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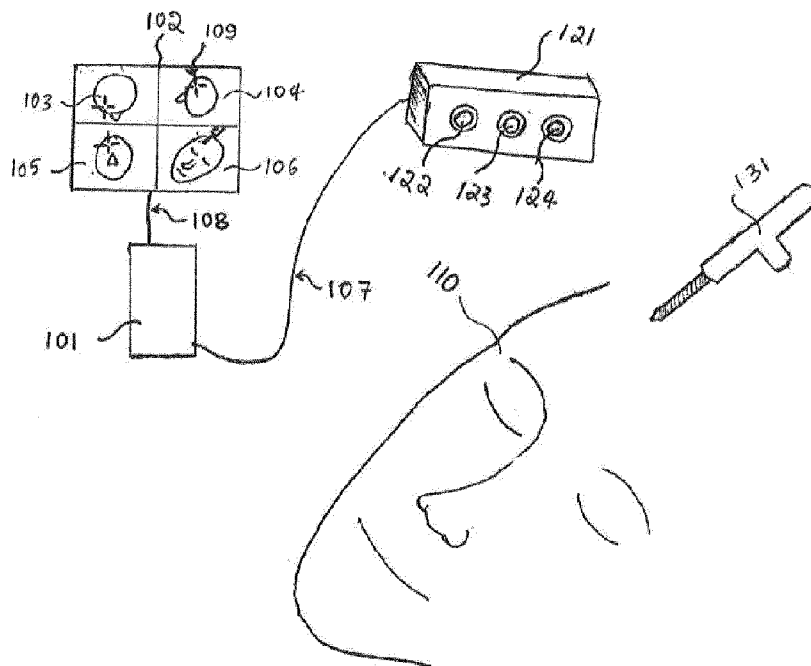


Fig. 2:

(57) Abstract: Method for tracking an object with respect to a body comprising the steps of: providing a three-dimensional model of said body; providing a three-dimensional model of said object; and tracking the position of said object in said three-dimensional model of said body on the basis of a sensor measuring repeatedly a three-dimensional surface of said body and said object.

TRACKING APPARATUS FOR TRACKING AN OBJECT WITH RESPECT TO A BODY

Field of the invention

[0001] The present invention concerns a method and a system for tracking an object with respect to a body for image guided surgery.

Description of related art

5 **[0002]** Currently, there are mainly Infra-Red (IR) camera based (US581105) and electromagnetic tracking based (US8239001) surgical navigation systems. They require specially designed markers to be rigidly fixed on the patient anatomy. The registration and calibrations processes for those systems consume precious intraoperative time. This results in a
10 loss of valuable operating room (OR) and surgeons time. In addition, the surgical navigation systems occupy considerable space in the OR and hence the hospitals need to reserve valuable OR space for these systems.

Brief summary of the invention

15 **[0003]** According to the invention, these aims are achieved by means of the tracking apparatus and method according to the independent claims.

[0004] The dependent claims refer to further embodiments of the inventions.

20 **[0005]** In one embodiment the step of tracking comprises the steps of: measuring by said sensor the three-dimensional surface; detecting at least one three-dimensional subsurface of the body and at least one three-dimensional subsurface of the object within the three-dimensional surface measured; and computing the relative position of the object in said three-dimensional model of said body on the basis of the at least one three-dimensional subsurface of the body and at least one three-dimensional
25 subsurface of the object. Preferably, in this embodiment the step of

computing the relative position comprises determining the position of the three-dimensional model of said body in the coordinate system of the sensor on the basis of the at least one three-dimensional subsurface of the body and determining the position of the three-dimensional model of the
5 object in the coordinate system of the sensor on the basis of the at least one three-dimensional subsurface of the object.

[0006] In one embodiment, the sensor is fixed on the object.

[0007] In one embodiment, the sensor is fixed on the body.

[0008] In one embodiment, the sensor is fixed in the tracking zone, i.e.
10 in a third coordinate system being independent of the movement of the body or the object.

[0009] In one embodiment, the step of tracking comprises the steps of: measuring by said sensor the three-dimensional surface; detecting at least one three-dimensional subsurface of the body; and computing the relative
15 position of the object in said three-dimensional model of said body on the basis of the at least one three-dimensional subsurface of the body, wherein the sensor is fixed on the object. In this embodiment preferably, the step of computing the relative position comprises determining the position of the three-dimensional model of said body in the coordinate system of the
20 sensor on the basis of the at least one three-dimensional subsurface of the body.

[0010] In one embodiment, the step of tracking comprises the steps of: measuring by said sensor the three-dimensional surface; detecting at least one three-dimensional subsurface of the object; and computing the relative
25 position of the object in said three-dimensional model of said body on the basis of the at least one three-dimensional subsurface of the body, wherein the sensor is fixed on the object. In this embodiment preferably, the step of computing the relative position comprises determining the position of the three-dimensional model of said object in the coordinate system of the

sensor on the basis of the at least one three-dimensional subsurface of the object.

[0011] In one embodiment, the at least one three-dimensional subsurface of the body is a true sub-set of the three-dimensional surface of the body measured and/or the at least one three-dimensional subsurface of the object is a true sub-set of the three-dimensional surface of the object measured.

[0012] In one embodiment, at least one of the at least one three-dimensional subsurface of the body and/or object is a topographical marker fixed to the body and/or object.

[0013] In one embodiment, the at least one three-dimensional subsurface of the body and/or object is additionally detected by an optical camera included in a common housing together with said sensor.

[0014] In one embodiment, at least one colour or pattern marker is fixed in the region of each of the at least one three-dimensional subsurface of the body and/or object and the optical camera detects the at least one colour or pattern marker.

[0015] In one embodiment, the method comprising the further steps of defining at least one point in the three-dimensional model of said body and/or in the three-dimensional model of said object and detecting the at least one three-dimensional subsurface of the body and/or of the object corresponding to said defined at least one point within the three-dimensional surface measured.

[0016] In one embodiment, the method comprises the further steps of defining at least one point in the three-dimensional model of said body and/or in the three-dimensional model of said object for tracking the position of the body and/or object.

[0017] In one embodiment, each point is defined by detecting a point in the three-dimensional surface measured by said sensor.

[0018] In one embodiment, each point is defined by detecting a point of an indicator means in the three-dimensional surface measured by said
5 sensor at the time of detecting an indicating event. Preferably, the indicator means is one finger of a hand and an indicating event is a predetermined movement or position of another finger of the hand.

[0019] In one embodiment, the point is detected automatically by detecting a known topographic marker fixed on the object and/or on the
10 body.

[0020] In one embodiment, the point is received from a database related to said three-dimensional model of said object.

[0021] In one embodiment, each point is defined by detecting an optical colour and/or optical pattern detected by a camera included in a common
15 housing together with said sensor.

[0022] In one embodiment, the step of providing the three-dimensional model of the object comprises the step of comparing registered models of objects with the three-dimensional surface measured by said sensor.

[0023] In one embodiment, the step of providing the three-dimensional
20 model of the object comprises the step of detecting an identifier on the object and loading the model of said object on the basis of the identifier detected.

[0024] In one embodiment, the identifier comprises a topographical marker which is detected by said sensor.

[0025] In one embodiment, the identifier comprises an optical colour
25 and/or optical pattern detected by an optical camera included in a common housing together with said sensor.

[0026] In one embodiment, the method comprising the step of displaying the three-dimensional model of the body on the basis of the position of the object.

[0027] In one embodiment, the step of retrieving a distinct point of said
5 three-dimensional model of said object, wherein the three-dimensional model of the body is displayed on the basis of said point.

[0028] In one embodiment, an axial, a sagittal and a coronal view of the three-dimensional model of the body going through said distinct point is displayed.

10 **[0029]** In one embodiment, a three-dimensionally rendered scene of the body and the object are displayed.

[0030] In one embodiment, a housing of the sensor comprises a marker for a second tracking system and the second tracking system tracks the position of the marker on the sensor.

15 **[0031]** In one embodiment, the sensor comprises a first sensor and a second sensor, wherein the first sensor is mounted on one of the body, the object and the tracking space and the second sensor is mounted on another of the body, the object and the tracking space.

20 **[0032]** In one embodiment, said body is a human body or part of a human body.

[0033] In one embodiment, said body is an animal body or part of an animal body.

[0034] In one embodiment, said object is a surgical tool.

25 **[0035]** In one embodiment, the object is at least one of the surgical table, an automatic supporting or holding device and a medical robot.

[0036] In one embodiment, the object is a visualizing device, in particular an endoscope, an ultrasound probe, a computer tomography scanner, an x-ray machine, a positron emitting tomography scanner, a fluoroscope, a magnetic resonance Imager or an operation theatre
5 microscope.

[0037] In one embodiment, the sensor is fixed on the visualizing device which comprises an imaging-sensor.

[0038] In one embodiment, the position of at least one point of the three-dimensional model of the body is determined in the image created
10 by said image sensor on the basis of the three-dimensional surface measured by said sensor.

[0039] In one embodiment, the step of providing a three-dimensional model of said body comprises the step of measuring data of said body and determining the three-dimensional model of said body on the basis of the
15 measured data.

[0040] In one embodiment, the data are measured by at least one of computer tomography, magneto-resonance-imaging and ultrasound.

[0041] In one embodiment, the data are measured before tracking the relative position of the object in the three-dimensional model.

20 [0042] In one embodiment, the data are measured during tracking the relative position of the object in the three-dimensional model.

[0043] In one embodiment, the step of providing a three-dimensional model of said body comprises the step of receiving the three-dimensional model from a memory or from a network.

25 Brief Description of the Drawings

[0044] The invention will be better understood with the aid of the description of an embodiment given by way of example and illustrated by the figures, in which:

Fig. 1 shows an embodiment of a tracking method;

5 Fig. 2 shows an embodiment of a tracking apparatus without markers;

Fig. 3 shows an embodiment of a tracking method without markers;

10 Fig. 4 shows an embodiment of a method for registering the 3D surface mesh of the body to the 3D model of the body;

Fig. 5 shows an embodiment of a tracking apparatus and a tracking method using the fixing means of the body;

Fig. 6 shows an embodiment of a tracking apparatus and a tracking method for an open knee surgery;

15 Fig. 7 shows an embodiment of a tracking apparatus with optical markers;

Fig. 8 shows an embodiment of a tracking method with optical markers;

20 Fig. 9 shows an embodiment of a tracking method with optical markers;

Fig. 10 shows exemplary optical markers;

Fig. 11 shows a method for identifying tool by codes;

Fig. 12 shows a tool with a code;

Fig. 13 shows a tool with a code;

Fig. 14 shows a head with a code;

Fig. 15 shows a knee with a code;

5 Fig. 16 shows an embodiment of a tracking apparatus using an topographically encoded marker mounted on the body;

Fig. 17-20 show a method for selecting points and lines in the 3D surface-mesh by a thumb movement/gesture;

Fig. 21 shows an embodiment of a tracking method using topographically encoded markers;

10 Fig. 22 and 23 show two embodiments of topographically encoded markers;

Fig. 24 shows an embodiment of the coordinate transformations of the tracking apparatus and of the tracking method using a topographical marker fixed on the body;

15 Fig. 25 shows an embodiment of the tracking apparatus with the 3D surface-mesh generator being mounted on the body;

Fig. 26 shows an embodiment of the tracking apparatus with the 3D surface-mesh generator being mounted on the body;

20 Fig. 27 an embodiment of the tracking apparatus with the 3D surface-mesh generator being mounted on the object;

Fig. 28 shows zones on the head being suitable for tracking;

Fig. 29 shows an embodiment of a tracking method with the 3D surface-mesh generator mounted on the tool;

Fig. 30 shows an embodiment of the coordinate transformations of the tracking apparatus and of the tracking method with the 3D surface-mesh generator mounted on the tool;

5 Fig. 31 shows an embodiment of a tracking apparatus using two 3D surface generators;

Fig. 32 shows an embodiment of a tracking apparatus with the 3D surface-mesh generator mounted on the tool;

Fig. 33 shows an embodiment of a tracking apparatus combining 3D surface-mesh tracking with IR tracking;

10 Fig. 34 shows an embodiment of a tracking apparatus combining 3D surface-mesh tracking with electromagnetic tracking; and

Fig. 35 shows an embodiment of the controller.

Detailed Description of possible embodiments of the Invention

[0045] The proposed navigation system uses naturally occurring
15 topographically distinct region on the patient, when available, to establish the patient coordinates (see e.g. Fig. 2). Alternatively a small topographically encoded marker can also be fixed to the patient anatomy to establish the coordinate system (Fig. 16). However, there is no need to fix the topographically encoded markers rigidly to the anatomy as the
20 transformation between the marker and anatomy can be easily updated after detecting any relative motion. These topographically encoded markers and encoded surgical pointers can be easily printed using off-the-shelf 3D printers. Since the system is compact it can also be mounted directly on the patient or a surgical tool and hence saves space and reduces
25 the problem of maintaining line-of-sight as with the other systems. Many of the preparation steps could be automated and hence saving valuable OR and surgeon's time.

[0046] Fig. 1 shows steps of an embodiment of the tracking method. In a first step, the 3D Surface-mesh of the surgical field is generated in real-time. In a second step, the surface-mesh of the relevant regions segmented out. The relevant regions are the region of the body and the region of the object, here a tool. In a third step, the segmented surfaces are registered to their respective 3D models generated preoperatively, i.e. to the 3D rendered model of the body from preoperative images (e.g., CT, MRI, Ultrasound) and to the CAD model of the tool used. In a fourth step, a transformation between tooltip and the preoperative image volume is established on the basis of the registration of the surfaces to their respective models. In a fifth step, the relative position of the tool-tip to the preoperative data, registered to the patient, is updated in real-time by tracking topographically encoded (natural or marker) regions. In a sixth step, the tool-tip is overlaid on the preoperative images for navigation.

15 [0047] Fig. 2 shows a first embodiment of the tracking apparatus for tracking an object with respect to a body which allows marker-less navigation. The surfaces are identified, registered and tracked without fixing any markers on the patient or tools.

[0048] The body is in one embodiment a human body. The term body shall not only include the complete body, but also individual sub-parts of the body, like the head, the nose, the knee, the shoulder, etc.. The object moves relative to the body and the goal of the invention is to track the three-dimensional position of the object relative to the body over time. This gives information about the orientation and movement of the object relative to the body.

[0049] The object is in one embodiment a surgical tool. In Fig. 2, the object is pointer 131. Alternatively, the object could also be a part of the body or of a further body, e.g. the hand of the surgeon. However, the object can be anything else moving relative to the body. The term object shall include not only the complete object, but also subparts of the object.

[0050] The tracking apparatus comprises a 3D surface-mesh generator 122, 123, a video camera 124, a controller 101, an output means 102 and input means (not shown).

5 [0051] The 3D surface-mesh generator 122, 123 is configured to measure the three-dimensional surface of any object or body within the field of view of the 3D surface-mesh generator 122, 123 in real-time. The resulting 3D surface-mesh measured is sent to the controller 101 over the connection 107. In one embodiment, the three-dimensional surface is measured by time-of-flight measurements.

10 [0052] The video camera 124 measures image data over time and sends the image data to the controller 101 over the connection 107. In this embodiment, the field of view of the video camera 124 is the same as the field of view of the 3D surface-mesh generator 122, 123 such that it is possible to add the actual colour information to the measured 3D surface-mesh. In another embodiment, the field of view of the video camera 124 and the 3D surface-mesh generator 122, 123 are different and only those image information relating to the 3D surface mesh measured can be used later. The video camera 124 is optional and not essential for the invention, but has the advantage to add the actual colour information of the pixels of the measured 3D surface mesh. In the present embodiment, the video camera 124 and the 3D surface-mesh generator 122, 123 are arranged in the same housing 121 with a fixed relationship between their optical axes. In this embodiment, the optical axes of the video camera 124 and the 3D surface-mesh generator 122, 123 are parallel to each other in order to have the same field of view. The video camera 124 is not essential in the present embodiment for the tracking, since no optical markers are detected. The video camera 124 could however be used for displaying the colours of the 3D surface mesh.

20 [0053] The controller 101 controls the tracking apparatus. In this embodiment, the controller 101 is a personal computer connected via a cable 107 with the housing 121, i.e. with the video camera 124 and the 3D surface-mesh generator 122, 123. However, the controller 101 could also be

a chip, a special apparatus for controlling only this tracking apparatus, a tablet, etc.. In this embodiment, the controller 101 is arranged in a separate housing than the housing 121. However, the controller 101 could also be arranged in the housing 121.

5 [0054] Fig. 35 shows schematically the functional design of controller 101. The controller 101 comprises 3D body data input means 201, 3D object data input means 202, 3D surface-mesh input means 203, video data input means 204, calibrating means 205, body surface segment selector 206, object surface segment selector 207, surface segment tracker 208, object
10 tracker 209 and an output interface 210.

[0055] The 3D body data input means 201 is configured to receive 3D body data and to create a 3D body model based on those 3D body data. In one embodiment, the 3D body model is a voxel model. In one embodiment, the 3D body data are 3D imaging data from any 3D imaging device like e.g.
15 magneto resonance tomography device or computer tomography device. In the latter embodiment, the 3D body data input means 201 is configured to create the 3D model on the basis of those image data. In another embodiment, the 3D body data input means 201 receives directly the data of the 3D model of the body.

20 [0056] The 3D object data input means 201 is configured to receive 3D object data and to create a 3D body model based on those 3D body data. In one embodiment, the 3D object model is a voxel model. In another embodiment, the 3D object model is a CAD model. In one embodiment, the 3D object data are 3D measurement data. In another embodiment, the 3D
25 object data input means 201 receives directly the data of the 3D model of the object. The 3D model is preferably a voxel model.

[0057] The 3D surface-mesh input means 203 is configured to receive the 3D surface-mesh data from the 3D surface-mesh generator 122, 123 in real-time. The video data input means 204 is configured to receive the video
30 data of the video camera 124 in real-time.

[0058] The calibrating means 205 is configured to calibrate the video camera 124 to obtain the intrinsic parameters of its image sensor. These parameters are necessary to obtain the accurate measurements of real world objects from its images. By registering 122-123 and 124 to each other
5 it is possible to establish a relation between the voxels of surface-mesh generated by 3D surface-mesh generator 122,123 to the pixels generated by the video camera 124.

[0059] The body surface segment selector 206 is configured to select a plurality of points on the surface of the body. In one embodiment, four or
10 more points are selected for stable tracking of the body orientation. The points should be chosen such that their surface topography around this point is characteristic and good to detect in the 3D surface-mesh measured. E.g. a nose, an ear, a mouth, etc. could be chosen. The body surface segment selector 206 is further configured to register the selected points to
15 the 3D model of the body.

[0060] The object surface segment selector 207 is configured to select a plurality of points on the surface of the object. In one embodiment, four or more points are selected for stable tracking of the object orientation. The points should be chosen such that their surface topography around this
20 point is distinct and good to detect in the 3D surface-mesh measured. E.g. the tool tip and special topographical markers formed by the tool can be used as object points. . The object surface segment selector 207 is further configured to register the selected points to the 3D model of the object.

[0061] The surface segment tracker 208 is configured to track the
25 plurality of points of the body and the plurality of points of the object in the surface-mesh received from the 3D surface-mesh generator 122, 123. Since the tracking is reduced to the two sets of points or to the two sets of segment regions around those points, the tracking can be performed efficiently in real-time.

[0062] The object tracker 209 is configured to calculate the 3D position of the object relative to the body based on the position of the plurality of points of the body relative to the plurality of points of the object.

[0063] The output interface 210 is configured to create a display signal showing the relative position of the object to the body in the 3D model of the body. This could be achieved by the display signal showing a 3D image with the 3D position of the object relative to the body. In one embodiment, the surface of the body can be textured with the colour information of the video camera, where the surface-mesh is in the field of view of the video camera (and not in the shadow of an 3D obstacle). Alternatively or additionally to the 3D image, this could be achieved by showing intersections of the 3D model determined by one point of the object. In one embodiment, this point determining the intersections is the tool tip. In one embodiment, the intersections are three orthogonal intersections of the 3D model through the one point determined by the object, preferably the axial, sagittal and coronal intersection. In another embodiment, the intersections can be determined by one point and one orientation of the object.

[0064] The tracking apparatus comprises further a display means 102 for displaying the display signal. In Fig. 2, the display signal shows the mentioned three intersections and the 3D image with the body and the object.

[0065] In Fig. 2, the object is a pointer 131 designed with an integrated and unique topographic feature for tracking it easily by the surface-mesh generating camera. The tip of the pointer 131 is displayed as a marker 109 on the monitor 102 over the axial 103, sagittal 104 coronal 105 views of the preoperative image data. It is also displayed on the 3D rendered scene 106 of the patient preoperative data.

[0066] Fig. 3 describes the steps involved in the functioning of the embodiment in Fig. 2. Steps 613, 617 and 620 can be replaced by an automatic process to automate the whole navigation system. A template

based point cloud identification algorithm can be included in the process for automation.

[0067] In step 618, Preoperative image data e.g. computer tomography, magneto resonance, ultrasound, etc. can be obtained or measured and a
5 3D model of the body is created. In step 619, a 3D model of the surgical surface is calculated based on the preoperative image data. In step 620, four points are selected on the 3D model of the body, where there is distinct topographic feature in order to create a coordinate system of the body. In step 621, patches of the surfaces around these points are extracted
10 containing the distinct topographic features for detecting those points in future frames of the 3D surface-mesh. Alternatively, those points could be chosen on the 3D surface-mesh.

[0068] In step 611, the 3D model of the pointer is obtained by its CAD model. In step 612, the tooltip position is registered in the model by
15 manual selection. Alternatively this step can also be performed automatically, when the tool tip is already registered in the CAD model of the object. In step 613 four points on the surface of the 3D model of the object are selected, where there is a distinct topographic feature. In step 614, patches of the surfaces around these points are extracted containing
20 the distinct topographic features.

[0069] The steps 611 to 615 and 618 to 621 are performed before the tracking process. The steps 616 to 617 and 622 to 624 are performed in real-time.

[0070] In step 615, the 3D surface-mesh generator 122, 123 is placed so
25 that the surgical site is in its field of view (FOV). In step 616, surfaces in the surgical field are generated by the 3D surface-mesh generator 122, 123 and sent to the controller 101. In step 617, the specific points selected in steps 620 and 613 are approximately selected for initiating the tracking process. This could be performed manually or automatically.

[0071] In step 622, Patches of the surfaces determined in steps 620 and 613 are registered to their corresponding surfaces on the 3D surface-mesh.

[0072] In step 623, surfaces in the surgical field are generated by the 3D surface-mesh generator 122, 123 and sent to the controller 101 and the patches of the surfaces are tracked in the 3D surface-mesh and the registration of those patches is updated in the 3D model of the body. Step 623 is performed continuously and in real-time.

[0073] In step 624, the tooltip is translated to the preoperative image volume (3D model of the body) on the basis of the coordinates of the four points of the body relative to the four coordinates of the object so that the position of the tooltip in the 3D model of the body is achieved.

[0074] Fig 4 shows how the 3D surface-mesh can be registered relative to the 3D model of the body, i.e. how the coordinates of the 3D surface-mesh of the body in the coordinate system of the 3D surface-mesh generator 122, 123 can be transformed to the coordinates of the 3D model of the body. In step 1.31, a surface-mesh is generated from the surgical field. In step 1.32, the relevant mesh of the body is segmented out. In step 1.33, a coordinate system of the body is established by choosing one topographically distinct region. Four points on this topographical distinct region define the coordinate system of the system. Such regions could be the nose, a tooth, etc. . In step 1.34, the 3D model from preoperative CT/MRI is registered to the coordinates of the established coordinate system. Preferably, this is performed first by identifying the four points of the coordinate system of the 3D surface-mesh in the surface of the 3D model of the body. This yields an approximative position of the 3D surface-mesh on the 3D model. This can be achieved by a paired point based registration. In a second step, the exact position of the 3D surface-mesh of the body in the 3D model of the body is determined on the basis of the 3D surface-mesh and the surface of the body of the 3D model of the body. This can be performed by an iterative closest point algorithm of the point cloud of the 3D surface-mesh of the body and of the point cloud of the surface of the 3D model of the body. In step 1.35, the topographically distinct regions

are continuously tracked and coordinates are updated by repeating step 1.34 for subsequent frames of the 3D surface-mesh generator. In step 1.36, the updated coordinates are used for the navigational support. The process for detecting the exact position of the 3D surface-mesh of the object in the CAD model of the object corresponds to the process of Fig. 4.

[0075] Fig. 5 shows a tracking apparatus using a topographical marker 809 being in a fixed position with the body 801 for tracking the relative position of the tool 802. In the shown embodiment, the body is the head of a patient. The head 801 is fixed for the operation by fixing means 809, which fixes the head e.g. to the operation table 808. Since the head 801 is in a fixed relationship with the fixing means 809, the topographical features of the fixing means could be used as well to determine the position and orientation of the body in the 3D surface-mesh instead of the topographical features of the body.

[0076] In step 812, meshes of the relevant surfaces from the surgical field are generated along with their relative position. In step 814, preoperative image data are measured or received and in step 815, a 3D model is generated on the basis of those preoperative image data. In step 816, the mesh of the body, here the head, generated by the 3D surface-mesh generator 122, 123 are registered with the 3D model of the body generated in step 815. This can be performed as explained with the previous embodiment by selecting at least three non-coplanar points in the 3D model and on the surface for an approximative position of the 3D surface-mesh in the 3D model of the body. Then, the exact position is detected by an iterative algorithm using the approximative position as a starting point. In step 817, the 3D surface-mesh of the fixing means or a distinct part of it (here indicated with 2) is registered in the 3D model of the body on the basis of the position of the 3D surface-mesh of the body relative to the 3D surface-mesh of the fixing means. Preferably, a CAD model of the fixing means is provided. The 3D surface-mesh of the fixing means is registered with the CAD model of the fixing means. This can be done as with the registration of the body-surface to the 3D model of the body. Like that the transformation from the CAD model to the 3D surface-

mesh generator 122,123 coordinate system is known. With the transformations of the body and fixing means into the 3D surface-mesh coordinates, the fixed position of the body compared to the fixing means is known. In step 818, the 3D surface-mesh of the tool 802 is registered to the

5 CAD model. In step 819, the tooltip of the tool 802 is registered with the preoperative image volume (3D model of the body). In step 810, the 3D surface meshes of the fixing means and of the tool are tracked in real-time. In step 810, the position of the 3D surface of the fixing means in its 3D model (which has a known relation to the 3D model of the body) and the

10 position of the object surface in the CAD model of the object are performed regularly. As described previously, for determining the position, first the approximative position is determined on a limited number of points and an exact position is determined on the basis of a high number of points by using an iterative algorithm. Based on this tracking result, in step

15 812, images of the preoperative image data are shown based on the tip of the tool 802. Due to the fixed relation between the body and the fixing means, the tracking can be reduced to the topographically distinct fixing means. The steps 814 to 819 are performed only for initializing the tracking method. However, it can be detected, if the body position changes in

20 relation to the fixing means. In the case, such a position change is detected, the steps 816 and 817 can be updated to update the new position of the body to the fixing means.

[0077] The steps 816, 817 and 818 could be either automated or approximate manual selection followed by pair-point based registration

25 could be done. Once manually initialised these steps can be automated in next cycle by continuously tracking the surfaces using a priori positional information of these meshes in previous cycles.

[0078] Fig. 6 shows a possibility where marker-less tracking apparatus and tracking procedure is used for knee surgeries to navigate bone cuts.

30 Fig. 6 shows the articular surface of femur 433 and the articular surface of tibia 434 which are exposed during an open knee surgery. The surface-mesh generator 121 (here without a video camera 124) captures the 3D surface-mesh of the articular surface of the femur 433 and of a surgical saw

955 whose edge has to be navigated for the purpose of cutting the bone. The steps involved for providing navigation are enlisted in Fig. 6. In steps 1.51 and 1.52, the femur articular and the tool 3D surface-mesh is captured by the surface-mesh generator 121 and sent to the controller. The 3D
5 surface-mesh of the femur articular is registered to the 3D model in step 1.54 and the 3D surface-mesh of the tool is registered to the CAD model of the tool in step 1.53. In step 1.55, the transformation between the tool edge and the preoperative image volume is calculated based on the relative 3D position between the tool surface-mesh and femur surface-
10 mesh. In step 1.56, the edge of the tool is shown in the preoperative images for navigation.

[0079] Fig. 7 shows a tracking apparatus according to a second embodiment which is coupled with 2D markers. As an example a surgery around the head (Ear, Nose and throat surgeries, maxillo facial surgeries, dental surgeries and neurosurgeries) are shown. The device 121 comprising
15 the 3D surface-mesh generator 122, 123 and the video camera 124 is used to generate the relevant surfaces from the surgical field. Preoperatively the video camera (124) and sensor of 3D surface-mesh generator (122,123) are calibrated and registered. Prior to surgery the patient is fixed with coloured
20 markers 111,112,113,114. These markers can be easily segmented in video images by colour based segmentation. The markers are designed so that the centre of these markers can be easily calculated in the segmented images (e.g., estimating their centroid in binary images). The individual markers can be identified based on their specific size and shape in the
25 corresponding surface- mesh regions generated by 122-123. Identifying the markers individually will help in extracting a surface-mesh between these markers in order to automatically establish a co-ordinate system on the patient. The coordinate system could be determined only on the basis of the four colour markers or on the basis of four points on the 3D surface-
30 mesh which are determined based on the four colour markers. In a second step the exact position of the 3D surface-mesh on the 3D model of the body is calculated based on the surface-mesh of the body and the surface of the 3D model. Due to the approximate position of the 3D surface-mesh, this second step can be performed in real-time. A pointer 131 is also

provided with coloured markers 132,133,134 to help its segmentation in the video image and obtain its surface mesh. Even if the centrepoint of each colour marker might not be exact, it is sufficient for determining the approximate position of the tool in the CAD-model. This will also help in
5 automatically establishing a co-ordinate system on the pointer. The tip of the pointer 135 is displayed as marker 109 on the monitor 102 over the axial 103, sagittal 104 coronal 105 views of the preoperative image data. It is also displayed on the 3D rendered scene 106 of the patient preoperative data.

- 10 **[0080]** The steps of a tracking method of the tracking apparatus of Fig. 7 is shown in Fig. 8. In step 151, the 3D mesh-surface generator 122, 123 and the video camera are calibrated and the calibration data are registered in order to relate the colour points taken with the video camera 124 to the points of the 3D surface mesh. In step 152, the colour markers 111, 112,
15 113, 114 are pasted on surfaces relevant for the surgery so that a topographically distinct region is in between the markers 111,112,113,114. In step 153, the relevant regions are identified based on the colour markers. In step 154, the surface-mesh of the body is obtained. In step 155, a coordinate system of the body/patient P is established on the basis of the
20 position of the colour coded regions on the 3D surface mesh or on positions determined based on those positions. In step 156, the 3D model derived from preoperative imaging is registered to the coordinate system of the body P. The exact position of the 3D surface-mesh of the body in the 3D model of the body is calculated on the basis of the 3D surface-mesh of the
25 body and the 3D surface from the 3D model of the body. The transformation between the 3D model and the body is updated in step 157. In other words, the transformation from the 3D surface-mesh generator 122, 123 to the 3D model is determined. In step 161, the surface-mesh of the pointer is obtained from the 3D surface-mesh generator 122, 123
30 together with the colour information of the pointer obtained from the video camera 124. A coordinate system T of the pointer is established on the basis of the position of the colour codes 132, 133, 134 on the 3D surface-mesh or based on positions determined based on those positions in step 162. In step 163, the CAD model of the pointer 131 is registered to the

surface-mesh of the pointer 131 by a two-step process. First the points defining the coordinate system, e.g. the positions of the colour codes, are found in the 3D model of the object for an approximative position of the 3D surface-mesh in the 3D model of the object (e.g. by a paired point based registration). In a second step, the exact position is determined based on the 3D surface-mesh of the tool and the surface of the tool from the 3D model of the tool. In step 164, the transformation between the CAD model and T is updated. In other words, a transformation of the coordinate system of the CAD model into the coordinate system of the 3D surface-mesh generator 122, 123 is determined. In step 165, the pointer tip is transformed to the patient coordinates using the transformation from the CAD model to the 3D surface-mesh generator 122, 123 and the transformation from the 3D surface-mesh generator 122, 123 to the 3D model of the patient. In step 158, the transformation of steps 157 and 164 are updated in real-time. In step 159, the tool-tip position is overlaid to the preoperative image data.

[0081] Fig. 9 shows again the steps of the tracking method using colour markers. In step 181, coloured markers are attached on the body. In step 182, markers are segmented by coloured based segmentation in the video image. In step 183, the centre of the segmented colour blobs is obtained. In step 184, the corresponding points of the blob centres in the 3D surface-mesh is achieved on the basis of the calibration data. In step 184, the surface-mesh between these points is obtained. In steps 188, 189, the 3D model of the body is created on the basis of preoperative imaging. In step 190, the points on the 3D model are selected so that they approximately correspond to the position of markers attached on the body. In step 194, the surface-mesh of the 3D model between those points is obtained. In step 191, based on the approximative points on the 3D model and the centre points of the colour blobs, the approximative position of the 3D surface-mesh of the body in the 3D model of the body is determined. Preferably, this is done by a paired point based registration of these two point groups. In step 192, on the basis of this approximative position, an approximative transformation between the 3D surface-mesh of the body and the 3D surface of the 3D model is obtained. In step 193, this approximative

transformation or this approximative position is used for determining a starting/initiation point of an iterative algorithm to determine the exact position/transformation in step 186. In step 186, an iterative algorithm is used to find the exact position of the 3D surface-mesh of the body in the
5 3D model of the body based on the surface-meshes of steps 194 and 185 with the initiation determined in step 193 on the basis of the approximative position. Preferably, this iterative algorithm is an iterative closest point algorithm. In step 187, the preoperative data are registered to the 3D surface-mesh of the body.

10 **[0082]** The same method can be followed to register the CAD model of the surgical pointer to its surface mesh.

[0083] Fig 4 shows details of the steps involved in registering the preoperative data to the patient for 3D topographic distinct regions. However, also the process of Fig. 9 could be used for registering the
15 preoperative data to the patient by 3D topographic distinct region, if the colour points are replaced by the four points of the distinct topographic region. The same method can be followed to register the CAD model of the surgical pointer to its surface mesh with 3D topographical distinct points.

[0084] Fig. 10 shows a possibility of using coloured strips on the body
20 (patient anatomy) to segment and register the surface meshes. 411 and 412 are the coloured marker strips that can be pasted on the patient's skin. Similarly strips can also be used, during surgery, on the exposed bony surfaces to establish the coordinate systems for registering their 3D models to the generated surface-meshes.

25 **[0085]** Fig. 11 shows a method where in automatic identification of the respective Computer Aided Design (CAD) model of a given tool. The tool can also be fixed with a square tag or a barcode for identification. In a first step, the surgical tool is provided with a visual code, e.g. a barcode, which is related to the CAD model of the tool in a database. The tool is captured
30 with the 3D surface-mesh generator 122, 123 and the 3D surface-mesh of the tool is created. At the same time, the video image of the tool is created

by the video camera 124. The visual code is segmented and identified in the video image. The identified visual code is read out and the related CAD model is looked up in a database. Then the CAD model identified is registered to the surface-mesh of the tool.

- 5 [0086] Fig. 12 shows a tool 302 with a square marker 301 with a binary code. The topographical T at the end of the tool facilitates to detect the exact position of the tool in the 3D surface-mesh.

[0087] In Fig. 13, the Tool 304 is fixed with a bar code 303 and the topographical form of the tool is different.

- 10 [0088] Figure 14 and 15 show a scenario where square markers with binary codes are used to identify and initialize the registration of the surfaces. These markers are identified and tracked by the video camera 124. Initial estimation of the square markers 6D position, i.e. 3D position and orientation, is done by processing the video image. This information is used
15 for initializing the registration of the surfaces. The binary code will be specific for individual markers. This specificity will help in automatically choosing the surfaces to be registered. Fig. 14 shows a square binary coded marker attached on the fore head of the patient. Figure 15 shows the use of markers where a bony surface is exposed. The markers 431 and 432 are
20 pasted on femur 433 and tibia 434, respectively.

- [0089] Figure 16 shows a tracking apparatus and a tracking method using topographically coded 3D markers. The proposed navigation system using topographically encoded markers placed rigidly on the patient anatomy. This illustrates the scenario in surgeries around head, for
25 example. The marker 201 with topographically distinct feature is placed on the forehead with a head band 202 to secure it. The three arms of the marker are of different length for unique surface registration possibility. The pointer 131 is also designed so that a distinctly identifiable topographical feature is incorporated in its shape. The distinct surface
30 shape features help in establishing co-ordinate systems, registration of their respective 3D models and tracking.

[0090] Fig 17 shows a method to initiate registration of the 3D surfaces to the patient anatomy by tracking the surgeon hand 951, tip of index finger in particular, and identifying the thumb adduction gesture 953 as the registration trigger. For example, the index finger can be placed on
5 surface points 201a, 201b, 201c and 201d and registration is triggered by thumb adduction gesture. Similarly, same kind of method can be used to register 3D model of the pointer 131 to the real-time surface-mesh by placing the index finger at points 131a, 131b, 131c in Fig 18. The tip can be calibrated using the same method as shown in Fig 18. It can also be used to
10 register the edges of a tool as shown in Fig. 19, where index finger is kept at one end of the edge 956 and registration initiated by thumb adduction action. The index finger is slow slid over the edge 954, keeping the thumb adducted, to register the complete edge. When the index finger reaches the other end of the edge, thumb is abducted to terminate the registration
15 process. Figure 20 shows another example where a surface of bone, e.g. femur articular surface of knee joint 433, is registered in a similar method.

[0091] Visually coded square markers can be attached on the encoded marker and pointer for automatic surface registration initialization. Their 6D information can be obtained by processing the video image. This can be
20 used in initializing the registration between the surface-mesh and the 3D models.

[0092] Fig. 21 shows steps of the tracking method using 3D topographic markers. In step 3.51, a topographically encoded marker is fixed on the patient anatomy, preferably at a position, which does not move much
25 relative to the part of the body relevant for surgery. In this case, the topographic marker is placed on the front which has only minimal skin movements compared to the skull of the head. The coordinate system is registered in the 3D model of the body. This could be done by registering the 3D surface of the body in the 3D model of the body (select min. 3
30 points, detect approximate position, detect exact position, determine transformation). Then the 3D surface of the topographically encoded marker is registered in its CAD model body (select min. 3 points, detect approximate position, detect exact position, determine transformation). By

the two determined transformations, the exact position of the CAD model of the topographically encoded marker is known in the 3D model of the body. As a consequence, only the position of the 3D surface-mesh of the topographically encoded marker in the CAD model of the marker can be
5 tracked (detect the at least 3 points defined before on the 3D surface-mesh of the marker, detect approximate position, detect exact position, determine transformation). Since the marker is topographically distinct, the determining of its position is more precise and faster than the features of the body, especially in regions without distinct features. This embodiment
10 is similar to the embodiment of Fig. 5. It is also possible to detect changes in the position between the body and the marker and to update this position automatically. .

[0093] Fig. 22 shows another view of the topographically encoded marker fixed on fore head using a head band as also shown in Fig. 16 and
15 17. It is not necessary to fix this marker rigidly to the anatomy, since registration between the marker and the anatomical surface is regular updated and checked for any relative movement. This is because the coordinate system determined by the 3D topographic marker serves only for the approximate position of the 3D surface-mesh in the 3D model,
20 which is then used for determining the exact position. In steps 3.52 and 3.53, the 3D surface-mesh of the body and of the topographically encoded marker is generated. In step 3.54, the coordinate system is determined on the basis of the topographically encoded marker upon the topographically encoded marker is detected. The coordinate system could be established by
25 four characteristic points of the topographically encoded marker.

[0094] Fig. 23 shows another design of a topographically encoded marker that can be used.

[0095] Figure 24 shows various coordinates involved in the navigation setup using topographically marker 201 and pointer 131 with
30 topographically distinct design. P is the co-ordinate system on the marker 201, O is the coordinate system on the 3D surface-mesh generator 121, R is the coordinate system on the pointer 131, I represent the coordinate system

of the preoperative image data. The pointer tip is registered on the R (Pointer calibration) either by pivoting or registering its surface mesh to its CAD 3D model. At least four distinct points (G1) are chosen in the image data I, so that they are easily accessible on the patient 110 with the pointer tip. Using the calibrated pointer 131 the corresponding points (G2) on the patient are registered to the marker P. By means of paired point registration between G1 and G2 the approximative transformation $T(P, I)$ is established. The exact transformation $T(P, I)$ is then obtained by the iterative closest point algorithm as explained already before. The transformation $T(O, P)$ and $T(O, R)$ are obtained by registering the CAD 3D models of marker and pointer to their respective mesh-surfaces. This can be done automatically or by manually initializing the surface based registration and tracking. For navigation, the pointer tip is displayed on the image data by following equation:

$$K(I) = T(P, I)^{-1} T(O, P)^{-1} T(O, R) K(R) \quad (E1)$$

where $K(R)$ is the tip of the pointer in R coordinates and $K(I)$ is its transformation in image coordinates I. By continuously updating the transformations $T(O, P)$ and $T(O, R)$ and, in real-time, for every frame of surface-mesh generate navigational support can be provided. The transformation $T(P, I)$ is determined only once.

[0096] Fig. 25 shows a tracking apparatus with the 3D surface-mesh generator 122, 123 mounted on the body. In case optical information is used also the video camera 124 is mounted together with the 3D surface-mesh generator 122, 123 on the body. Figure 25 illustrates a setup where in the 3D surface-mesh generator 122, 123 is mounted on the body 110, in this case on the patient's head, to track the surgical tool, an endoscope 905 in this example. The tip of the endoscope is registered to the topographic feature that is continuously tracked 906 by registering the CAD model of the endoscope lens 904 to the 3D surface mesh generated. This is done, as described before, by detecting four points of the tool in the 3D surface-mesh of the tool, calculating the position of the tool 905 in the CAD model by comparing those four points with four corresponding points in the CAD

model and by calculating the exact position of the 3D surface-mesh of the tool in the CAD model of the tool by an iterative algorithm which uses the rough estimate of the position based on the four points as starting point.

5 [0097] The position of the 3D surface-mesh of the body in the 3D model of the body must be determined only once, because the 3D surface-mesh generator 122, 123 has a fixed position on the body.

10 [0098] From the exact position of the 3D surface-mesh of the object in the 3D surface model of the object and the exact position of the 3D surface-mesh of the body in the 3D surface model of the body, the exact position of the tool known from the CAD model can be transferred to the exact position in the 3D model of the body with the preoperative data. The transformation of endoscope tip to the pre-operative data is calculated and overlaid on the monitor 102, as explained before, to provide navigational support during surgeries, e.g. ENT and Neurosurgeries in this example.

15 [0099] Fig. 26 illustrates an example of mounting the 3D surface-mesh generator 501 directly on the patient anatomy, on the maxilla in this example, using a mechanical mount 502. The upper-lip of the patient is retracted using a retractor 504 so that the teeth surfaces are exposed. The exposed teeth surface is rich in topographical features. These topographical
20 features are used to select four points for the rough estimate of the position of the 3D surface-mesh of the body in the 3D model of the body. Therefore, the preoperative data can be effectively registered to the 3D surface-mesh of the body. This can be used for providing navigation in Dental, ENT (Ear, Nose and Throat), Maxillo-Facial and neurosurgeries.

25 [00100] Fig. 27 shows a tracking apparatus, wherein 3D surface-mesh generator is mounted on the object itself, here the surgical tools/instruments. The tip of the endoscope is registered in the co-ordinates of 121. The 3D surface-mesh of the body 110, of the face in this example, is generated. The subsurface of the mesh which represent the rigid regions of the face (see Fig. 28), for e.g. Forehead 110A or nasal bridge region 110B,
30 are identified and segmented. The identification of these subsurface can be

done by manual pointing as illustrated in Fig.17 or by pasting colour coded patches as described in previous sections. Thus identified and segmented subsurface patches are registered to the corresponding regions on the 3D model identified before using the thumb-index gesture method as

5 illustrated in Fig. 17 and 20. Surface to surface registration of these two surfaces gives the transformation matrix required to transform the tip of endoscope into the co-ordinates of the pre-operative image volume (For e.g. CT/MRI). The tip can be overlaid on axial 103, sagittal 104, coronal 105 and 3D rendered scene 106 of the preoperative image data. In next step by

10 tracking only one of the topographically rich region (e.g. 110B) and updating the said transformation in real-time navigational support could be provided to the operating surgeon. A similar setup can be used for navigating a needle in ultrasound guided needle biopsy. The 3D surface-mesh generator 122, 123 can be mounted on the Ultrasound (US) probe

15 and its imaging plane registered in its co-ordinates. The needle is tracked, in a similar way as we are tracking the pointers, and the trajectory of the needle is overlaid on the US image to provide navigation.

[00101] Fig. 29 shows the steps of a tracking method with the 3D surface-mesh generator 122, 123 mounted on the tool. In a first step 4.32, the

20 surface-mesh generator 122, 123 is mounted on the tool and the tool tip is registered in the coordinate system of the 3D surface-generator 122, 123. In step 4.33, a frame is acquired from the 3D surface-mesh generator 122, 123. In step 4.34, the surgeon's points out the relevant regions by thumb-index gesture. In step 4.35, these regions are segmented-out and the

25 corresponding surface-mesh patches are taken. In step 4.36, the surgeon identifies one of the patch, which is topographically rich, to establish a coordinate system and further tracking. In step 4.37, the segmented patches are registered to their corresponding region on the 3D model derived from preoperative data. In step 4.38, the tip of the endoscope is

30 overlaid in the preoperative image volume. In step 4.39, the previously identified, topographically rich, patch is continuously tracked and the 3D position of the established co-ordinates updated in real-time. In step 4.40, the tip of the endoscope overlaid in the preoperative image volume is updated in real-time. In this case there is no detection of the object

needed, because the object is in the same coordinate system as the 3D surface-mesh generator 122, 123.

[00102] Fig. 30 shows an apparatus where the surface-mesh generator 121 is mounted on a medical device, e.g. an endoscope 905. The body/patient 110 is fixed with a topographical marker which has the coordinate system P. The Preoperative image volume is registered to P, by means of paired point registration followed by surface based registration as described before. E is the endoscope optical co-ordinate system. V is the video image from the endoscope. Any point on the patient preoperative image data, PP, can be augmented on the video image, VP, by the equation

$$V(p)=C T(E,O)T(O, P)T(P,I) P(P) \quad (E2)$$

Where T(E, O) is a registration matrix that can be obtained by registering the optical co-ordinates, E, to the surface-mesh generator (121). C is the calibration matrix of the endoscope. The calibration matrix includes the intrinsic parameters of the image sensor of the endoscope camera. By using the same equation E2 any structures segmented in the preoperative image can be augmented on the video image. Similarly the tumor borders, vessel and nerve trajectories marked out in the preoperative image volume can be augmented on the endoscope video image for providing navigational support to the operating surgeon. Similarly the position of a surgical probe or tool can be augmented on these video images.

[00103] The same system can be used by replacing endoscope with any other medical devices e.g. medical microscope, Ultrasound probe, fluoroscope, X-Ray machine, MRI, CT, PET CT.

[00104] Fig. 31 depicts the system where multiple 3D surface-mesh generators (121a,121b) can be connected to increase the operative volume and accuracy of the system. Such a setup will also help in reaching the anatomical regions which are not exposed to one of the surface-mesh generator.

[00105] Fig. 32 shows a setup where the 3D surface-mesh generator 121 is directly mounted on the surgical saw 135. This setup can be used to navigate a cut on an exposed bone 433 surface.

[00106] Fig. 33 and Fig. 34 show a tracking apparatus using 3D surface-mesh generator 122, 123 combined other tracking cameras.

[00107] In fig. 33, a tracking apparatus Combined with an infrared based tracker (passive and/or active). The 3D surface-mesh generator 121b can be used to register surfaces. The infrared based tracker 143 helps to automatically detect the points on the 3D surface-mesh for the
10 approximative position of the 3D surface mesh in the preoperative data (similar to the colour blobs captured by the video camera 124). A marker 143b, which can be tracked by 143, is mounted on 121b and 121b's co-ordinates are registered to it. With this setup the surfaces generated by 121b can be transformed to co-ordinates of 143. This can be used to
15 register the surfaces automatically.

[00108] Fig. 34 illustrates the setup where the 3D surface-mesh generator 121 can be used to register surfaces with an electromagnetic tracker 141. A sensor 141a, which can be tracked by 141, is mounted on the 3D surface-mesh generator 121 and 121's co-ordinates are registered to it. With this
20 setup the surfaces generated by 121 can be transformed to co-ordinates of 141. This can be used to register the surfaces automatically.

[00109] The invention allows tracking of objects in 3D models of a body in real-time and with a very high resolution. The invention allows surface-mesh resolutions of 4 points/ square-millimeter or more. The invention
25 allows further to achieve 20 or more frames per second, wherein for each frame the position of the object/objects in relation to the patient body (error < 2mm) is detected to provide navigational support.

Claims

1. Method for tracking an object with respect to a body comprising the steps of:
 - providing a three-dimensional model of said body;
 - providing a three-dimensional model of said object;
 - 5 tracking the position of said object in said three-dimensional model of said body on the basis of a sensor measuring repeatedly a three-dimensional surface of said body and said object.
2. Method according to claim 1, wherein the step of tracking comprises for three-dimensional surfaces of said body and said object the steps of:
 - 10 detecting the three-dimensional surface of said body and detecting the three-dimensional surface of said object in said three-dimensional surface of said body and said object;
 - determining a rough position of the detected three-dimensional surface of the body in the three-dimensional model of said body; and
 - 15 determining an exact position of the three dimensional surface of the body in the three-dimensional model of said body by an iterative algorithm on the basis of the detected three-dimensional surface of said body and the surface of the body determined by the three-dimensional model of the body, wherein the iterative algorithm is initiated on the basis of the rough position of the detected three surface of the body in the three-dimensional model of the body;
 - and/or the steps of:
 - 25 determining a rough position of the detected three-dimensional surface of the object in the three-dimensional model of said object;
 - determining an exact position of the three dimensional surface of the object in the three-dimensional model of said object by an iterative algorithm on the basis of the detected three-dimensional surface of said object and the surface of the object determined by the three-dimensional model of the object, wherein the iterative algorithm is
 - 30

initiated on the basis of the rough position of the detected three surface of the object in the three-dimensional model of the object;

- 5 determining a transformation from the coordinates of the three-dimensional model of the object into the coordinates of the three-dimensional model of the body.

3. Method according to claim 2, wherein
the rough position of the detected three-dimensional surface of the object in the three dimensional model of the object is determined on the basis of at least three non-coplanar points detected on the three-
10 dimensional surface of the object and corresponding at least three non-coplanar points marked in the three-dimensional model of the object;
and/or

- the rough position of the detected three-dimensional surface of the body in the three dimensional model of the body is determined on
15 the basis of at least three non-coplanar points detected on the three-dimensional surface of the body and corresponding at least three non-coplanar points marked in the three-dimensional model of the body.

4. Method according to claim 3, wherein the at least three non-coplanar points on the three-dimensional surface of the object or of the
20 body are detected on the basis of topographically distinct points on the object or on the body.

5. Method according to claim 4, wherein the topographically distinct points are on a topographically distinct marker fixed on the object or the body.

- 25 6. Method according to claim 4, wherein the topographically distinct points are determined on the basis of topographically distinct parts of the body or the object.

7. Method according to claim 3, wherein the at least three non-coplanar points on the three-dimensional surface of the object or of the
30 body are detected on the basis of optically distinct points on the object or

on the body measured by a video camera having a known relationship for each pixel of the video camera to a point on the three-dimensional surface of the object or the body.

8. Method according to claim 7, wherein the video camera is in
5 the same housing as the sensor for measuring the three-dimensional surface.

9. Method according to any of claims 3 to 8, wherein the exact
position of the three-dimensional surface of the object or the body in the
three-dimensional model of the object or the body is determined on the
10 basis of a subsurface of the detected three-dimensional surface of said
object or said body and a subsurface of the surface of the object or said
body determined by its three-dimensional model, wherein the subsurface
of the detected three-dimensional surface of said object or said body is
determined on the basis of the at least three points on the three-
15 dimensional surface of the object or body.

10. Method according to any of the previous claims, wherein the
sensor is fixed on the object.

11. Method according to claims 1 to 8, wherein the sensor is fixed
on the body.

20 12. Method according to claims 1 to 8, wherein the sensor is fixed
in the tracking zone.

13. Method according to claim 1, wherein the step of tracking
comprises the steps of:
measuring by said sensor the three-dimensional surface;
25 detecting at least one three-dimensional subsurface of the
body and at least one three-dimensional subsurface of the object within
the three-dimensional surface measured;
computing the relative position of the object in said three-
dimensional model of said body on the basis of the at least one three-

dimensional subsurface of the body and at least one three-dimensional subsurface of the object.

14. Method according to claim 13, wherein the step of computing the relative position comprises determining the position of the three-
5 dimensional model of said body in the coordinate system of the sensor on the basis of the at least one three-dimensional subsurface of the body and determining the position of the three-dimensional model of the object in the coordinate system of the sensor on the basis of the at least one three-dimensional subsurface of the object.

10 15. Method according to claim 13 or 14, wherein the at least one three-dimensional subsurface of the body is a true sub-set of the three-dimensional surface of the body measured and/or the at least one three-dimensional subsurface of the object is a true sub-set of the three-dimensional surface of the object measured.

15 16. Method according to any of claims 1 to 15, comprising the further steps of defining at least one point in the three-dimensional model of said body and/or in the three-dimensional model of said object for tracking the position of the body and/or object, wherein each point is defined by detecting a point in the three-dimensional surface measured by
20 said sensor.

17. Method according to claim 16, wherein each point is defined by detecting a point of an indicator means in the three-dimensional surface measured by said sensor at the time of detecting an indicating event.

18. Method according to claim 17, wherein the indicator means is
25 one finger of a hand and an indicating event is a predetermined movement or position of another finger of the hand.

19. Method according to claim 16, wherein the point is detected automatically by detecting a known topographic marker fixed on the object and/or on the body.

20. Method according to claim 16, wherein the point is received from a database related to said three-dimensional model of said object.

21. Method according to any of the previous claims, wherein the step of providing the three-dimensional model of the object comprises the
5 step of comparing registered models of objects with the three-dimensional surface measured by said sensor.

22. Method according to any of the previous claims, wherein the step of providing the three-dimensional model of the object comprises the step of detecting an identifier on the object and loading the model of said
10 object on the basis of the identifier detected.

23. Method according to claim 22, wherein the identifier comprises a topographical marker which is detected by said sensor.

24. Method according to claim 22 or 23, wherein the identifier comprises an optical colour and/or optical pattern detected by an optical
15 camera included in a common housing together with said sensor.

25. Method according to any of the previous claims, comprising the step of displaying the three-dimensional model of the body on the basis of the position of the object.

26. Method according to claim 25 comprising the step of
20 retrieving a distinct point of said three-dimensional model of said object, wherein the three-dimensional model of the body is displayed on the basis of said point.

27. Method according to claim 26, wherein an axial, a sagittal and a coronal view of the three-dimensional model of the body going through
25 said distinct point is displayed.

28. Method according to any of claims 25 to 27, wherein a three-dimensionally rendered scene of the body and the object are displayed.

29. Method according to any of the previous claims, wherein a housing of the sensor comprises a marker for a second tracking system and the second tracking system tracks the position of the marker on the sensor.

30. Method according to any of the previous claims, wherein the
5 sensor comprises a first sensor for detecting a first field of view of the three-dimensional surface and a second sensor for detecting a second field of view of the three-dimensional surface, wherein the first sensor is mounted on one of the body, the object and the tracking space and the second sensor is mounted on another of the body, the object and the
10 tracking space.

31. Method according to any of the previous claims, wherein said body is a human body or part of a human body.

32. Method according to any of the previous claims, wherein said body is an animal body or part of an animal body.

15 33. Method according to any of the previous claims, wherein said object is a surgical tool.

34. Method according to any of the previous claims, wherein the object is at least one of the surgical table, an automatic supporting or holding device and a medical robot.

20 35. Method according to any of the previous claims, wherein the object is a visualizing device, in particular an endoscope, an ultrasound probe, a computer tomography scanner, an x-ray machine, a positron emitting tomography scanner, a fluoroscope, a magnetic resonance Imager or an operation theatre microscope.

25 36. Method according to the previous claim, wherein the sensor is fixed on the visualizing device which comprises an imaging-sensor.

37. Method according to claim 35 or 36, wherein the position of at least one point of the three-dimensional model of the body is determined in the image created by said image sensor on the basis of the three-dimensional surface measured by said sensor.

5 38. Method according to any of the previous claims, wherein the step of providing a three-dimensional model of said body comprises the step of measuring data of said body and determining the three-dimensional model of said body on the basis of the measured data.

10 39. Method according to the previous claim, wherein the data are measured by at least one of computer tomography, magneto-resonance-imaging and ultrasound.

40. Method according to any of the claims 38 and 39, wherein the data are measured before tracking the relative position of the object in the three-dimensional model.

15 41. Method according to any of the claims 38 and 39, wherein the data are measured during tracking the relative position of the object in the three-dimensional model.

20 42. Method according to any of claims 1 to 43, wherein the step of providing a three-dimensional model of said body comprises the step of receiving the three-dimensional model from a memory or from a network.

43. Non-transitory computer program configured to perform the method according to one of the previous claims, when executed on a processor.

25 44. Tracking apparatus comprising
a body data storage for storing a three-dimensional model of said body;
a object data storage for storing a three-dimensional model of said object;

a sensor for measuring repeatedly a three-dimensional surface of said body and said object; and

an object tracker for tracking the position of said object in said three-dimensional model of said body on the basis of the measured
5 three-dimensional surface of said body and said object.

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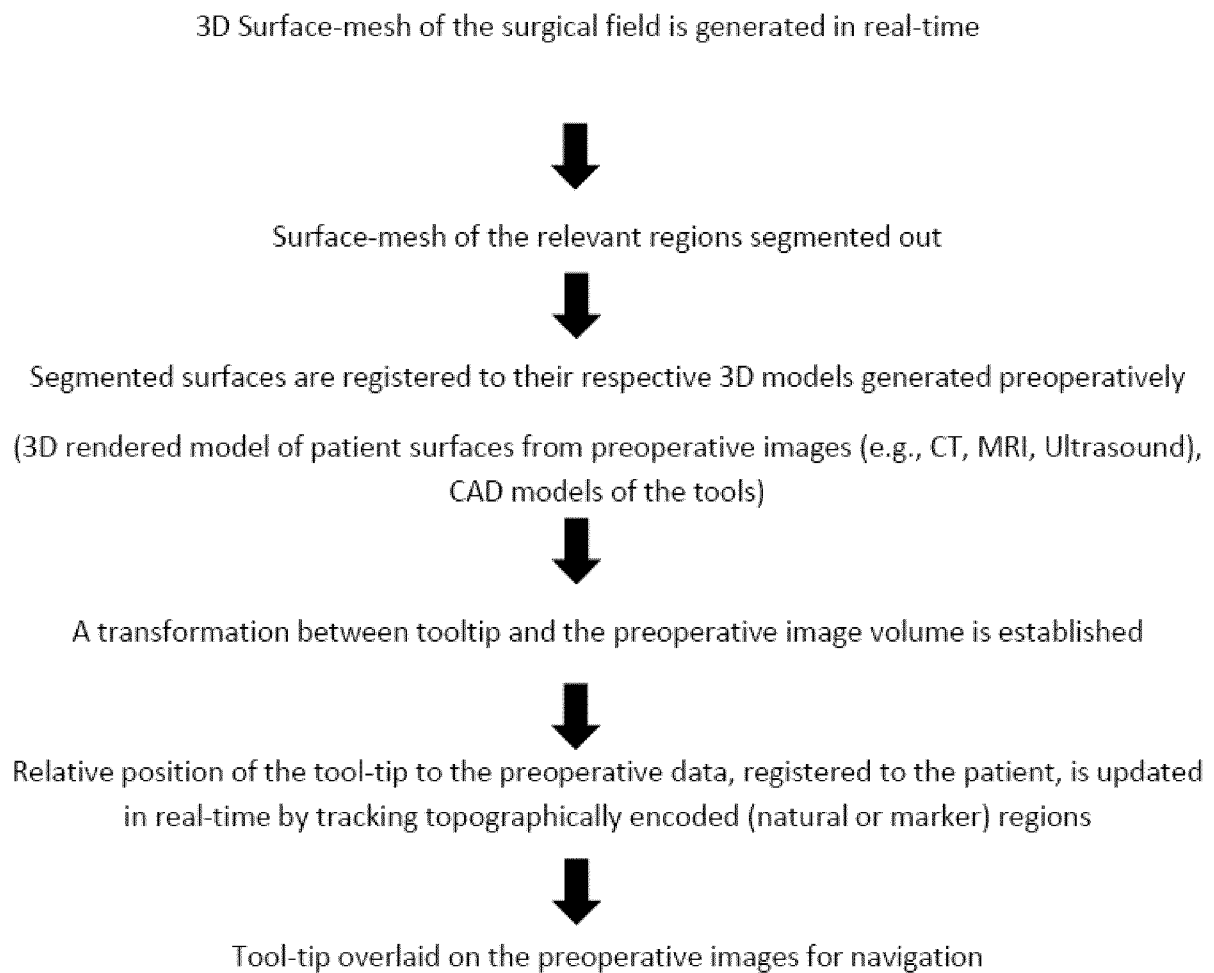


Fig. 1:

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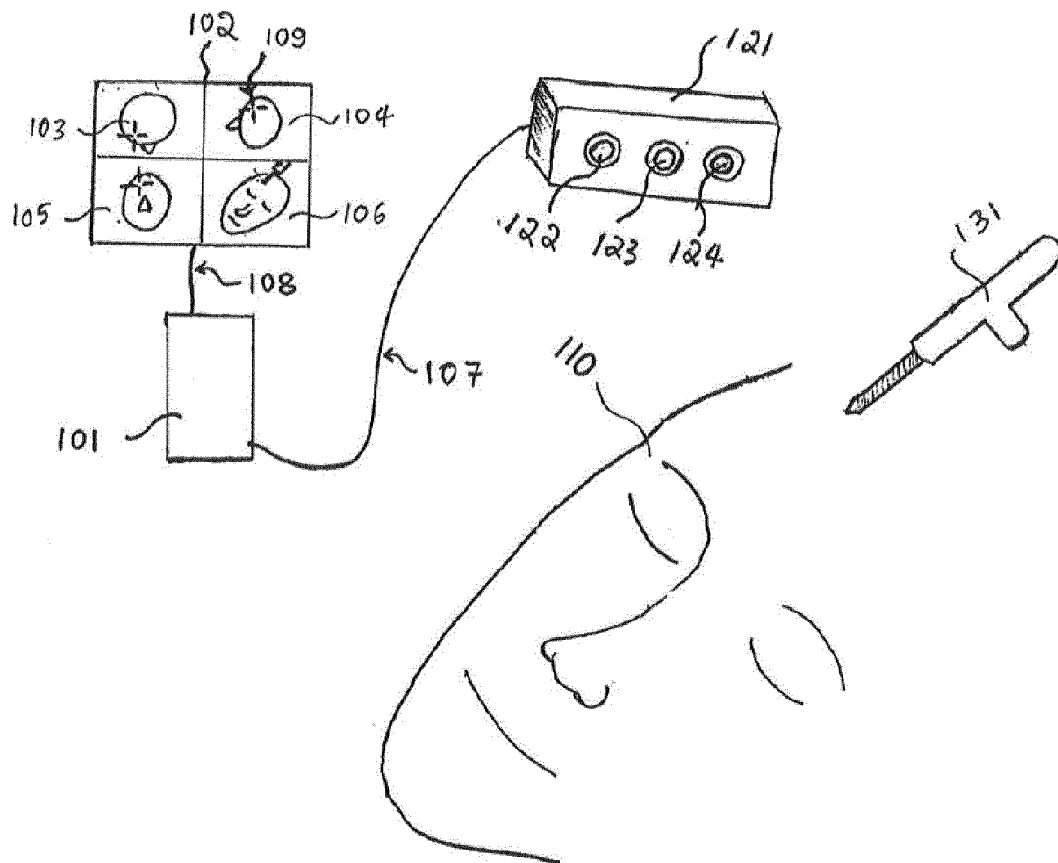


Fig. 2:

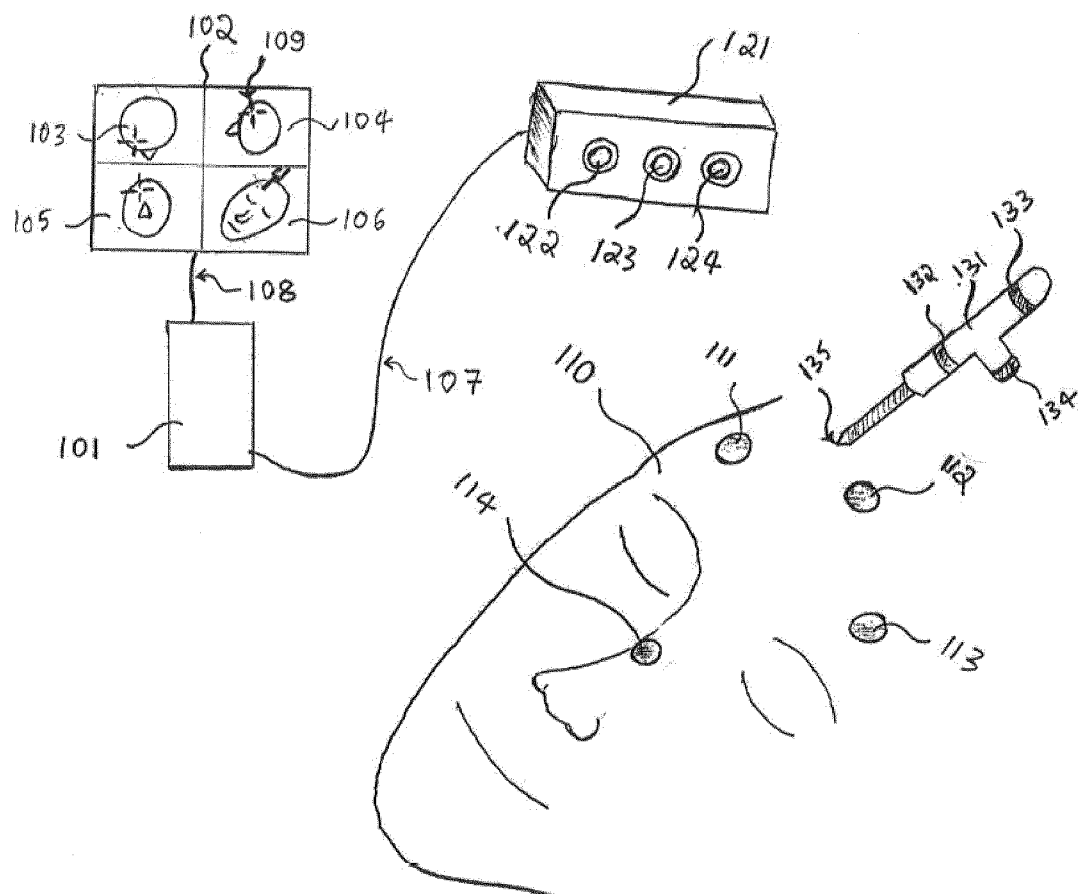


Fig. 7:

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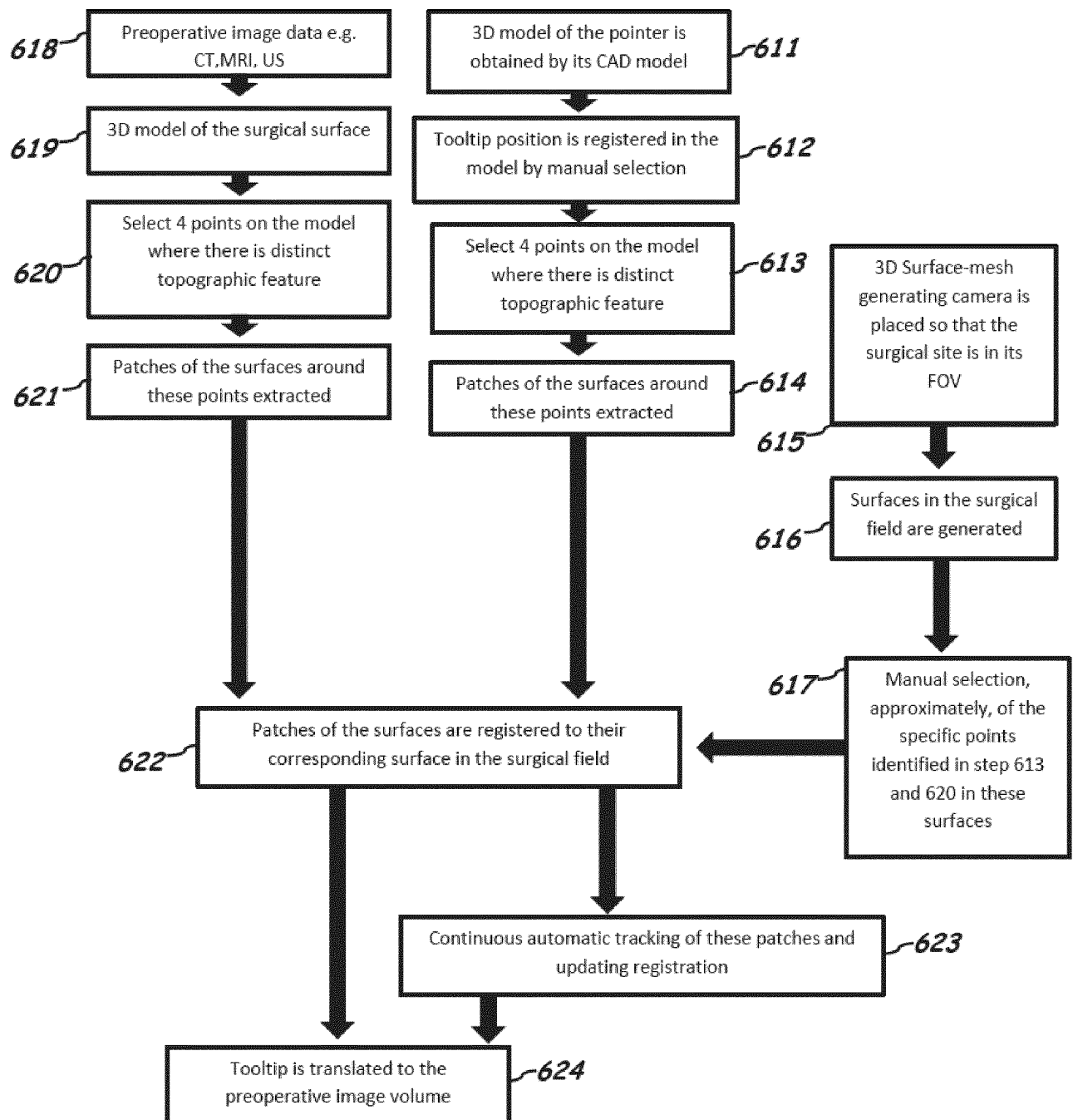


Fig. 3:

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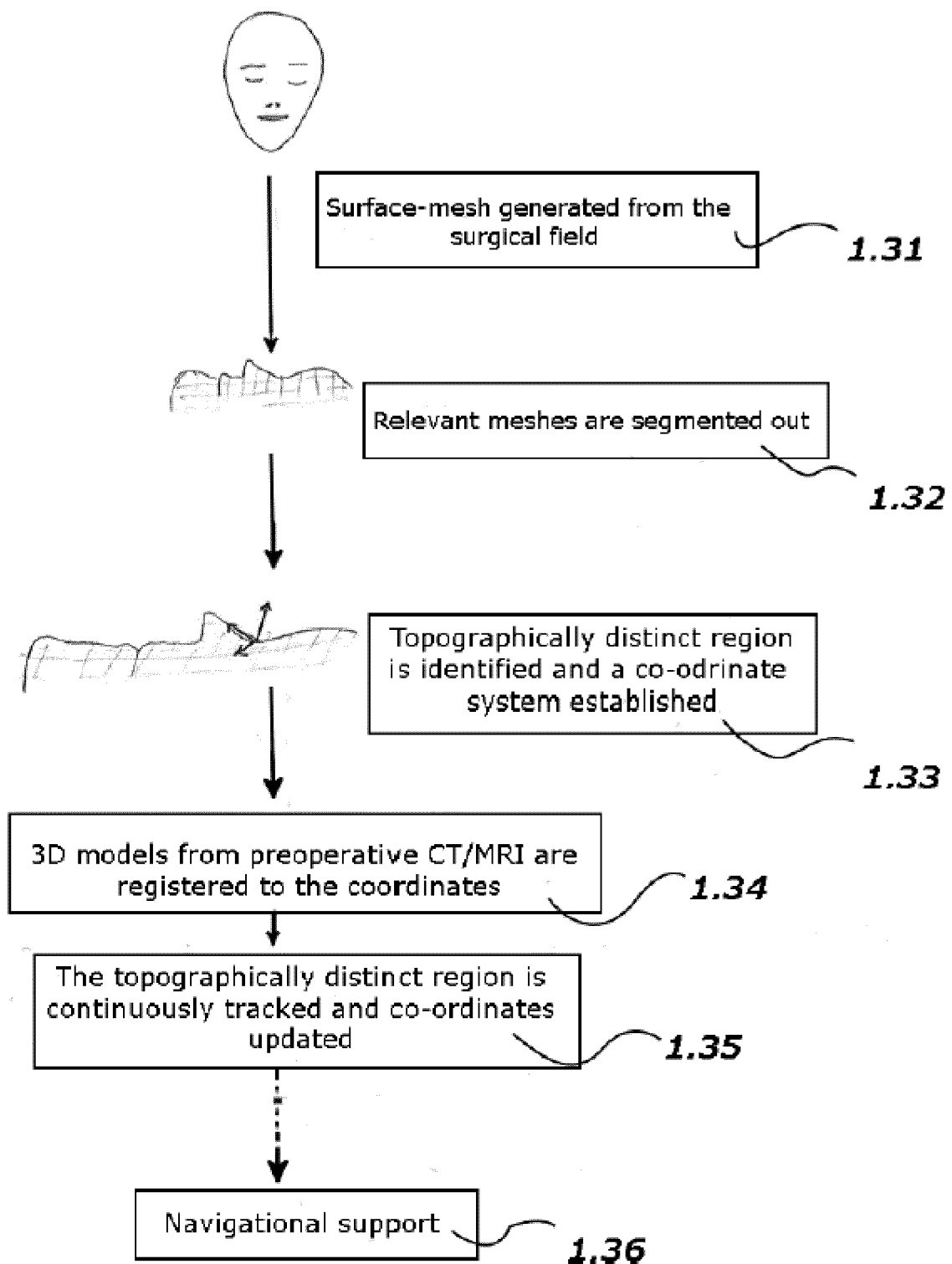


Fig. 4:

5/21

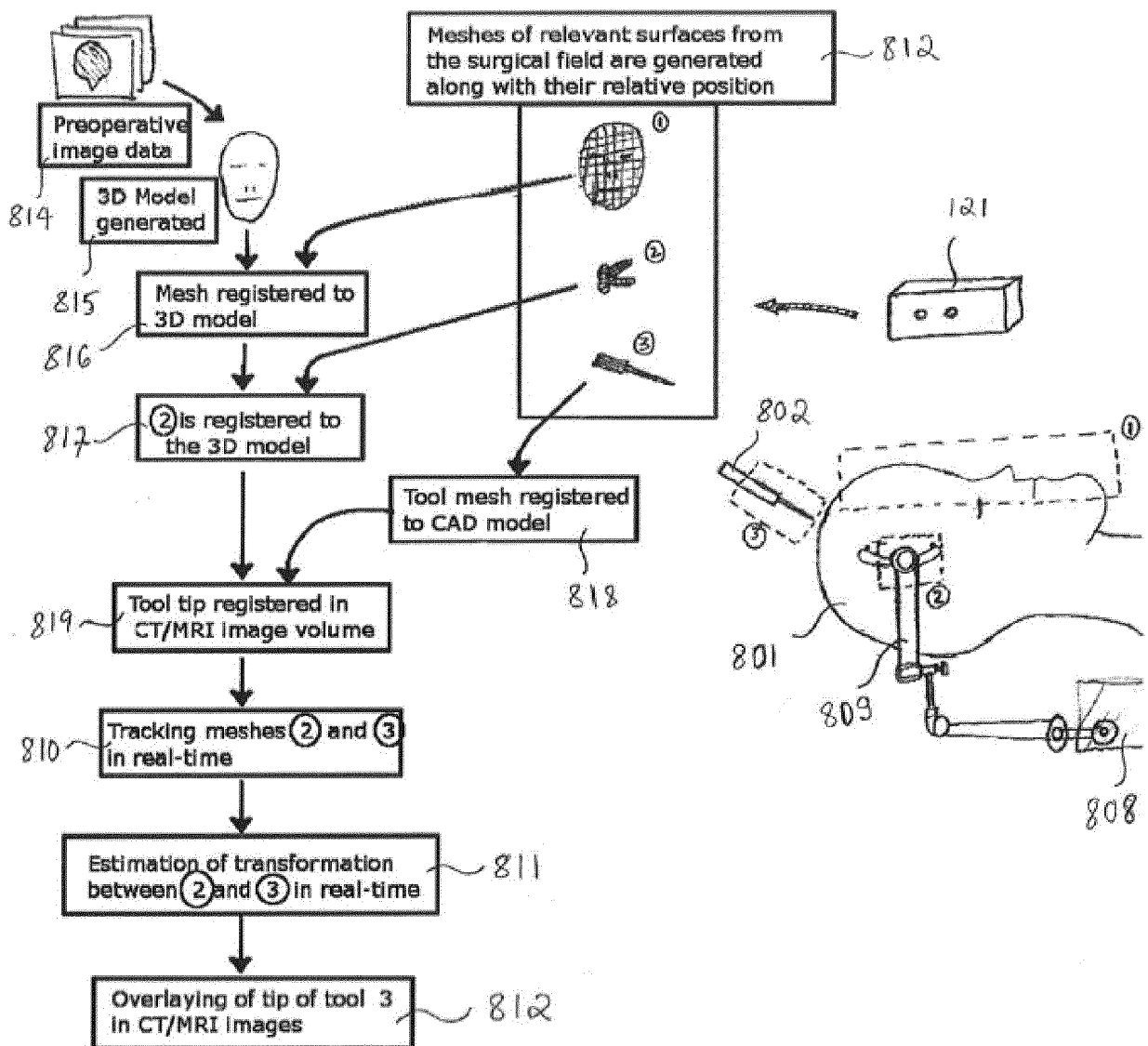


Fig. 5:

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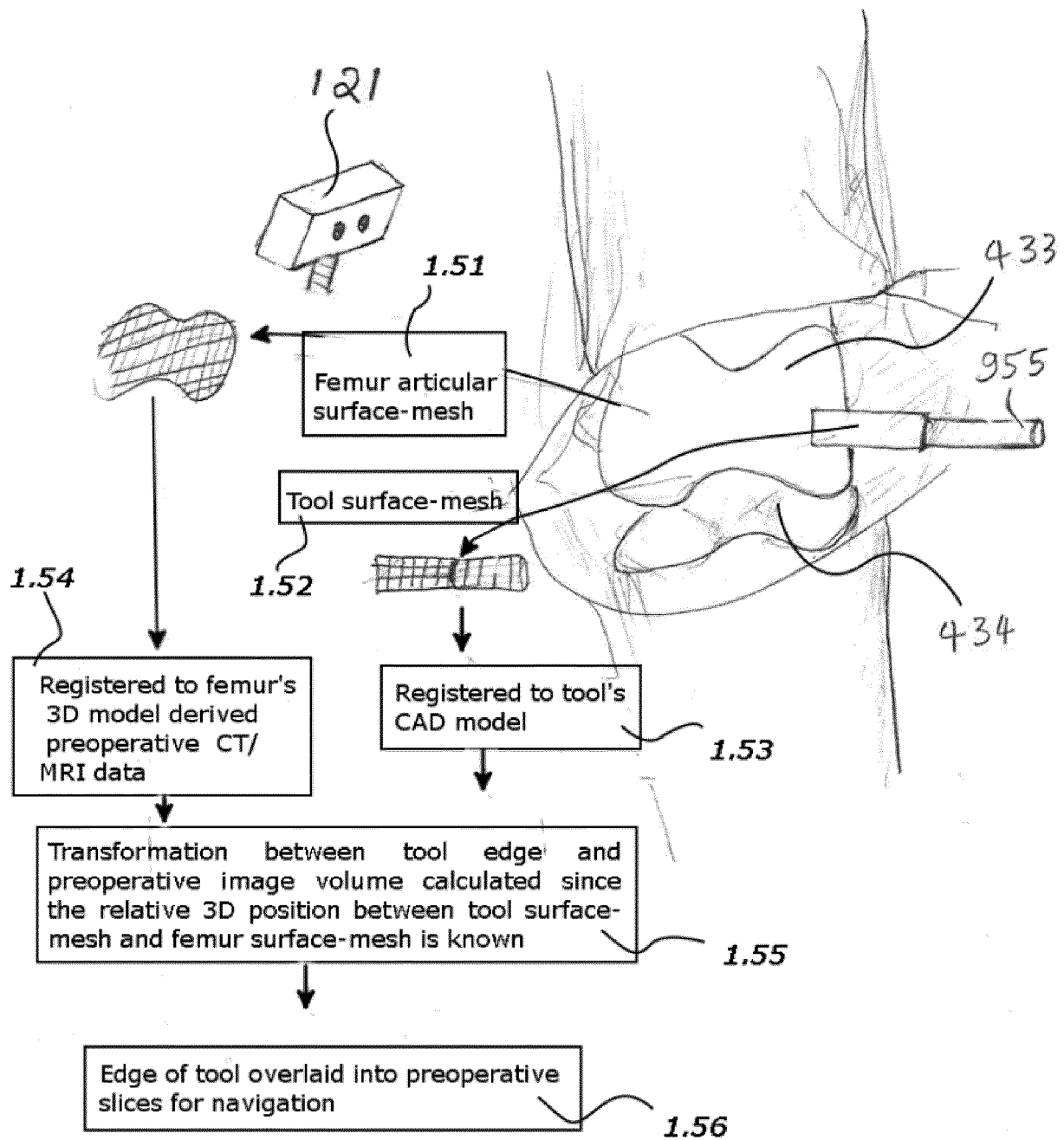


Fig. 6:

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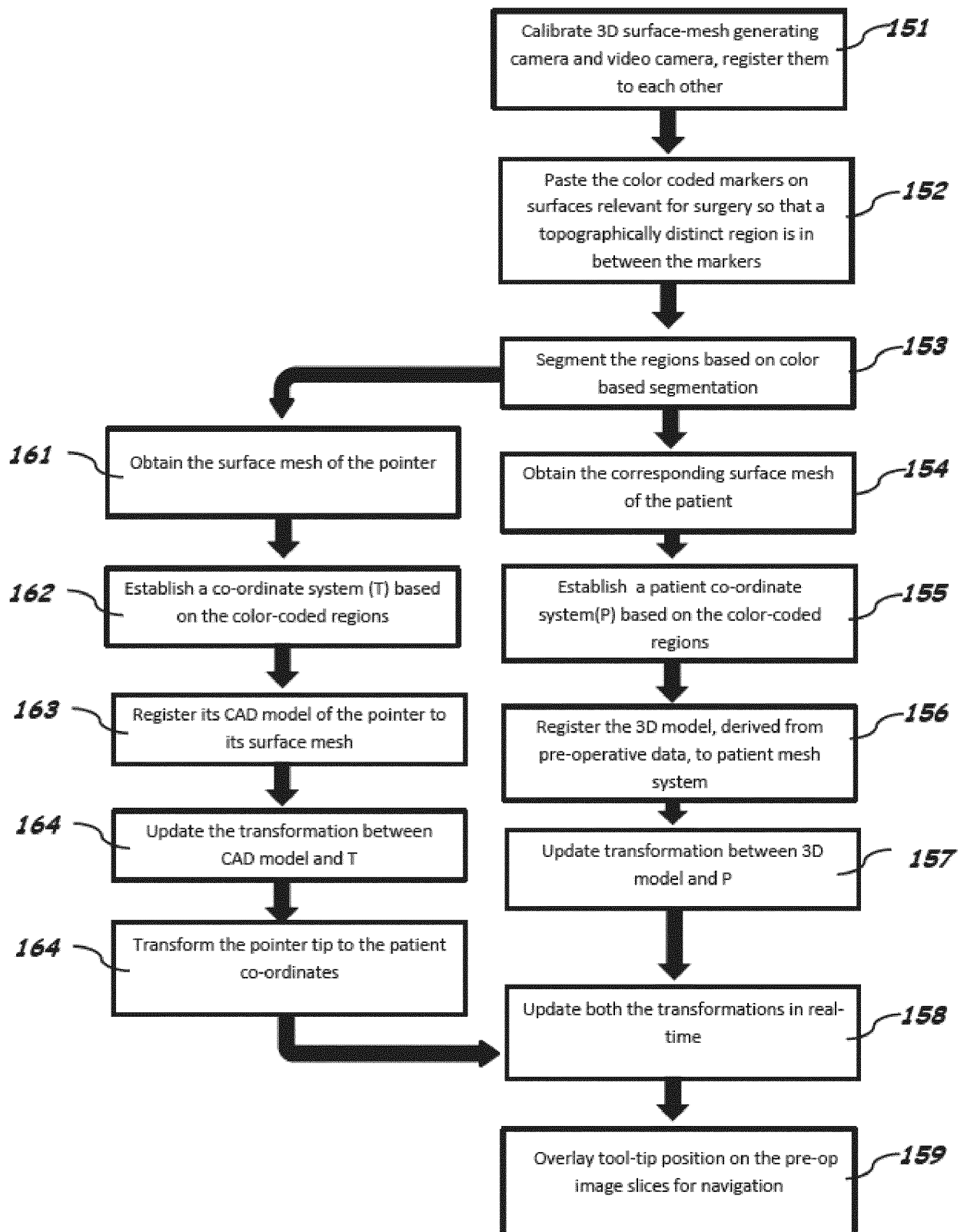


Fig.8:

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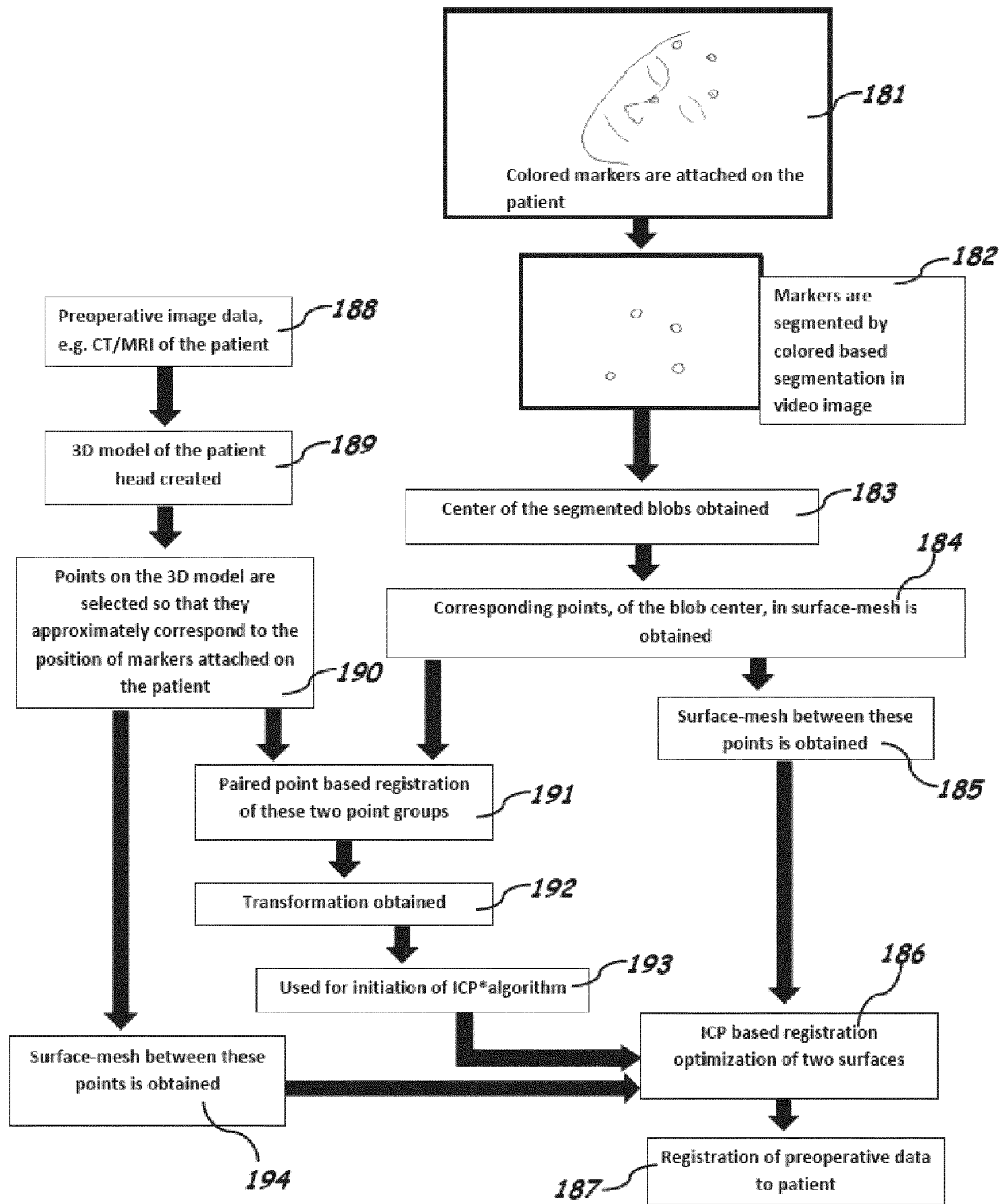


Fig.9:

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Fig. 10:

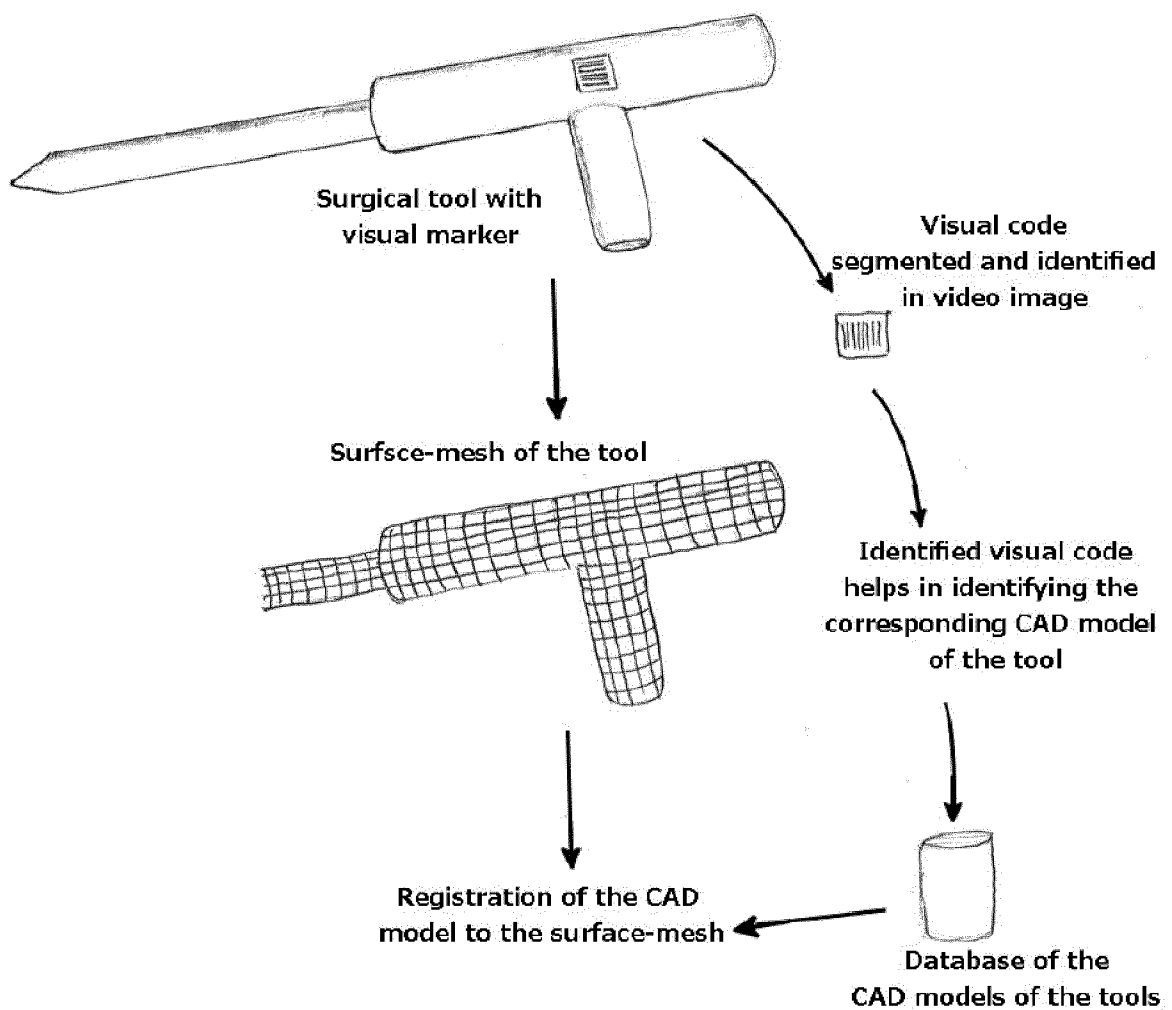


Fig. 11:

10/21

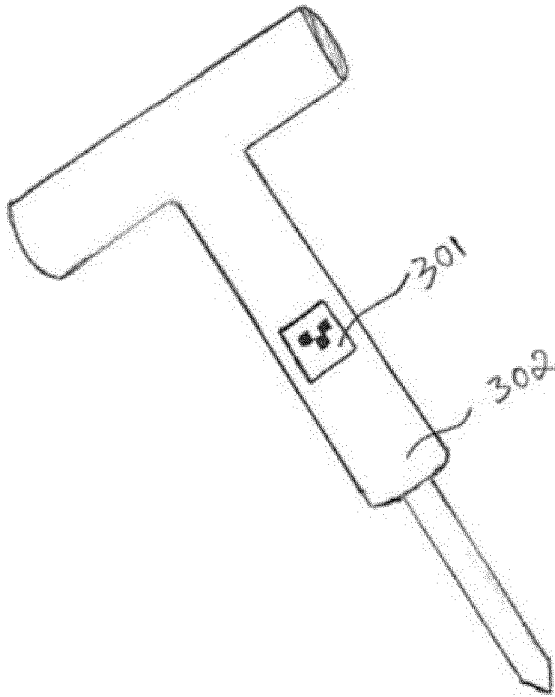


Fig. 12:

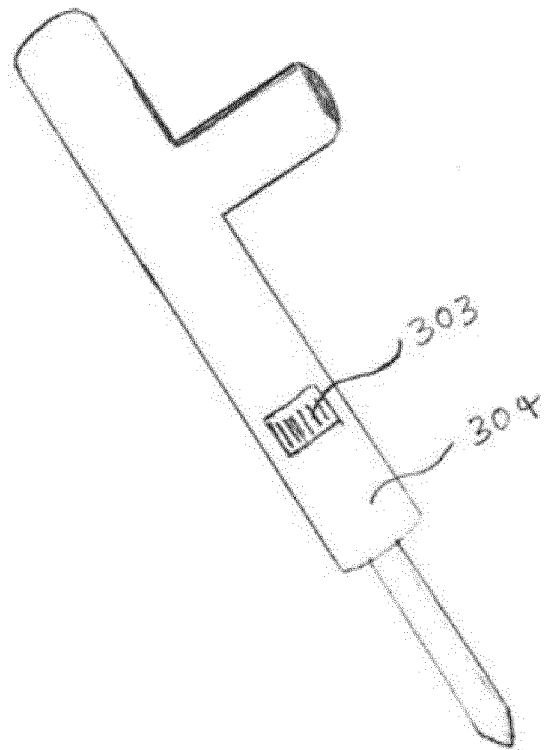


Fig. 13:

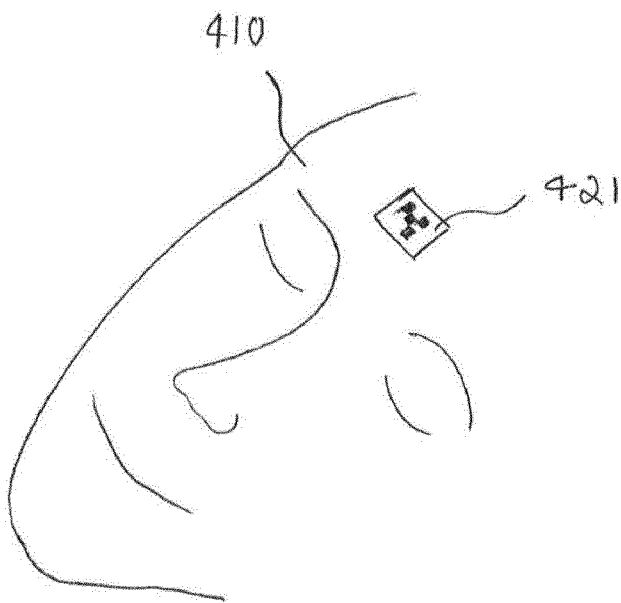


Fig. 14

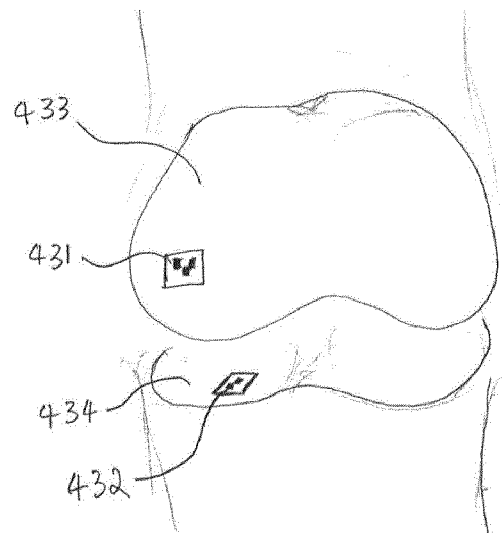


Fig. 15:

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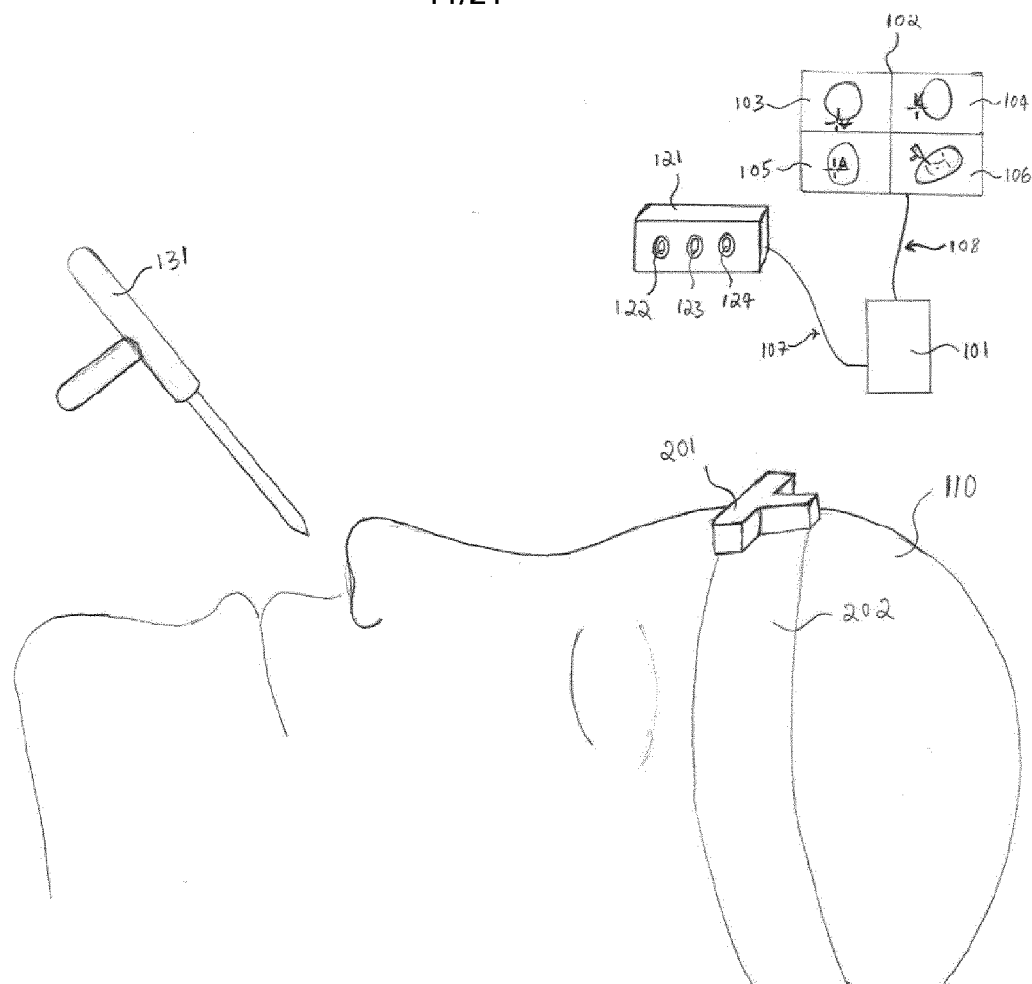


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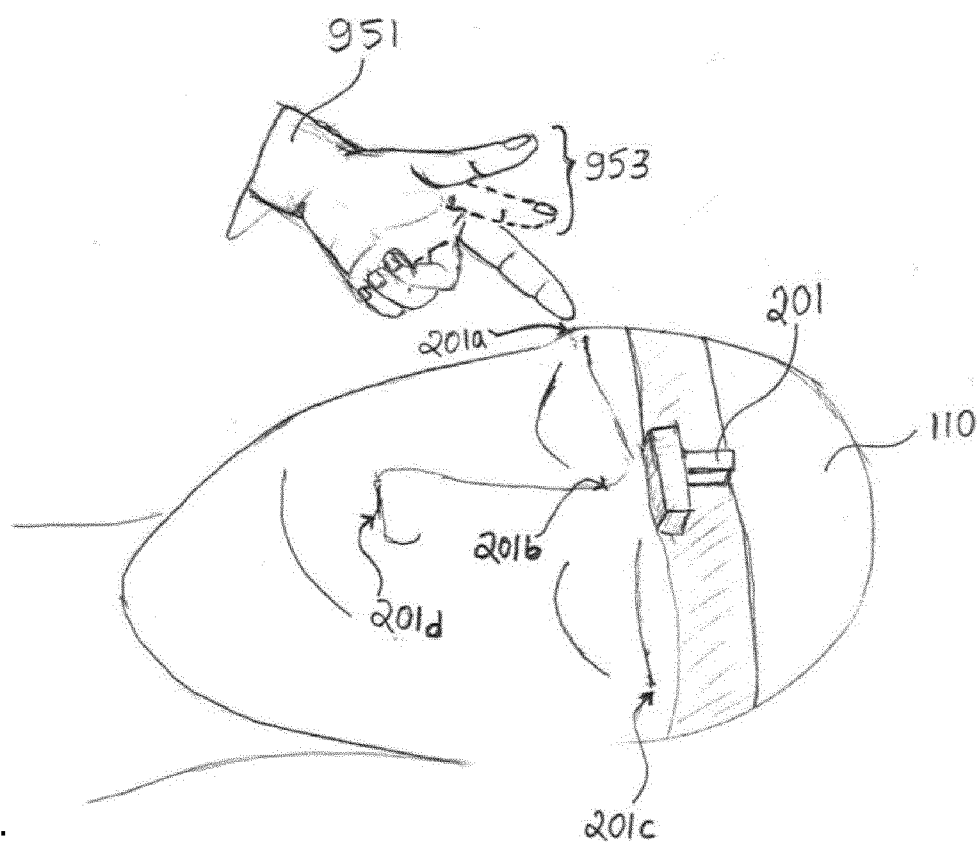


Fig. 17:

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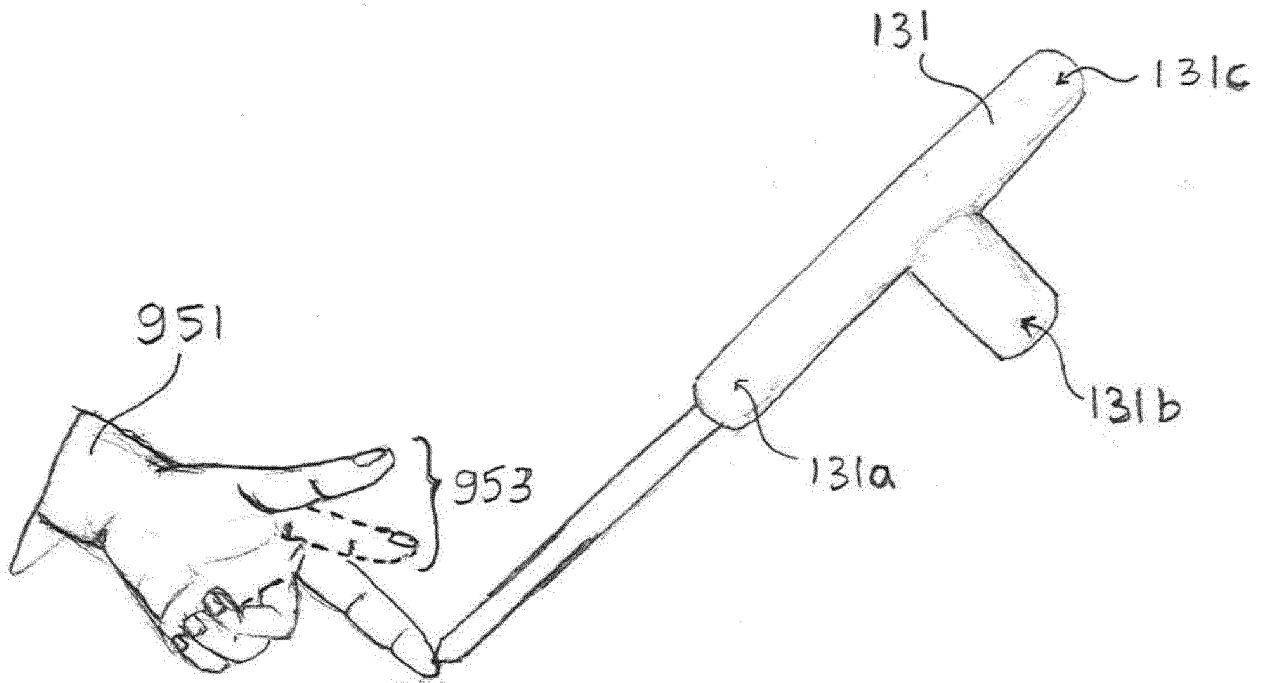


Fig. 18:

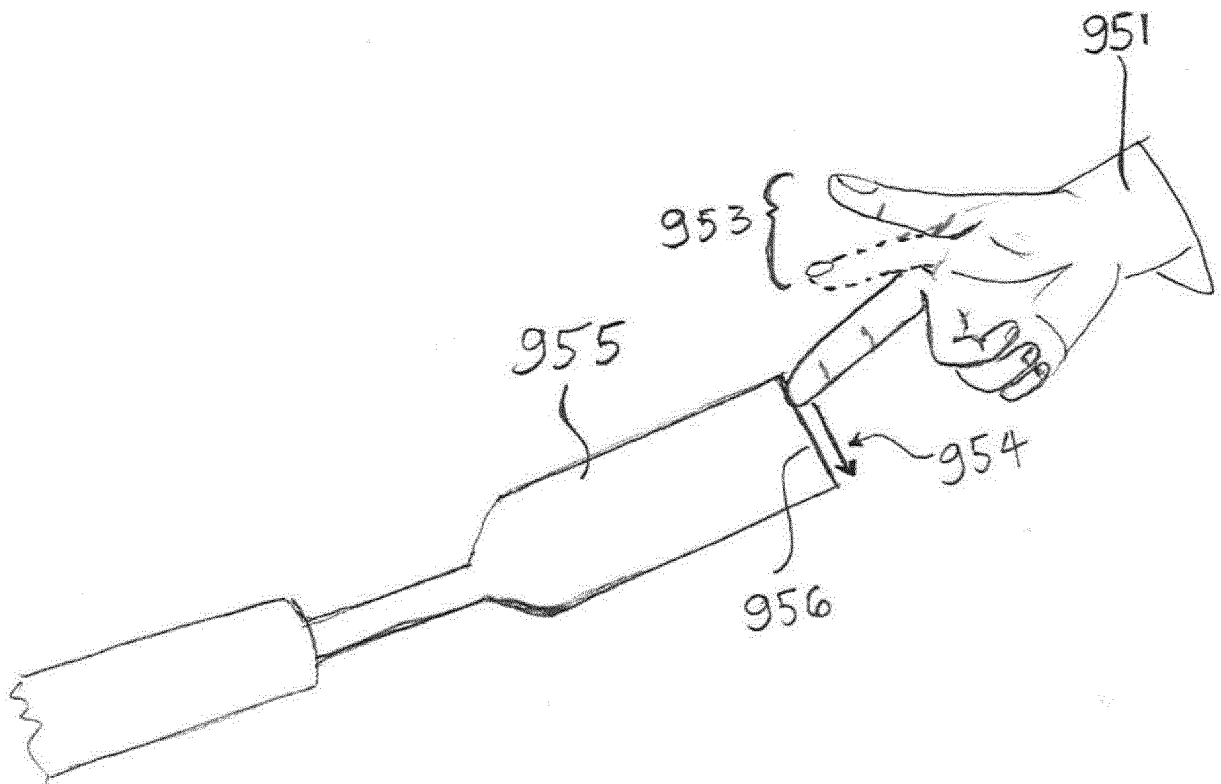


Fig. 19:

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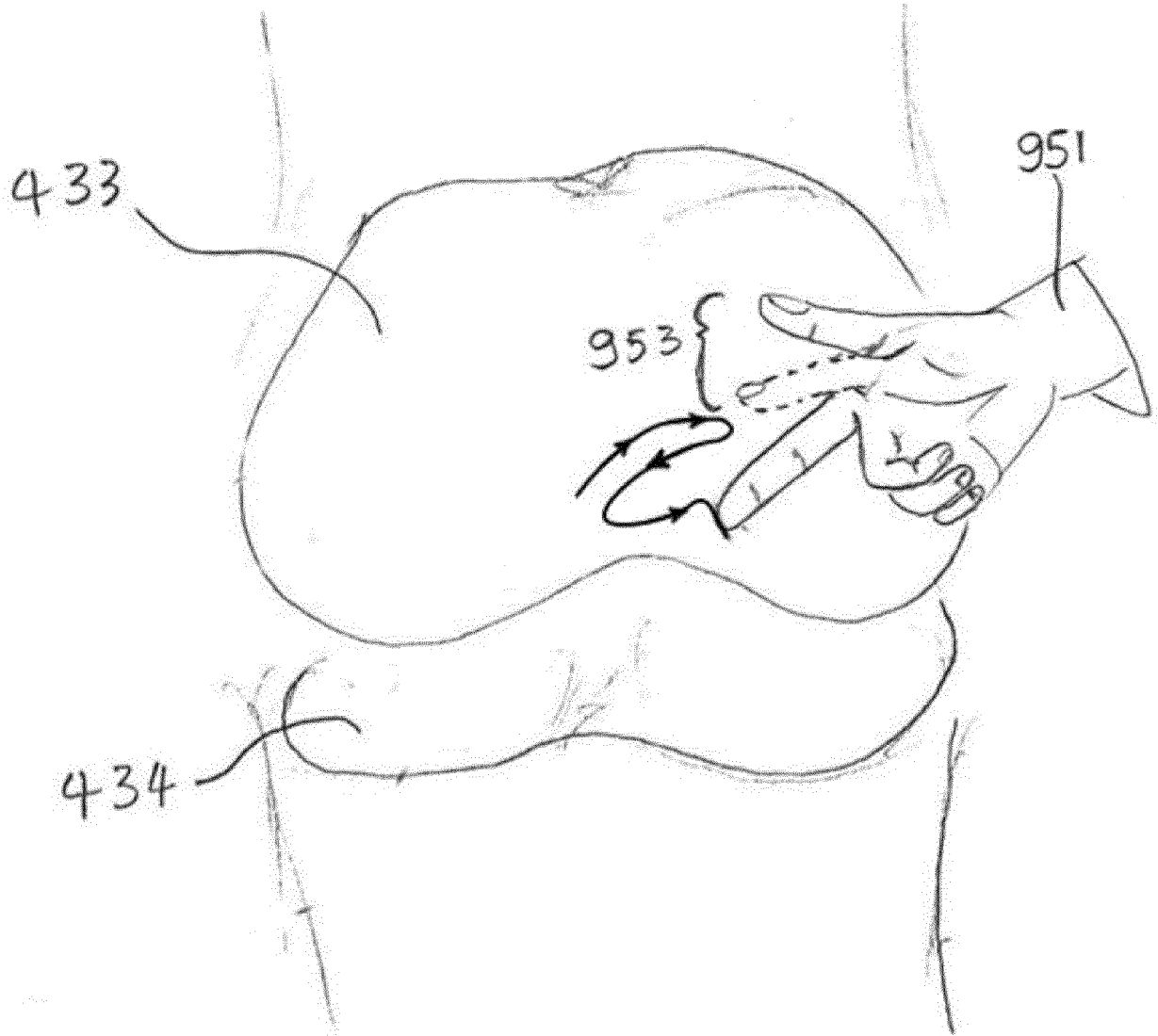


Fig. 20:

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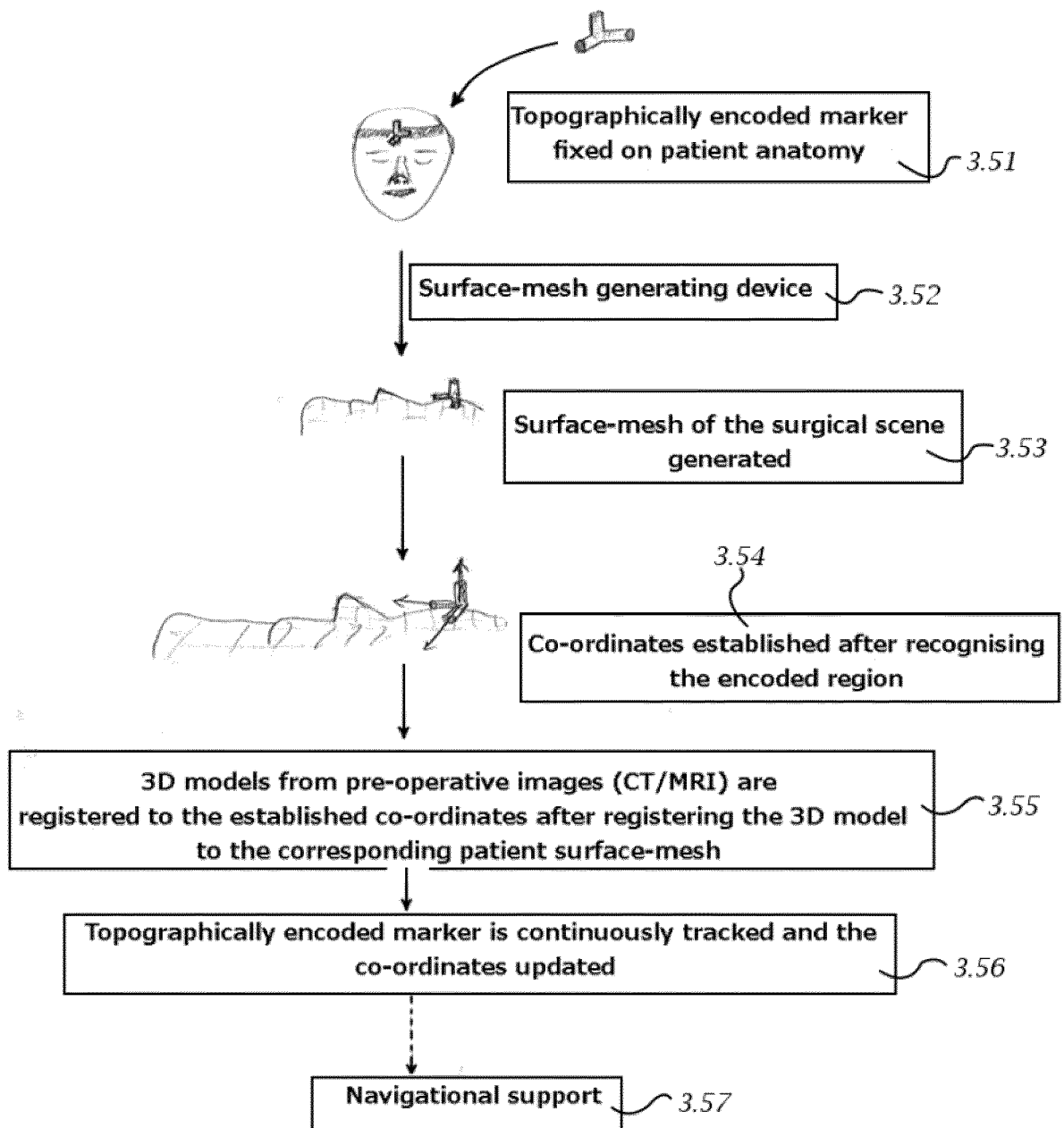


Fig. 21:

Fig. 22:

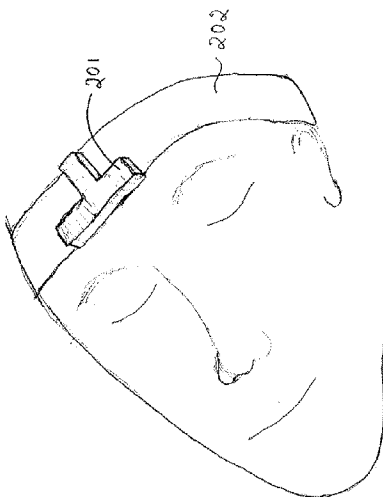
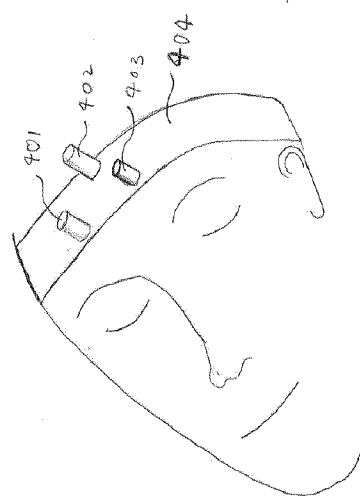


Fig. 23:



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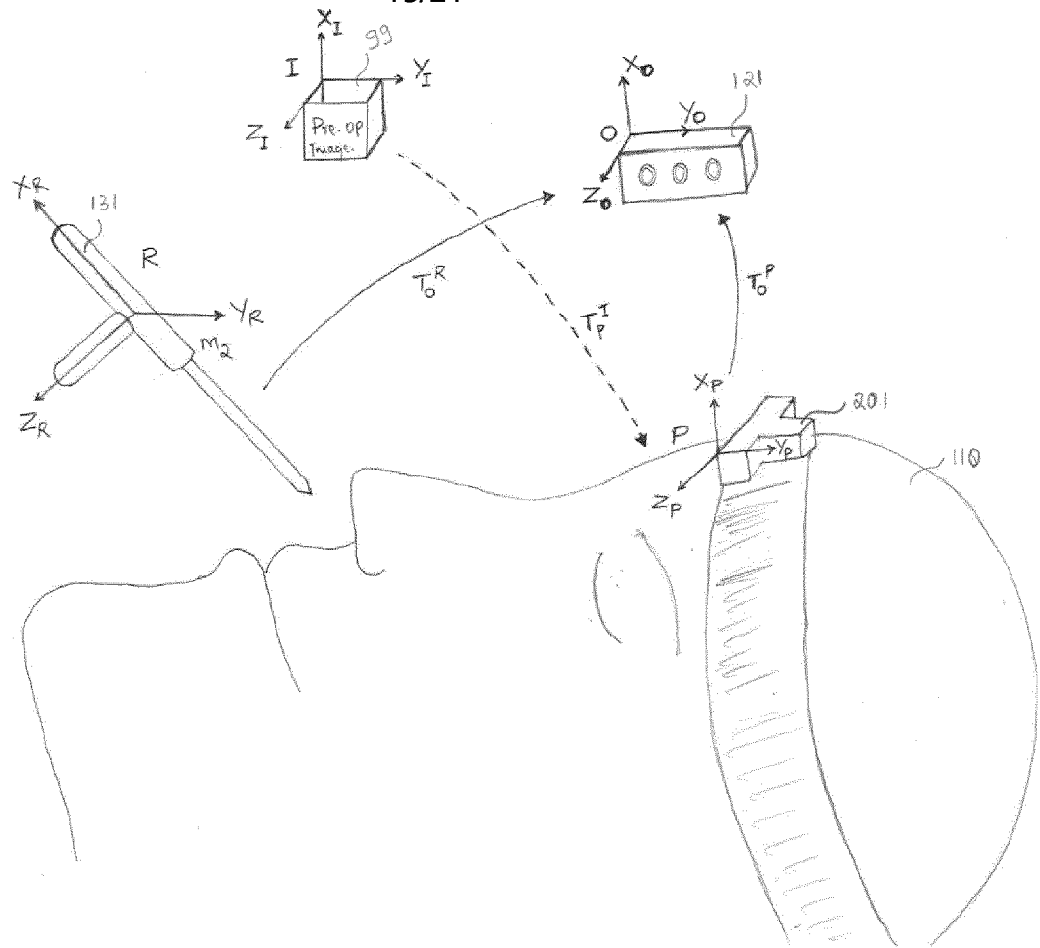


Fig. 24:

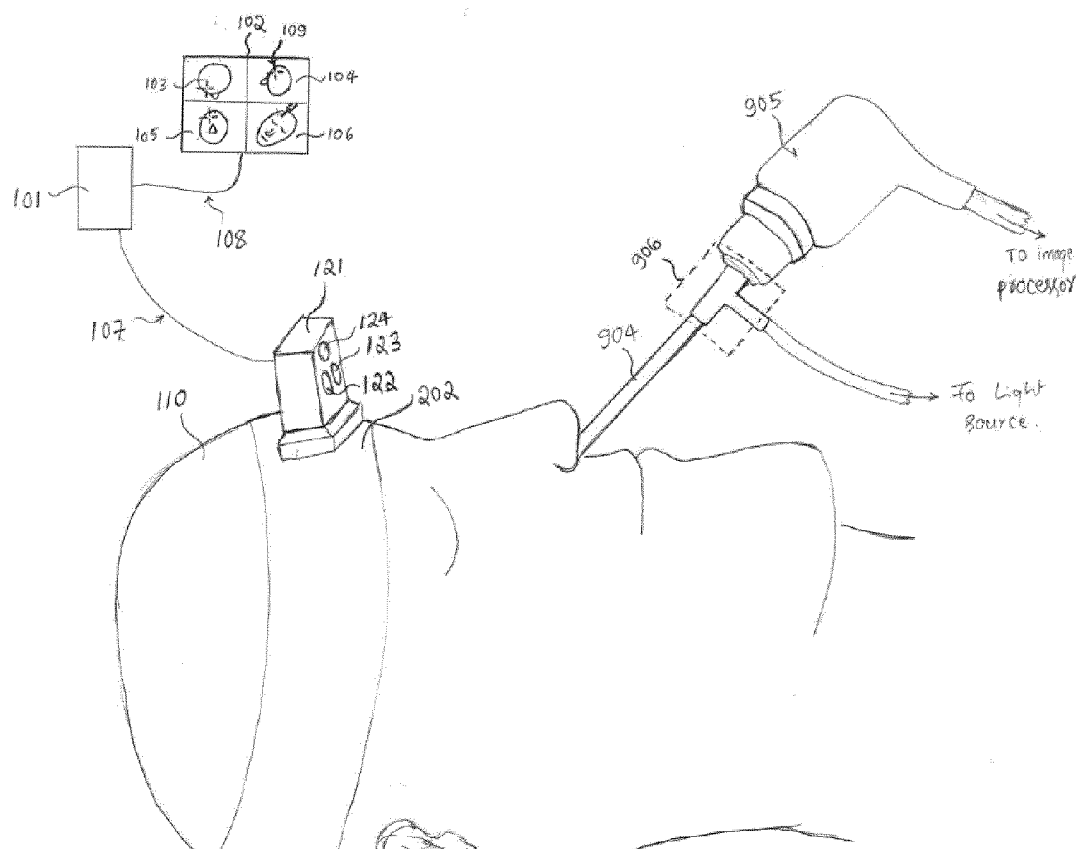


Fig. 25:

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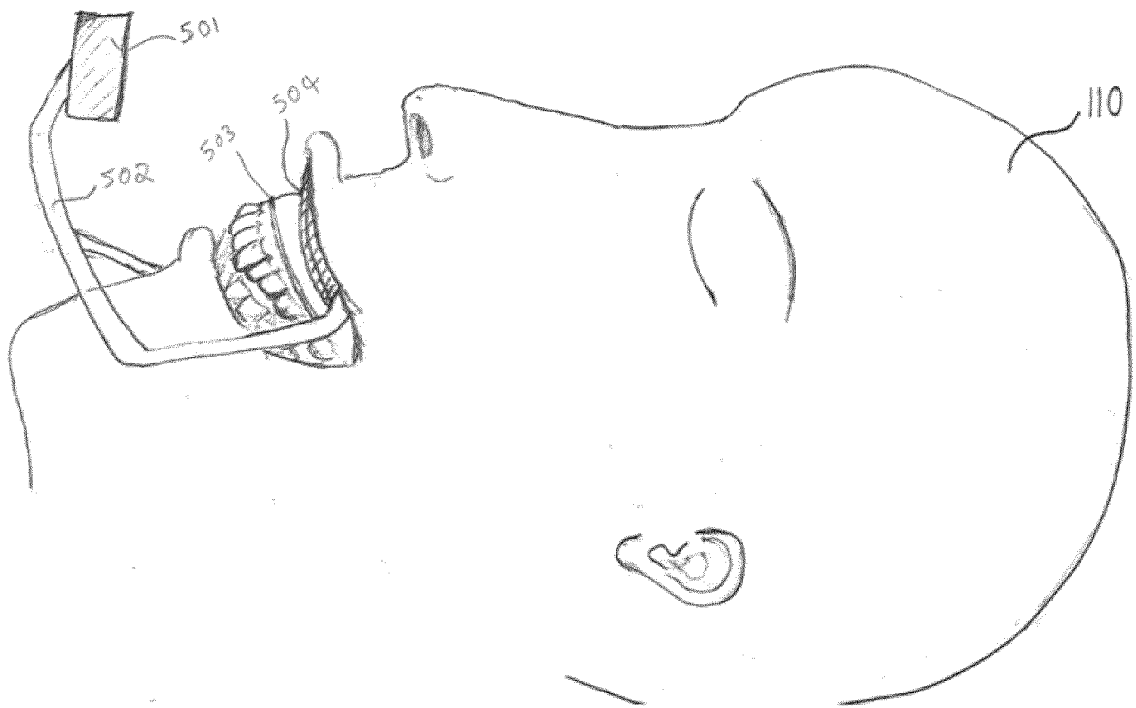


Fig. 26:

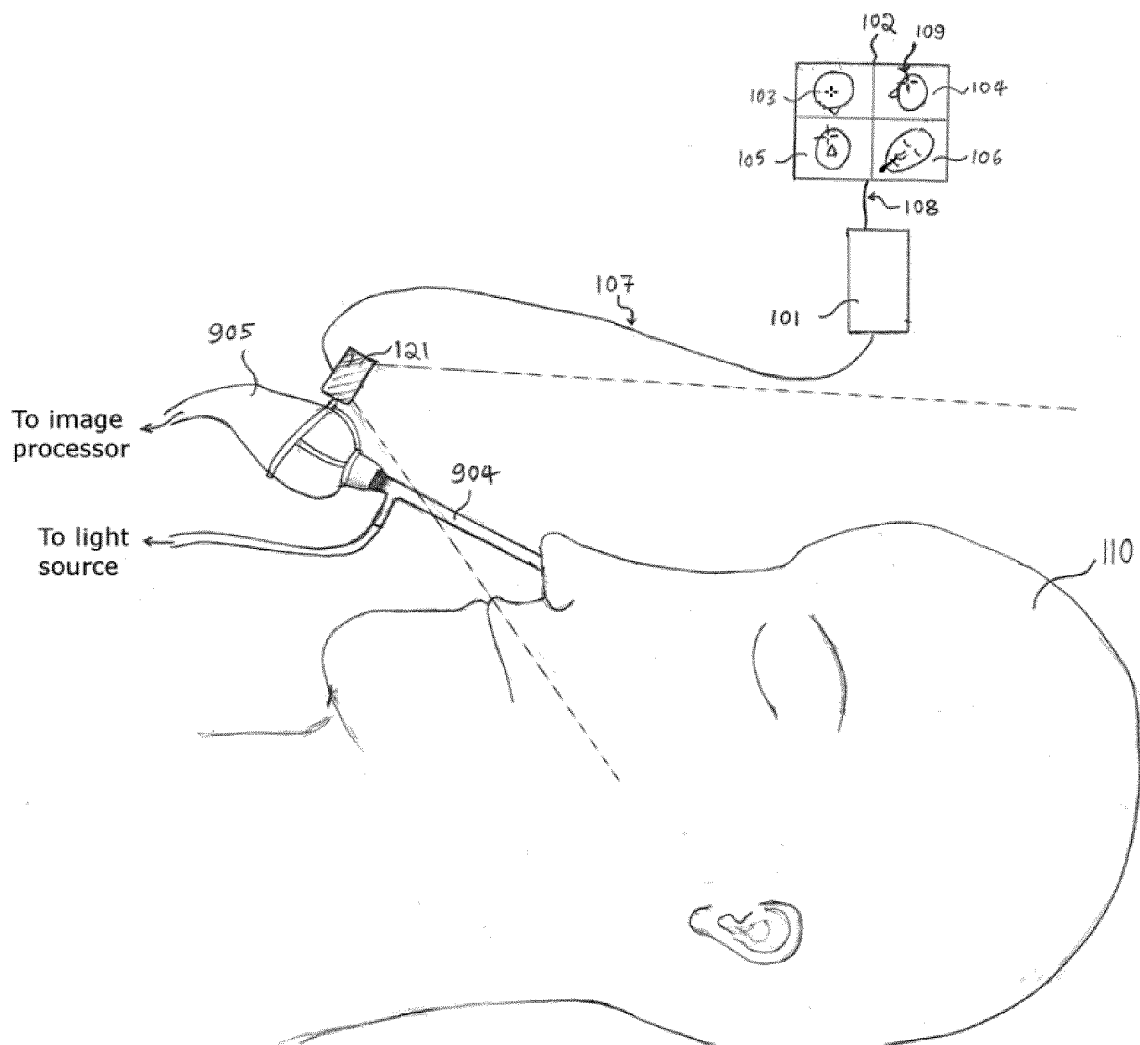


Fig. 27:

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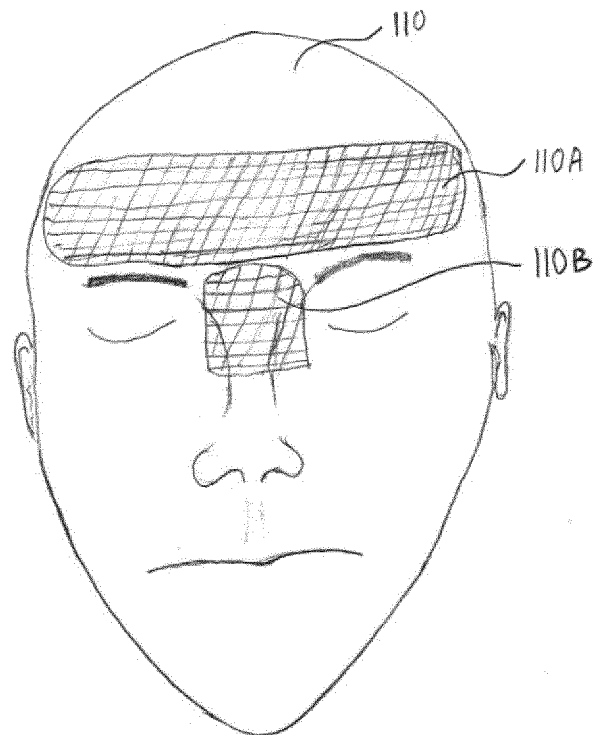


Fig. 28:

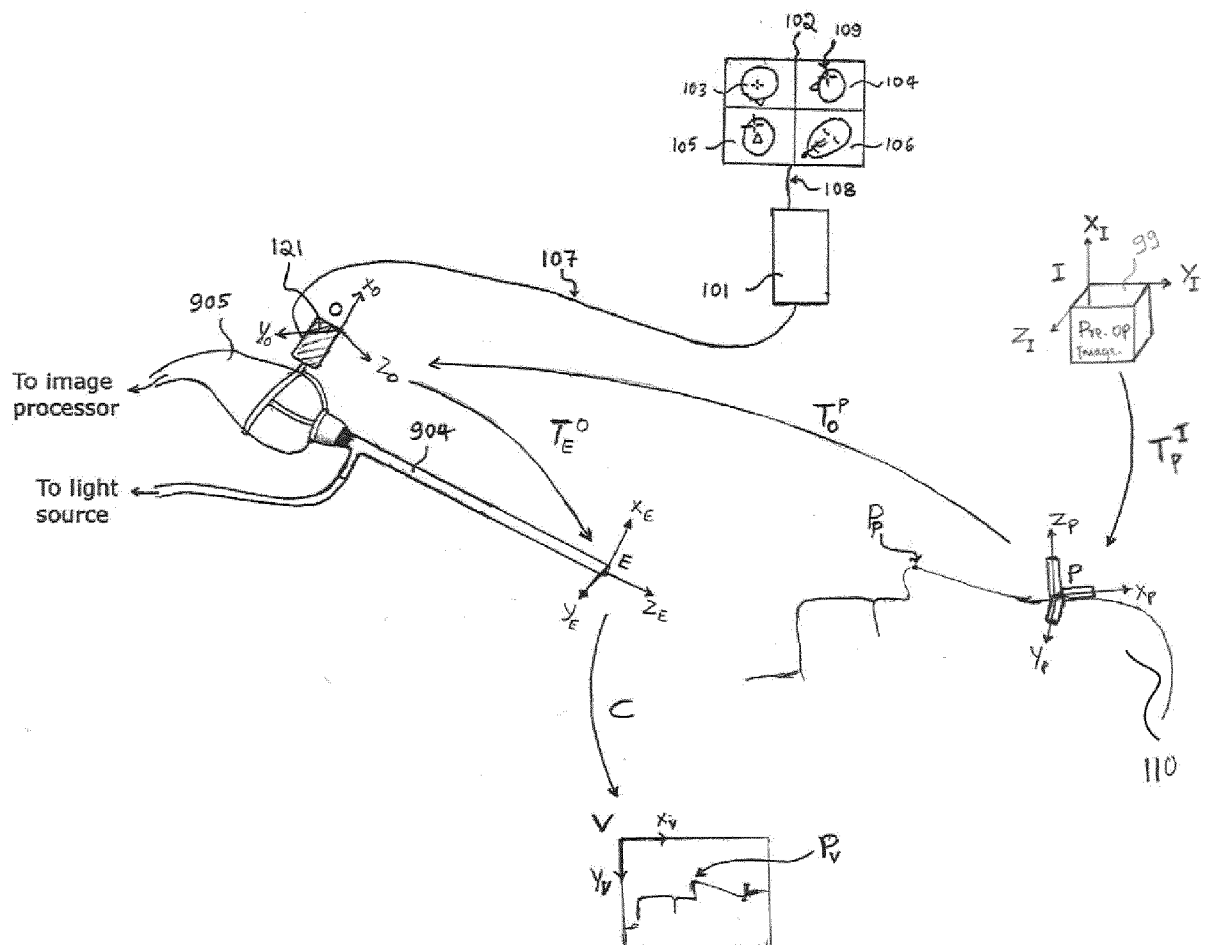


Fig. 30:

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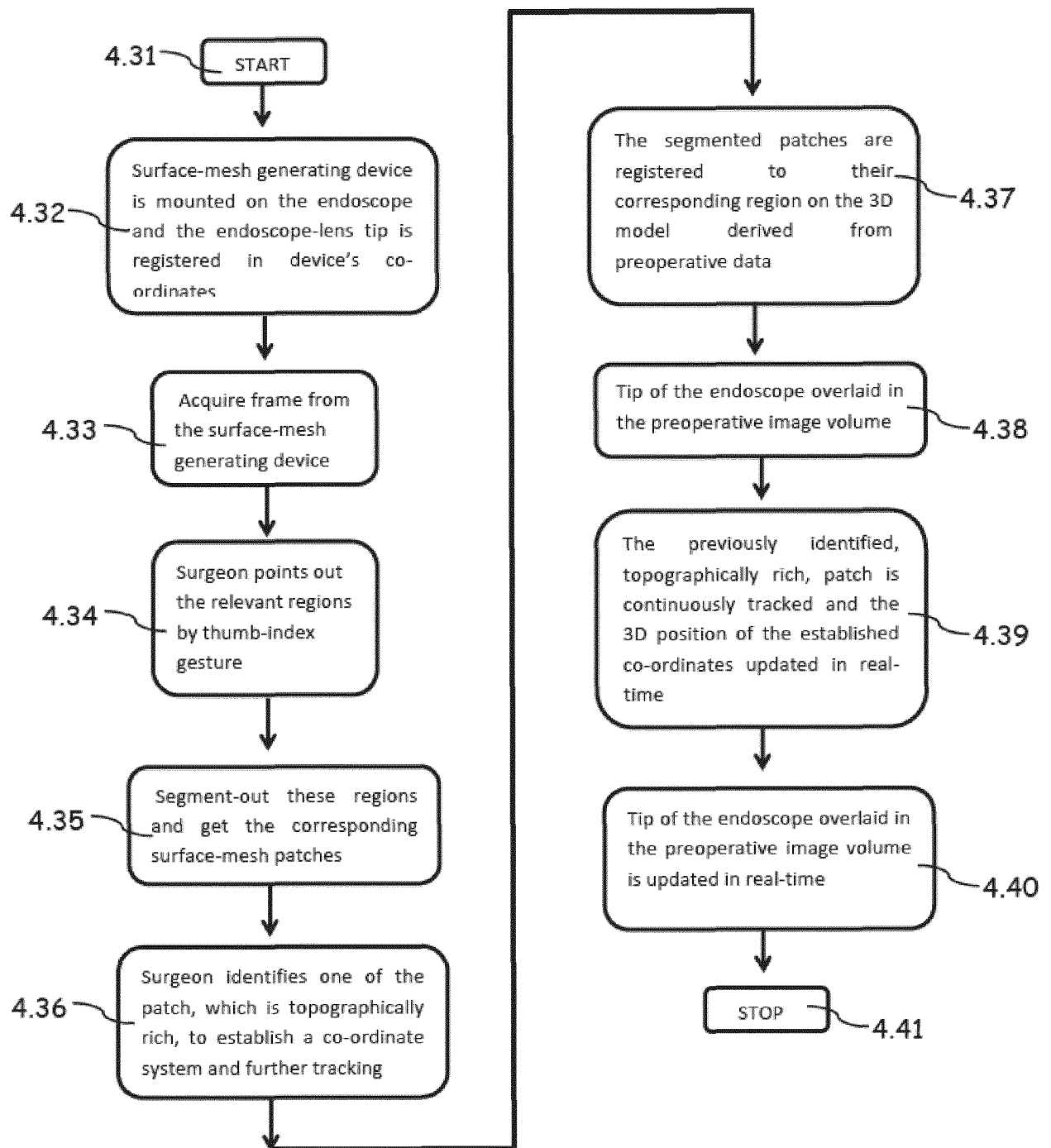


Fig. 29:

19/21

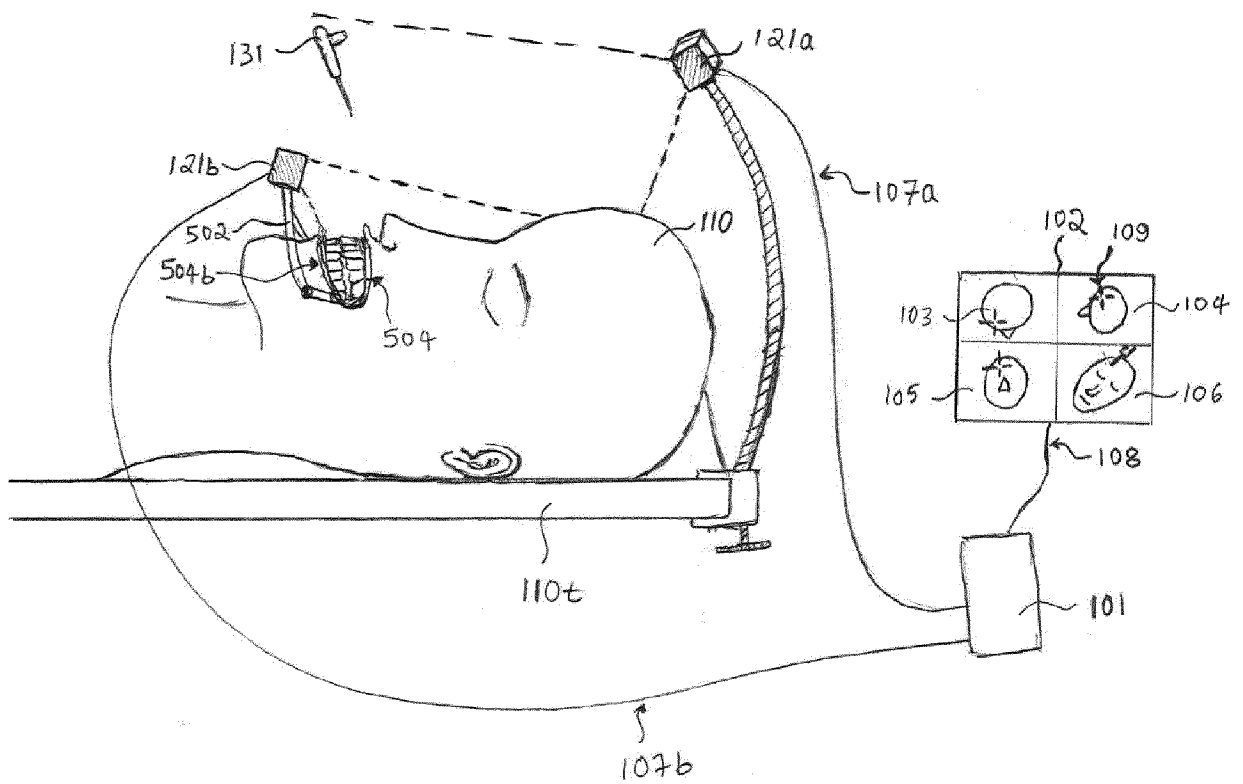


Fig. 31:

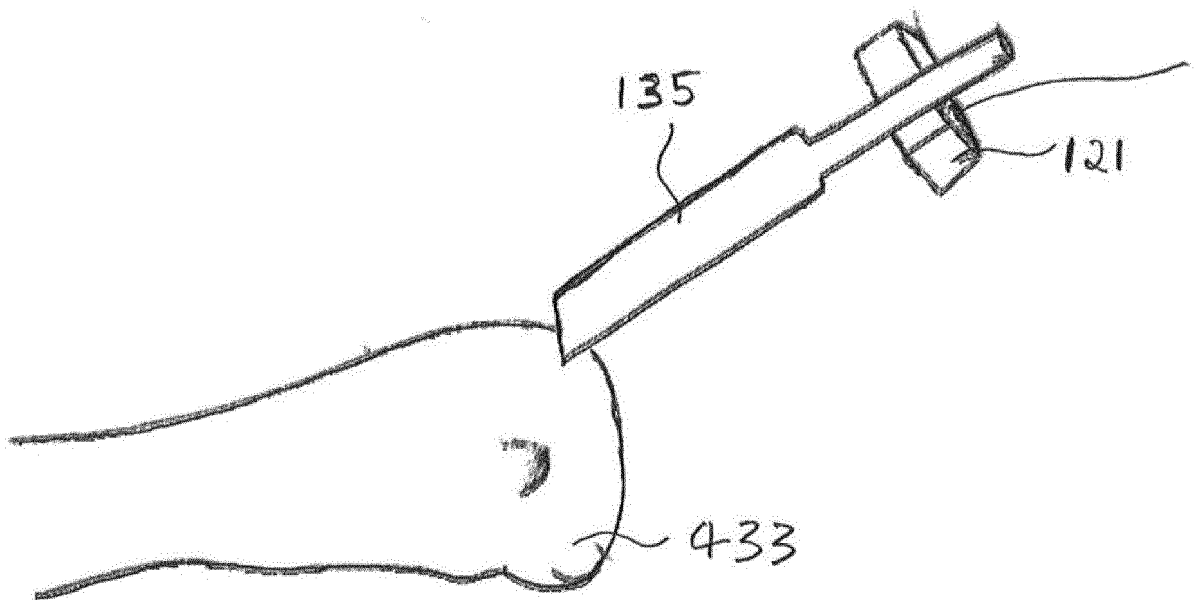


Fig. 32:

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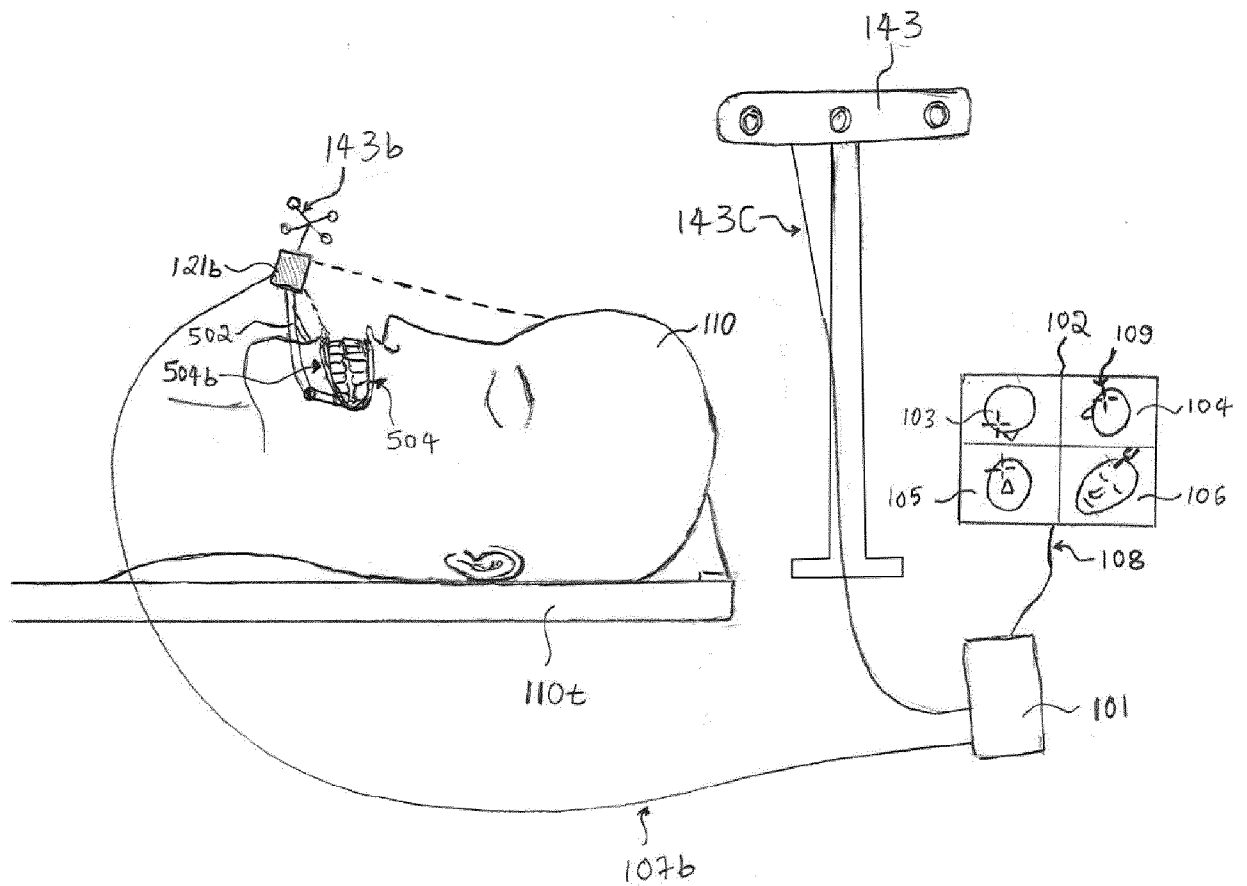


Fig. 33:

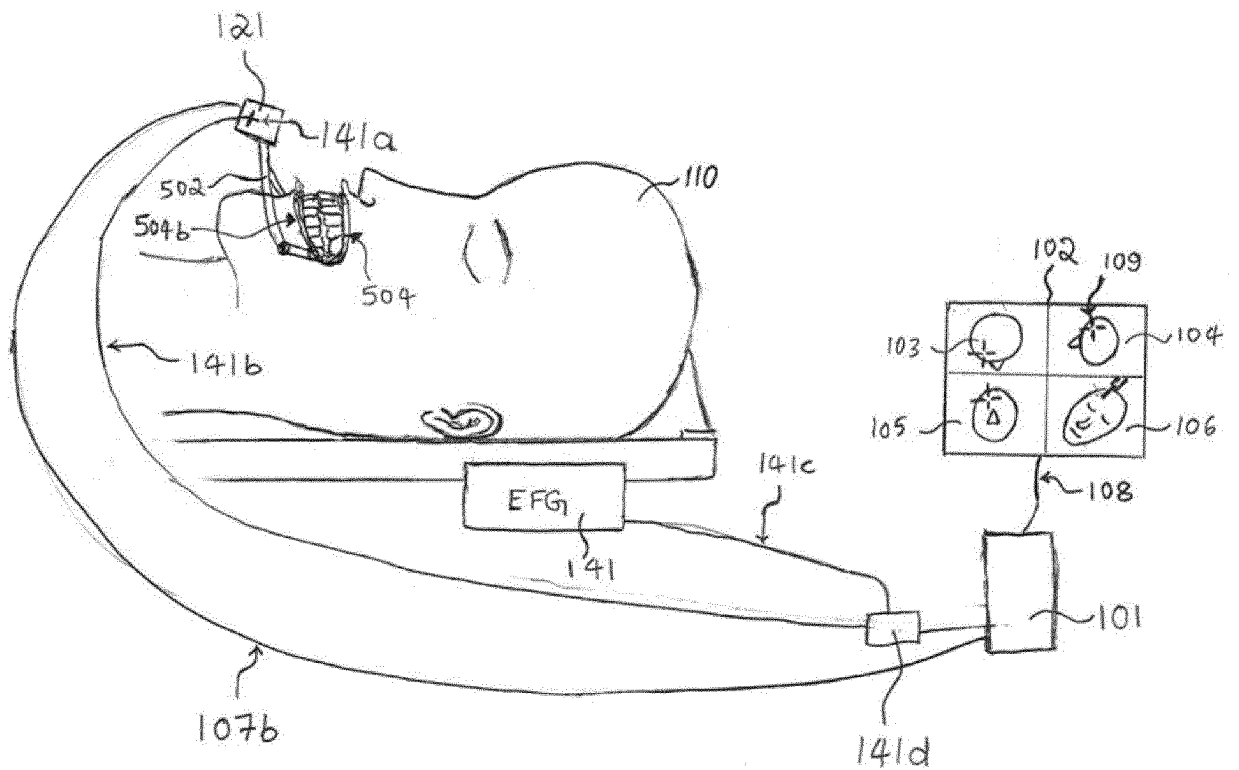


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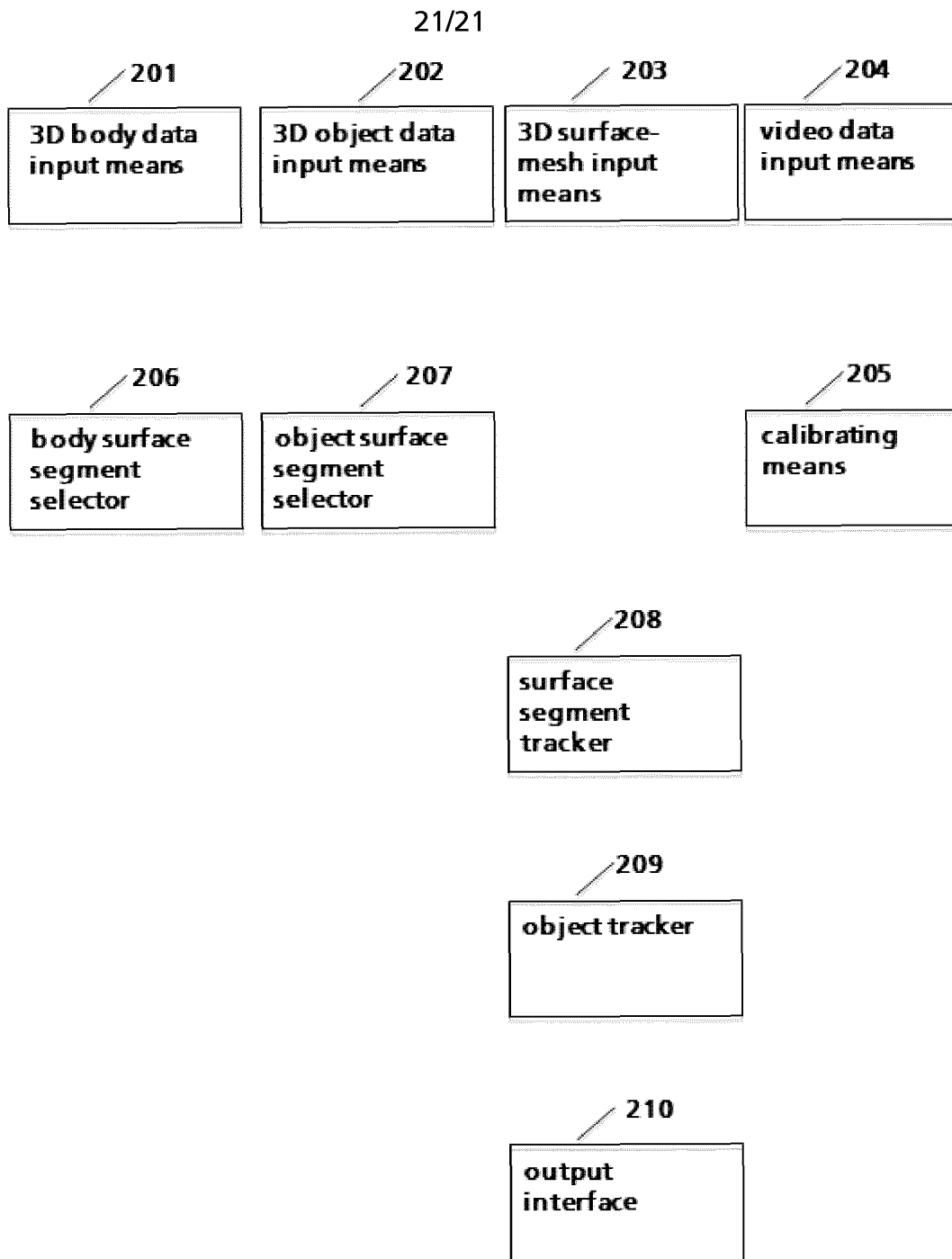


Fig. 35:

INTERNATIONAL SEARCH REPORT

International application No

PCT/EP2014/052526

A. CLASSIFICATION OF SUBJECT MATTER

INV. A61B19/00

ADD.

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

A61B G06F

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2009/068620 A1 (KNOBEL BRUNO [CH] ET AL) 12 March 2009 (2009-03-12) paragraph [0040] - paragraph [0107] paragraph [0172] - paragraph [0193]; figure 14	43,44
X	----- EP 2 233 099 A2 (MASMEC S R L [IT]) 29 September 2010 (2010-09-29) paragraph [0012] - paragraph [0051]; figures	43,44
X	----- WO 2009/045827 A2 (INTUITIVE SURGICAL INC [US]) 9 April 2009 (2009-04-09) paragraph [0191] - paragraph [0212]; figures 15, 16 ----- -/-	43,44



Further documents are listed in the continuation of Box C.



See patent family annex.

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier application or patent but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search

15 May 2014

Date of mailing of the international search report

23/05/2014

Name and mailing address of the ISA/

European Patent Office, P.B. 5818 Patentlaan 2
NL - 2280 HV Rijswijk
Tel. (+31-70) 340-2040,
Fax: (+31-70) 340-3016

Authorized officer

Croatto, Loredana

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2014/052526

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	WO 2007/106046 A2 (BRACCO IMAGING SPA [IT]; ZHU CHUANGGUI [SG]; AGUSANTO KUSUMA [SG]) 20 September 2007 (2007-09-20) paragraph [0058] - paragraph [0117]; figures -----	43,44
X	US 2011/306873 A1 (SHENAI KRISHNA [US] ET AL) 15 December 2011 (2011-12-15) paragraph [0045] - paragraph [0171]; claims 1-12, 23-31; figures -----	43,44
X	WO 2010/133994 A1 (KONINKL PHILIPS ELECTRONICS NV [NL]; PHILIPS INTELLECTUAL PROPERTY [DE]) 25 November 2010 (2010-11-25) page 1, line 18 - page 8, line 7; figures -----	43,44

INTERNATIONAL SEARCH REPORT

International application No.
PCT/EP2014/052526

Box No. II Observations where certain claims were found unsearchable (Continuation of item 2 of first sheet)

This international search report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☒ Claims Nos.: 1-42
because they relate to subject matter not required to be searched by this Authority, namely:
Rule 39.1(iv) PCT - Method for treatment of the human or animal body by surgery
2. ☐ Claims Nos.:
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:
3. ☐ Claims Nos.:
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box No. III Observations where unity of invention is lacking (Continuation of item 3 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

1. ☐ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.
2. ☐ As all searchable claims could be searched without effort justifying an additional fees, this Authority did not invite payment of additional fees.
3. ☐ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:
4. ☐ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

Remark on Protest

- ☐ The additional search fees were accompanied by the applicant's protest and, where applicable, the payment of a protest fee.
- ☐ The additional search fees were accompanied by the applicant's protest but the applicable protest fee was not paid within the time limit specified in the invitation.
- ☐ No protest accompanied the payment of additional search fees.

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/EP2014/052526

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 2009068620 A1	12-03-2009	CA 2611404 A1	14-12-2006
		DE 112006001514 A5	05-06-2008
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