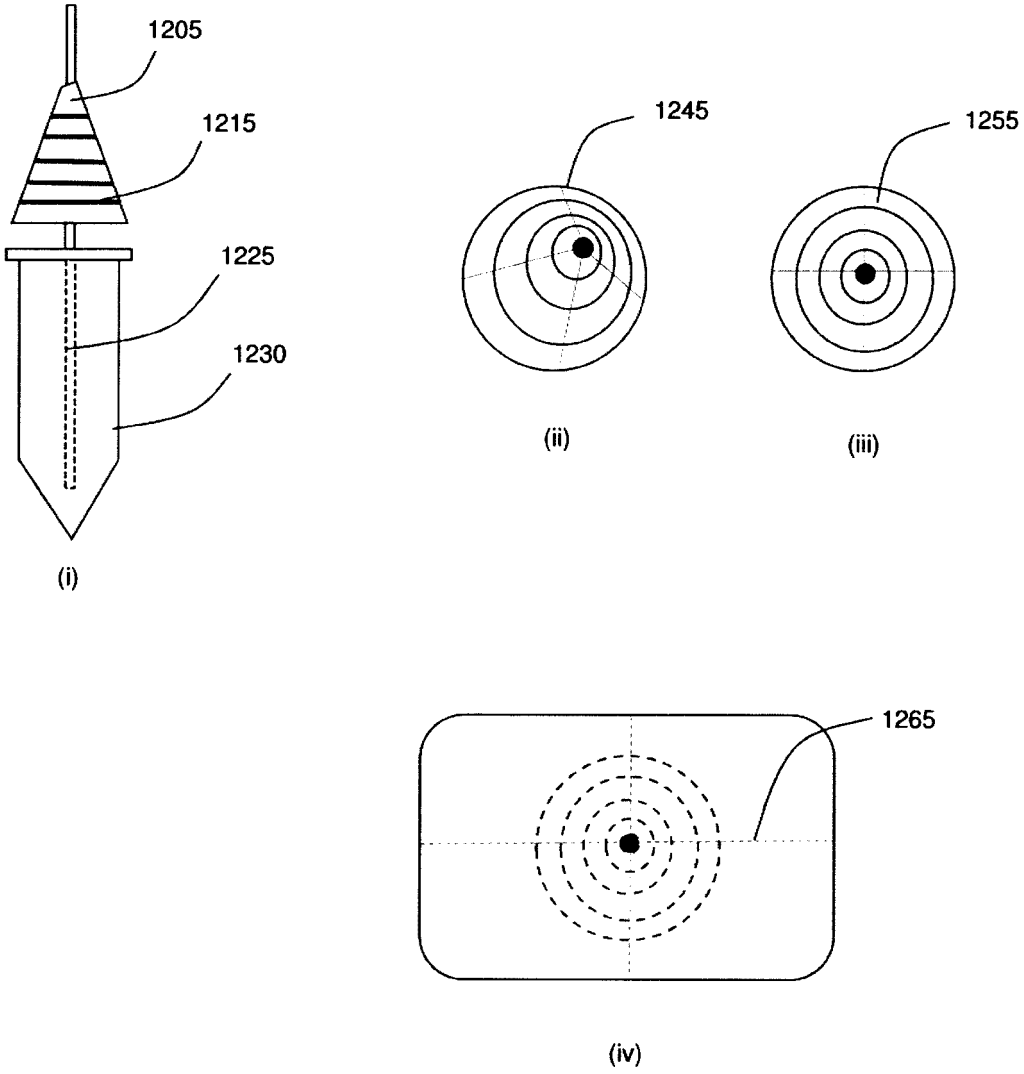


Figure 12B

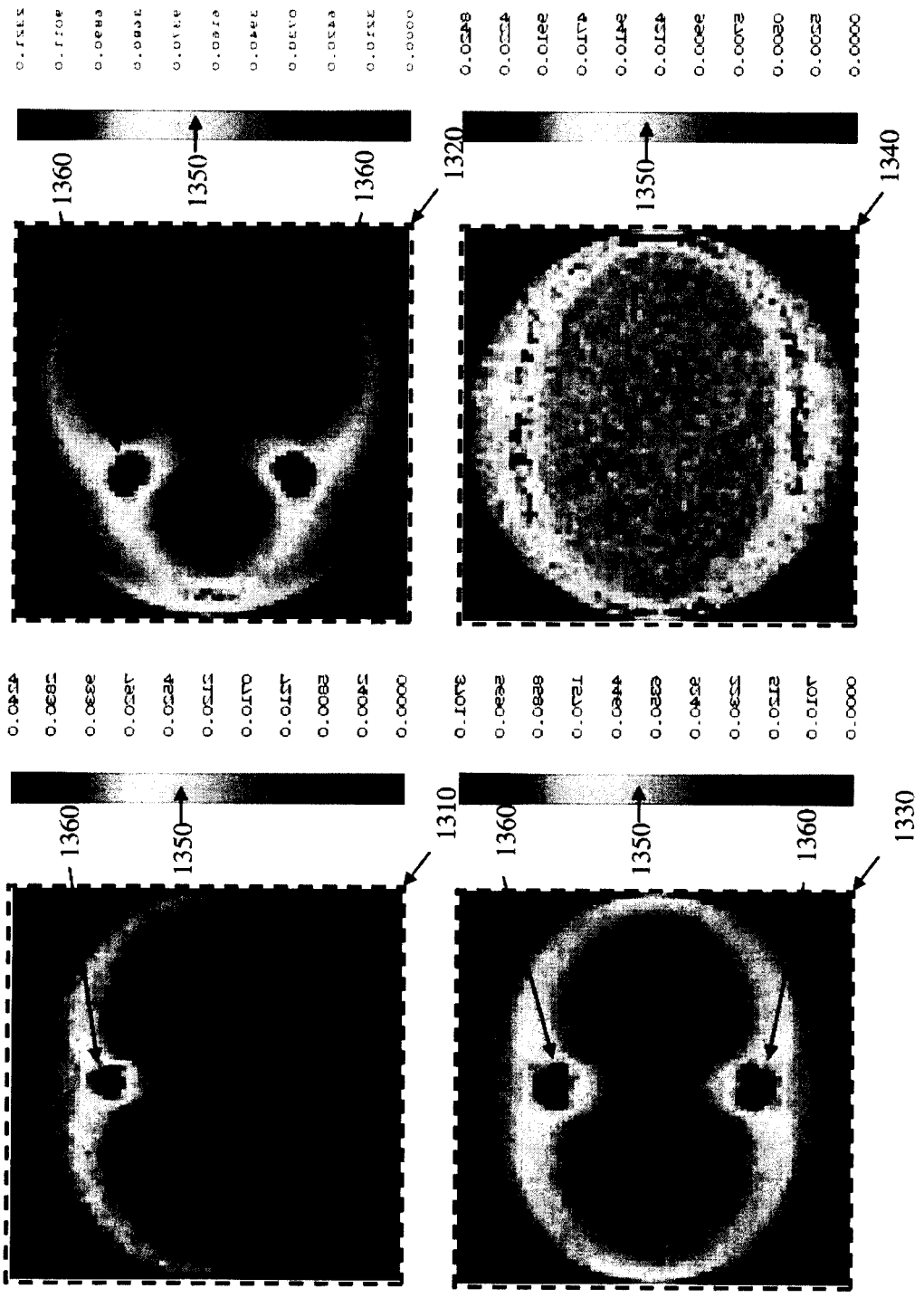

1360
1350
1360
1320
1350
1340
1360
1350
1360
1310
1360
1350
1360
1330

Figure 13

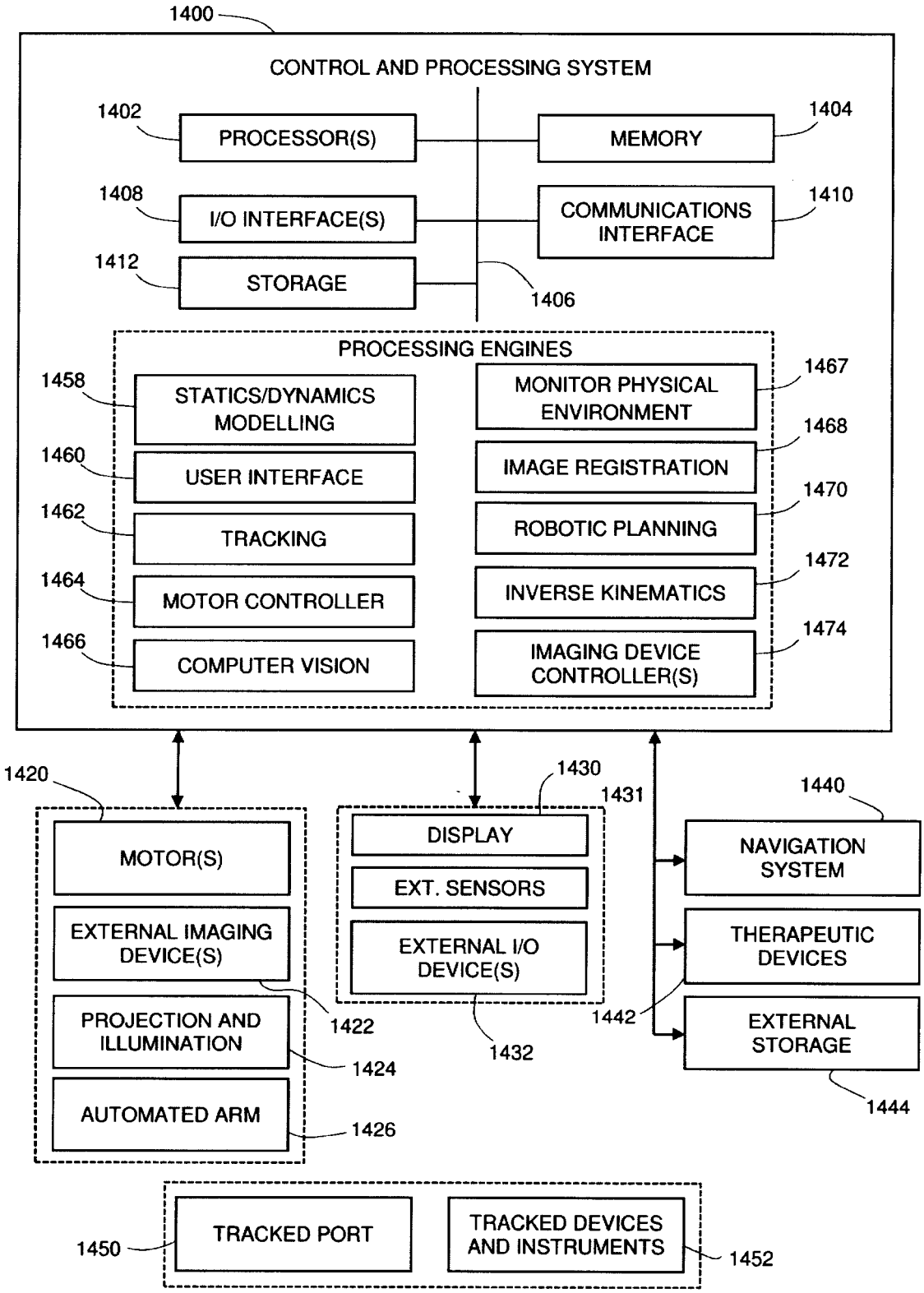

1400
CONTROL AND PROCESSING SYSTEM
1402
PROCESSOR(S)
1404
MEMORY
1408
I/O INTERFACE(S)
1410
COMMUNICATIONS INTERFACE
1412
STORAGE
1406
PROCESSING ENGINES
1458
STATICS/DYNAMICS MODELLING
1467
MONITOR PHYSICAL ENVIRONMENT
1460
USER INTERFACE
1468
IMAGE REGISTRATION
1462
TRACKING
1470
ROBOTIC PLANNING
1464
MOTOR CONTROLLER
1472
INVERSE KINEMATICS
1466
COMPUTER VISION
1474
IMAGING DEVICE CONTROLLER(S)
1420
MOTOR(S)
EXTERNAL IMAGING DEVICE(S)
PROJECTION AND ILLUMINATION
AUTOMATED ARM
1422
1424
1426
1430
1431
DISPLAY
EXT. SENSORS
EXTERNAL I/O DEVICE(S)
1432
1440
NAVIGATION SYSTEM
THERAPEUTIC DEVICES
EXTERNAL STORAGE
1442
1444
1450
TRACKED PORT
TRACKED DEVICES AND INSTRUMENTS
1452

Figure 14A

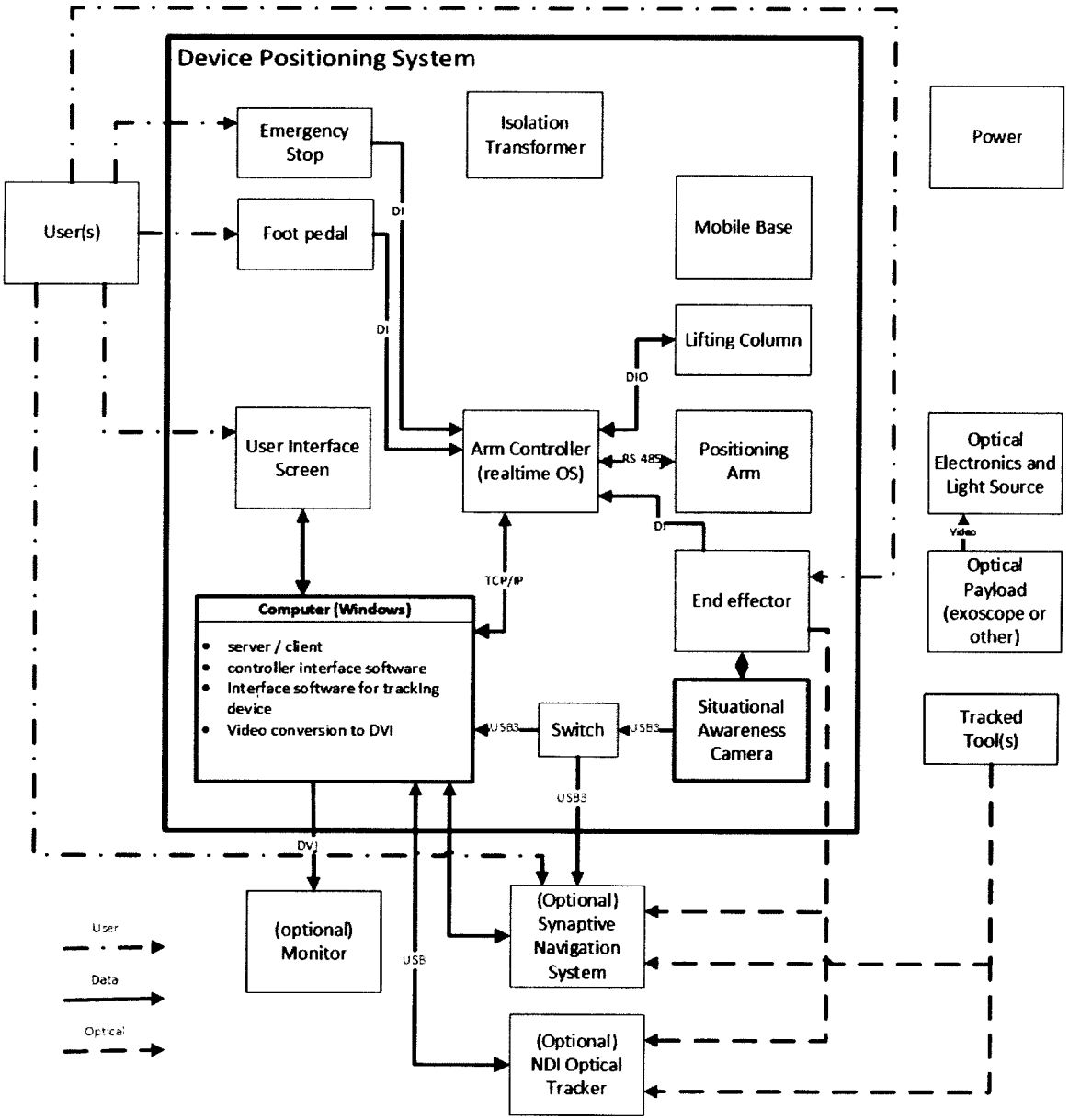

Device Positioning System
Emergency Stop
Isolation Transformer
Power
User(s)
Foot pedal
DI
Mobile Base
DI
Lifting Column
DIO
User Interface Screen
Arm Controller (realtime OS)
RS 485
Positioning Arm
Optical Electronics and Light Source
Video
DI
TCP/IP
End effector
Optical Payload (exoscope or other)
Computer (Windows)
server / client
controller interface software
Interface software for tracking device
Video conversion to DVI
USB3
Switch
USB3
Situational Awareness Camera
Tracked Tool(s)
USB3
DVI
(optional) Monitor
USB
(Optional) Synaptive Navigation System
(Optional) NDI Optical Tracker
User
Data
Optical

Figure 14B

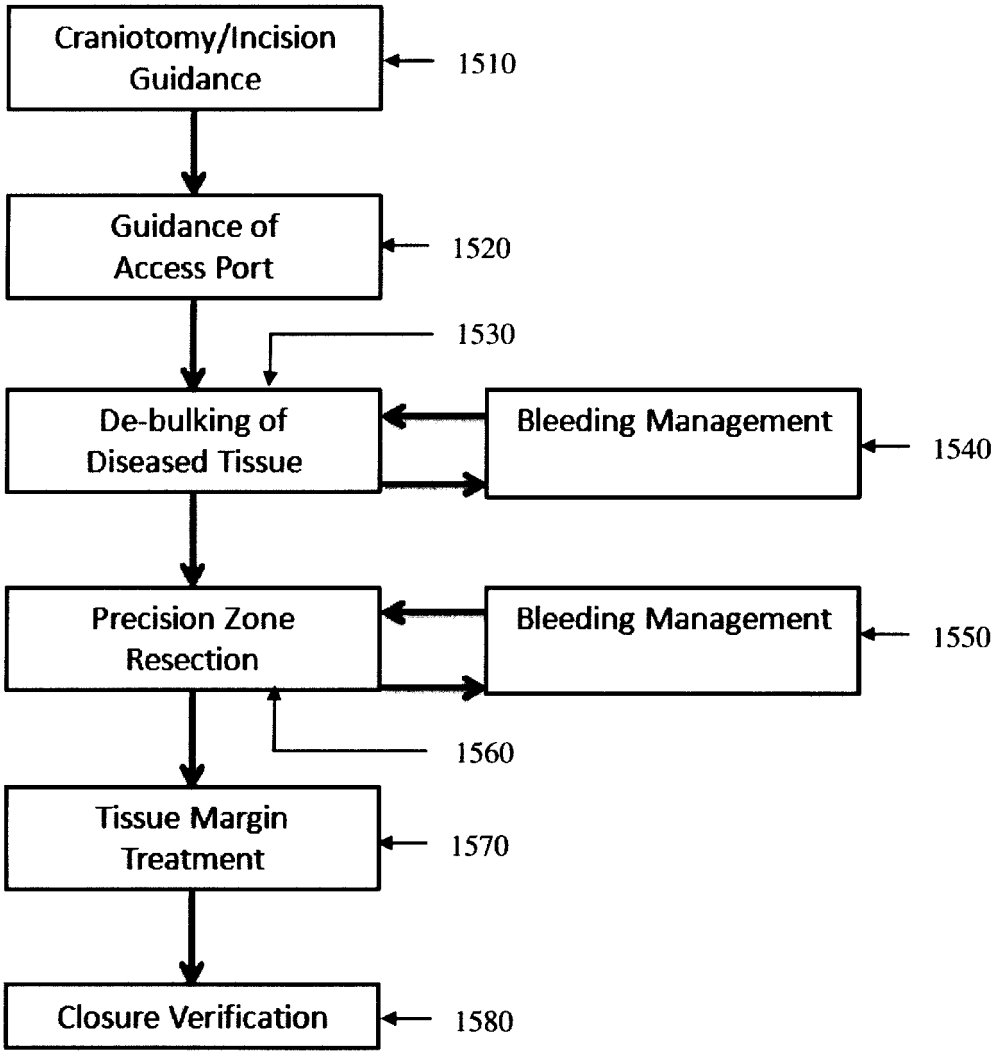

Craniotomy/Incision Guidance
1510
Guidance of Access Port
1520
1530
De-bulking of Diseased Tissue
Bleeding Management
1540
Precision Zone Resection
Bleeding Management
1550
1560
Tissue Margin Treatment
1570
Closure Verification
1580

Figure 15

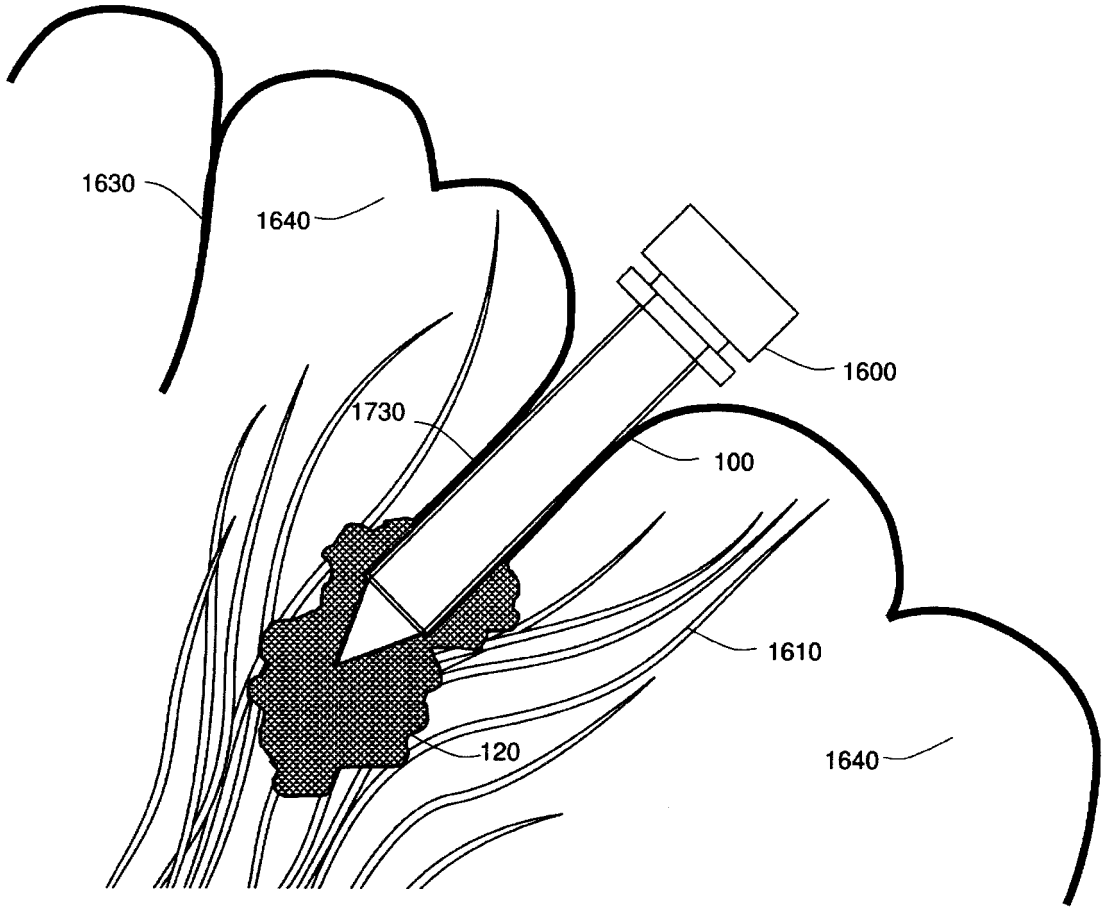


Figure 16A

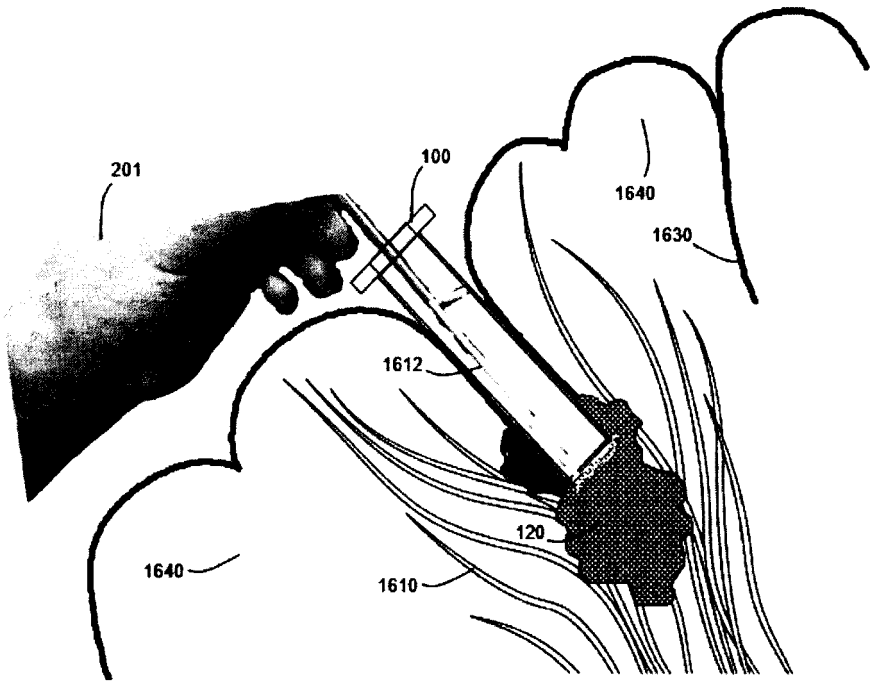


Figure 16B

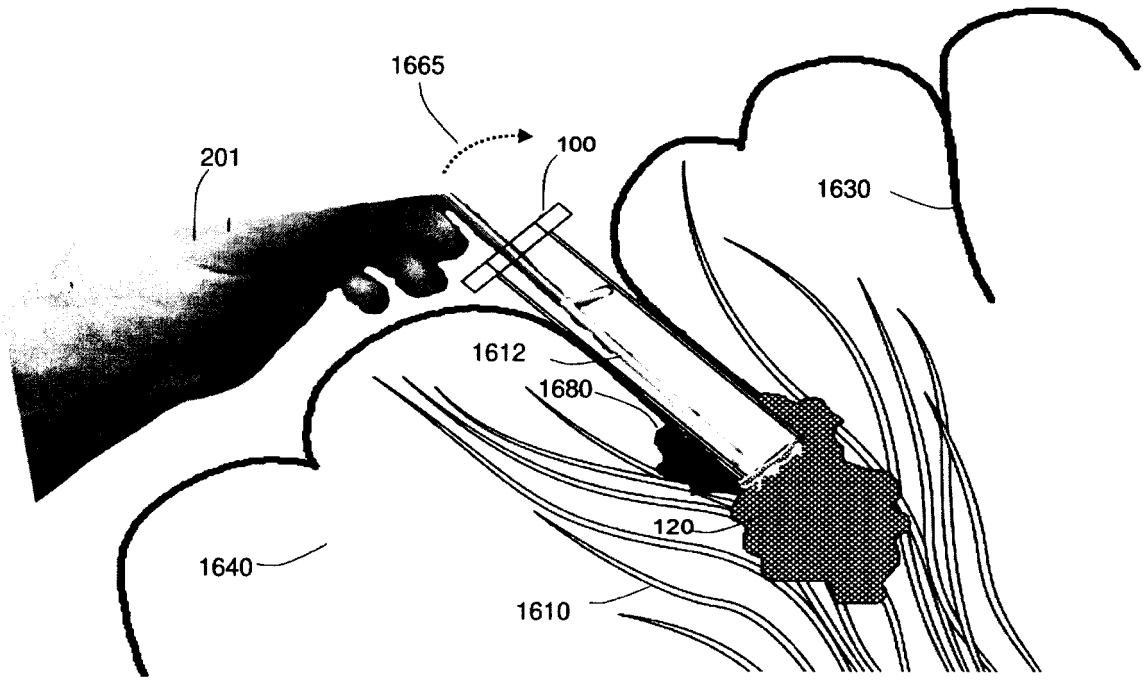


Figure 16C

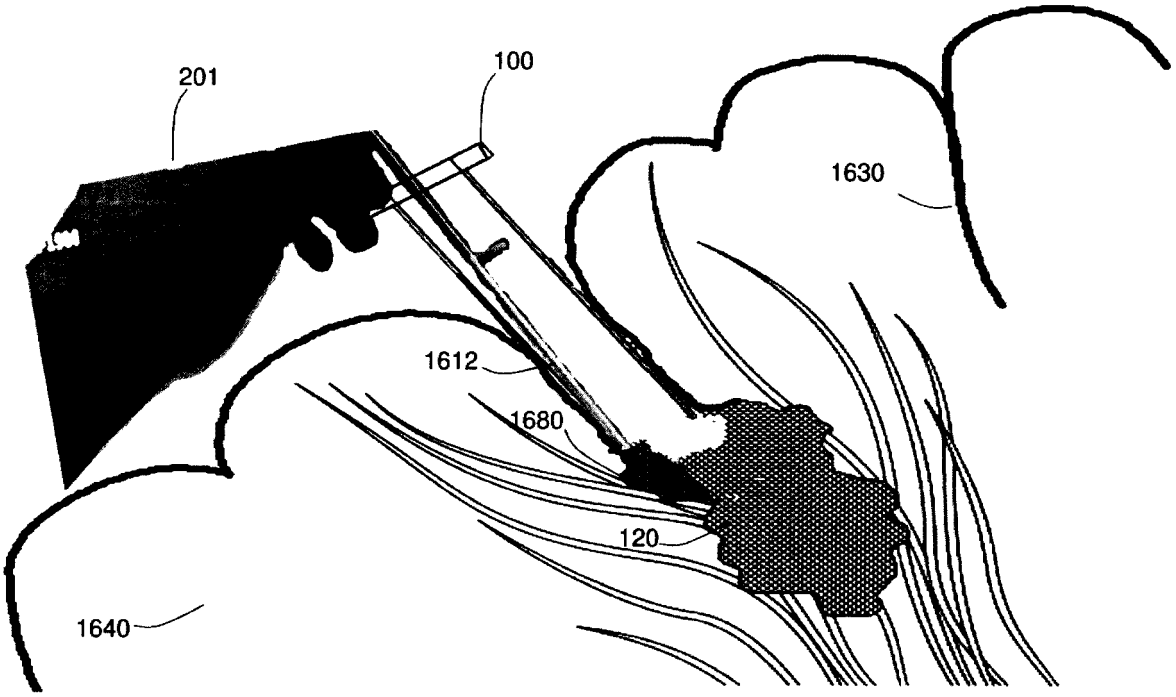


Figure 16D