

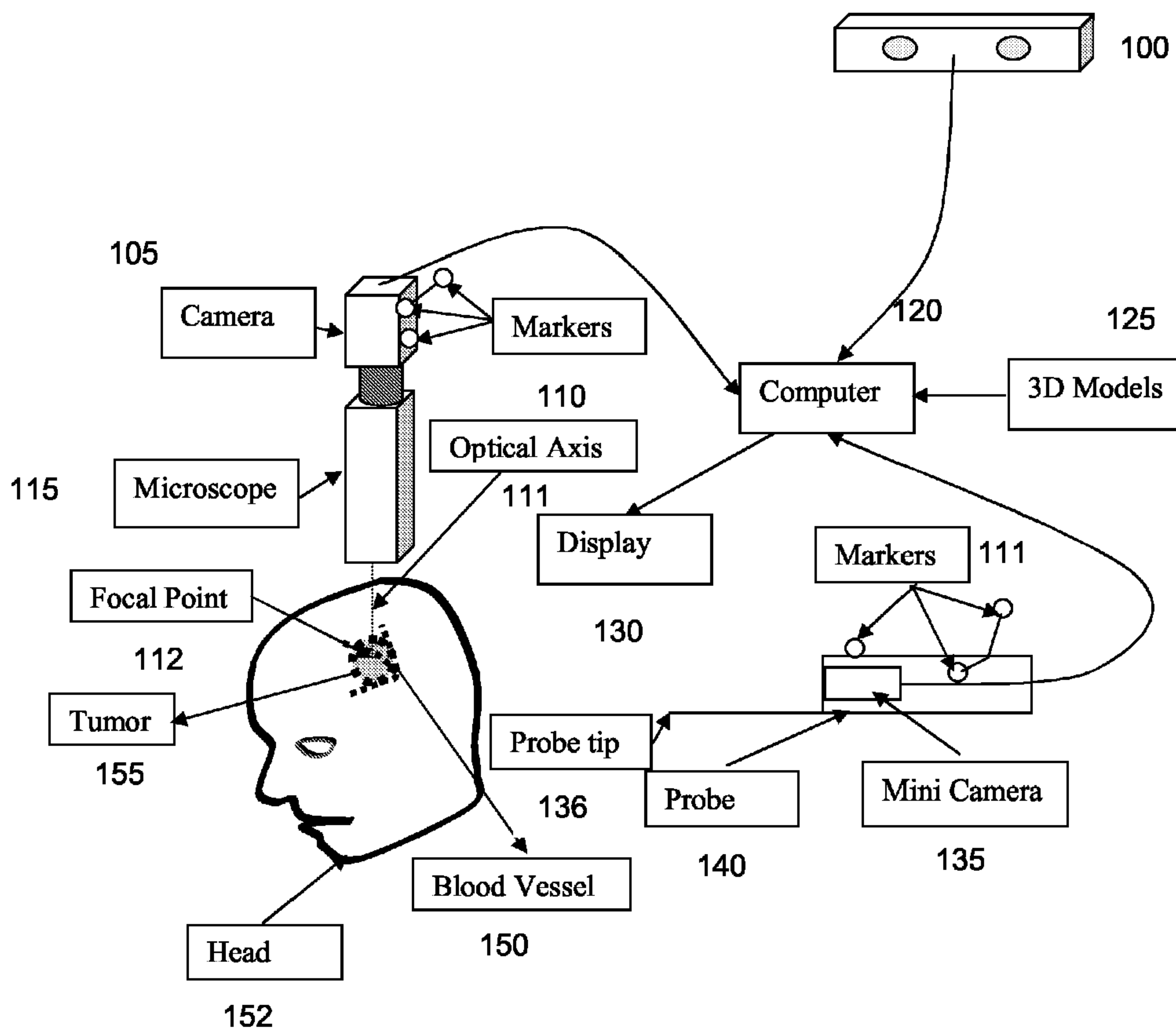


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(54) Titre : METHODES ET APPAREIL DE NAVIGATION ET VISUALISATION A DES FINS CHIRURGICALES A L'AIDE D'UN MICROSCOPE

(54) Title: METHODS AND APPARATI FOR SURGICAL NAVIGATION AND VISUALIZATION WITH MICROSCOPE



(57) Abrégé/Abstract:

An improved system and method for macroscopic and microscopic surgical navigation and visualization are presented. In exemplary embodiments of the present invention an integrated system can include a computer which has stored three dimensional

(57) **Abrégé(suite)/Abstract(continued):**

representations of a patient's internal anatomy, a display, a probe and an operation microscope. In exemplary embodiments of the present invention reference markers can be attached to the probe and the microscope, and the system can also include a tracking system which can track the 3D position and orientation of each of the probe and microscope. In exemplary embodiments of the present invention a system can include means for detecting changes in the imaging parameters of the microscope, such as, for example, magnification and focus, which occur as a result of user adjustment and operation of the microscope. The microscope can have, for example, a focal point position relative to the markers attached to the microscope and can, for example, be calibrated in the full range of microscope focus. In exemplary embodiments of the present invention, the position of the microscope can be obtained from the tracking data regarding the microscope and the focus can be obtained from, for example, a sensor integrated with the microscope. Additionally, a tip position of the probe can also be obtained from the tracking data of the reference markers on the probe, and means can be provided for registration of virtual representations of patient anatomical data with real images from one or more cameras on each of the probe and the microscope. In exemplary embodiments of the present invention visualization and navigation can be provided by each of the microscope and the probe, and when both are active the system can intelligently display a microscopic or a macroscopic (probe based) augmented image according to defined rules.

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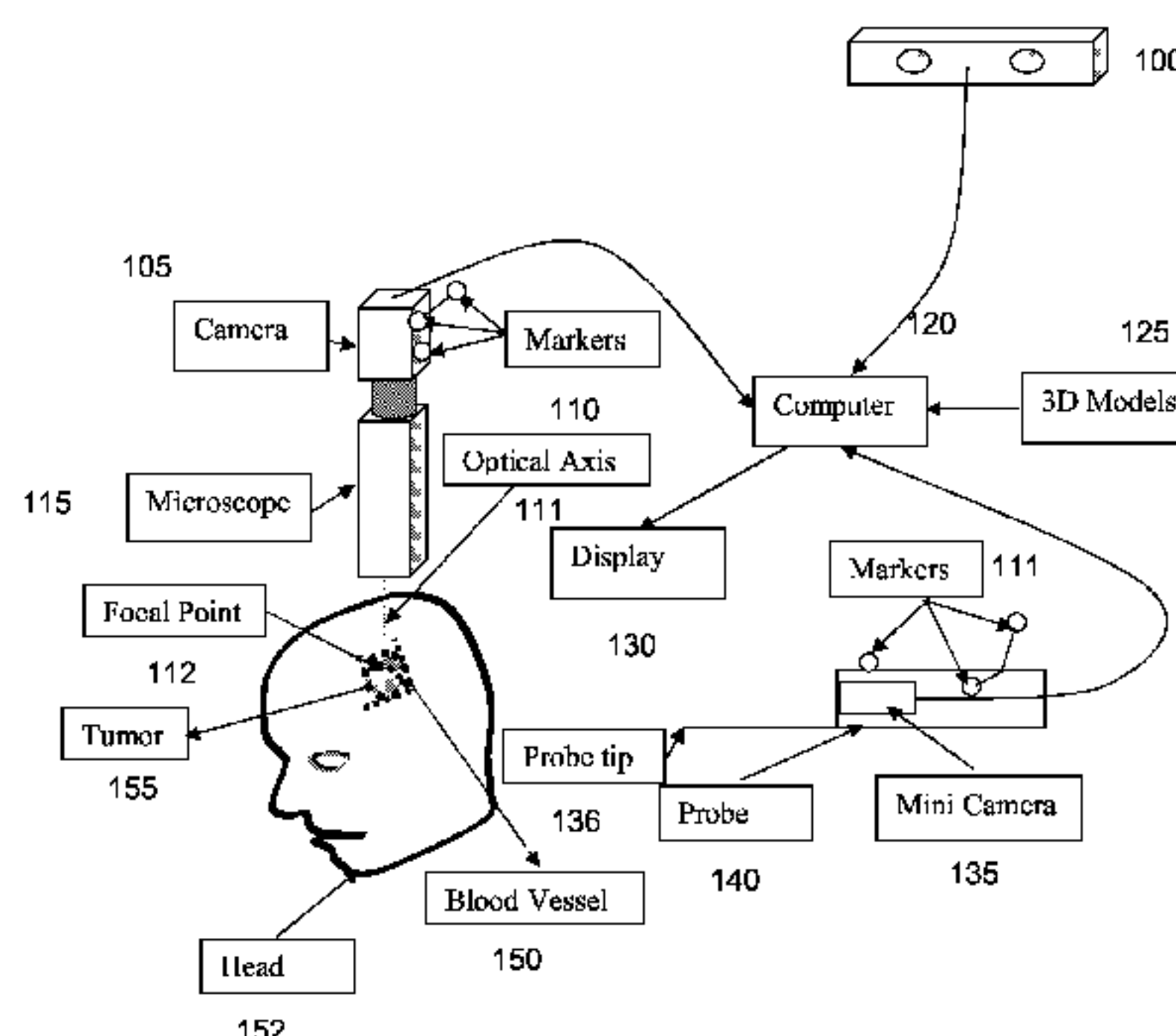
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(54) Title: METHODS AND APPARATI FOR SURGICAL NAVIGATION AND VISUALIZATION WITH MICROSCOPE



(57) Abstract: An improved system and method for macroscopic and microscopic surgical navigation and visualization are presented. In exemplary embodiments of the present invention an integrated system can include a computer which has stored three dimensional representations of a patient's internal anatomy, a display, a probe and an operation microscope. In exemplary embodiments of the present invention reference markers can be attached to the probe and the microscope, and the system can also include a tracking system which can track the 3D position and orientation of each of the probe and microscope. In exemplary embodiments of the present invention a system can include means for detecting changes in the imaging parameters of the microscope, such as, for example, magnification and focus, which occur as a result of user adjustment and operation of the microscope. The microscope can have, for example, a focal point position relative to the markers attached to the microscope and can, for example, be calibrated in the full range of microscope focus. In exemplary embodiments of the present invention, the position of the microscope can be obtained from the tracking data regarding the microscope and the focus can be obtained from, for example, a sensor integrated with the microscope. Additionally, a tip position of the probe can also be obtained from the tracking data of the reference markers on the probe, and means can be provided for registration of virtual representations of patient anatomical data with real images from one or more cameras on each of the probe and the microscope. In exemplary embodiments of the present invention visualization and navigation can be provided by each of the microscope and the probe, and when both are active the system can intelligently display a microscopic or a macroscopic (probe based) augmented image according to defined rules.

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METHODS AND APPARATI FOR SURGICAL NAVIGATION AND VISUALIZATION WITH MICROSCOPE

CROSS REFERENCE TO RELATED APPLICATIONS:

This application claims the benefit of United States Provisional Patent Application No. 60/660,845, filed on March 11, 2005, under common assignment herewith, which is hereby incorporated herein by this reference. This application also claims the benefit of PCT/ SG2005/00244, entitled Systems and Methods For Mapping A Virtual Model Of An Object To The Object ("Multipoint Registration") filed on 20 July 2005, which is also incorporated herein by reference. This application also incorporates herein by reference the disclosure of United States Patent Application No. 10,832,902, filed on April 27, 2004, and published as US Published Patent Application Publication No. 20050015005 ("the Camera-probe Application").

TECHNICAL FIELD:

[0001] The present invention relates to image-based surgical guidance and visualization systems.

BACKGROUND OF THE INVENTION

[0002] Neurosurgery is routinely conducted in two operational modes: a macroscopic mode and a microscopic mode. In the former a surgical field is generally viewed with the naked eye, and in the latter the surgical field is viewed

through a microscope. In each of these operational modes, image based navigation and visualization systems have been used with success in aiding physicians to perform a wide variety of delicate surgical procedures.

[0003] In image based navigation and visualization, images depicting the internal anatomies of a patient are generated, usually from magnetic resonance imaging (MRI), computer tomography (CT), and a variety of other technologies, prior to or during a surgery. A three-dimensional (3D) representation of the patient is generated from the images. The representation can be in various forms, from volume images and 3D models of various anatomical structures of the patient reconstructed from the images, to drawings, annotations and measurements added to illustrate a surgical plan, and a combine of them. At surgery, the 3D representation is aligned with the patient by registration. By linking the images of internal anatomy with the actual surgical field, navigation systems can improve the surgeon's ability to locate various anatomical features inside the patient in the operation.

[0004] In macroscopic navigation, a user (surgeon) holds a probe which is tracked by a tracking device. When such a probe is introduced into a surgical field, the position of the probe tip represented as an icon is drawn on the view of the 3D representation of the patient. Navigation helps the surgeon to decide the entry point, to understand the anatomic structures toward the target, and to avoid critical structures along the surgical path.

[0005] US Published Patent Application Publication No. 20050015005 describes an improved navigation system where the probe includes a micro camera. This enables augmented reality enhanced navigation within a given

operative field by viewing real-time images acquired by the micro-camera overlaid on the 3D representation of the patient.

[0006] During microscopic surgery, an operation microscope is often used to provide a magnification of the surgical field within which a surgeon is working. The microscope can be tracked for navigation purposes and its focal point can be usually shown in the 3D representation in place of the probe tip.

[0007] To avoid having to look away from a surgical scene to a monitor, “image injection” microscopes have been developed where the navigation view generated by the computer workstation is superimposed on the optical image of the microscope. Such a superposition requires that the image seen through the microscope and the superimposed image data conform geometrically.

[0008] Current image overlay in microscope-based navigation systems consists of two-dimensional contours superimposed onto an optical image plane. To get a three-dimensional impression a surgeon has to scroll through different image planes and mentally merge the injected contours into a three-dimensional model.

[0009] Such conventional techniques allow a surgeon to navigate in a surgical field in both macroscopic surgery as well as when performing microscopic surgery. However, they also have the following significant drawbacks.

[0010] First, it is not unusual that during microscopic surgery, a surgeon would want to switch between the microscope based and probe based navigation and visualization. To do this, a surgeon usually must move the microscope up

and/or away from the surgical field and then move the navigation probe into the surgical field, seriously interrupting normal surgical flow.

[0011] Second, to enable a surgeon to perform delicate procedures on microstructures, such as, for example, nerves and vessels, magnification of a microscope is usually set at a high level during the operation.

[0012] While this high level magnification does allow for the visualization of such microstructures, it also often limits the field of view. As the virtual image which can then be superimposed would have the same magnification ratio, the display of virtual objects is also limited. This can lead to a situation in which the surgeon cannot unambiguously identify an area that he is viewing through the microscope with an actual place on the patient. It is simply too small an area that he can view. As well, the overlay image may also not provide much useful information because the anatomic structures around the area are outside the field of view and thus not visible. Furthermore, under such circumstances a surgeon cannot see 3D structures of anatomic interest around the surgical field from a different point of view.

[0013] Third, during microscopic surgery, it is generally desirable for a surgeon to be fully aware of all of the structures around the surgical field. In conventional systems navigation views are superimposed on the optical view of the microscope. While this has the advantage that a surgeon can see a navigational view without looking away from the microscope, it has the disadvantages that only limited information in the navigation view can be displayed, that the display may seriously block the optical view of the surgeon, and the image injection increases the cost of the system.

[0014] Accordingly, what is needed in the art is a surgical navigation and visualization method and system which reduces the need to move off of the magnified view of a surgical field for navigation during microscopic surgery.

[0015] What is further needed in the art is a surgical imaging method and system which can provide integrated augmented reality enhanced microscopic and macroscopic navigation and visualization, as well as the facility to seamlessly and efficiently switch between them.

SUMMARY OF THE INVENTION

[0016] An improved system and method for macroscopic and microscopic surgical navigation and visualization are presented. In exemplary embodiments of the present invention an integrated system can include a computer which has stored three dimensional representations of a patient's internal anatomy, a display, a probe and an operation microscope. In exemplary embodiments of the present invention reference markers can be attached to the probe and the microscope, and the system can also include a tracking system which can track the 3D position and orientation of each of the probe and microscope. In exemplary embodiments of the present invention a system can include means for detecting changes in the imaging parameters of the microscope, such as, for example, magnification and focus, which occur as a result of user adjustment and operation of the microscope. The microscope can have, for example, a focal point position relative to the markers attached to the microscope and can, for example, be calibrated in the full range of microscope focus. In exemplary embodiments of the present invention, the position of the microscope can be

obtained from the tracking data regarding the microscope and the focus can be obtained from, for example, a sensor integrated with the microscope. Additionally, a tip position of the probe can also be obtained from the tracking data of the reference markers on the probe, and means can be provided for registration of virtual representations of patient anatomical data with real images from one or more cameras on each of the probe and the microscope. In exemplary embodiments of the present invention visualization and navigation images can be provided by each of the microscope and the probe, and when both are active the system can intelligently display either a microscopic or a macroscopic (probe based) real, virtual or augmented image according to defined rules.

BRIEF DESCRIPTION OF THE DRAWINGS

[0017] Figs. 1A-1C illustrate digital zooming of an augmented reality image according to an exemplary embodiment of the present invention;

[0018] Fig. 1D depicts an exemplary navigation system according to an exemplary embodiment of the present invention;

[0019] Fig. 2 shows a schematic depiction of a real image of an exemplary patient head according to an exemplary embodiment of the present invention;

[0020] Fig. 3 shows a schematic depiction of a virtual image of a tumor and blood vessel according to an exemplary embodiment of the present invention;

[0021] Fig. 4 shows a schematic depiction of a combined (augmented reality) image according to an exemplary embodiment of the present invention;

[0022] Fig. 5 shows a schematic depiction of a magnified augmented reality view according to an exemplary embodiment of the present invention;

[0023] Fig. 6 shows a schematic depiction of a magnified microscopic view according to an exemplary embodiment of the present invention;

[0024] Fig. 7 shows a schematic depiction of digitally zoomed-out (magnified) microscopic view according to an exemplary embodiment of the present invention;

[0025] Fig. 8 shows schematic depiction of an exemplary navigational view from a probe according to an exemplary embodiment of the present invention;

[0026] Fig. 9 shows an exemplary navigational view from a surgical microscope according to an exemplary embodiment of the present invention;

[0027] Fig. 10 shows the exemplary view of Fig. 9 after digitally zooming-in according to an exemplary embodiment of the present invention; and

[0028] Fig. 11 shows an exemplary augmented reality navigational view from an exemplary probe according to an exemplary embodiment of the present invention.

DETAILED DESCRIPTION OF THE INVENTION

[0029] In exemplary embodiments of the present invention, navigation and visualization in both macroscopic and microscopic surgery can be smoothly facilitated and integrated. Thus, in such exemplary embodiments, there is no need to move a surgical microscope off of, or away from, a surgical field for navigation or visualization during a microscopic surgery to implement macroscopic navigation or visualization. Further, in exemplary embodiments of the present invention an augmented reality enhanced navigation system can be provided which can, for example, provide both microscopic and macroscopic navigational information of three-dimensional (3D) anatomic structures of the patient to a surgeon without the need to move the microscope off of, or away from, as the case may be, the surgical field.

[0030] In exemplary embodiments of the present invention, a video camera can, for example, be rigidly attached to a microscope. A computer can, for example, store a virtual microscope camera model having the same imaging properties and pose (position and orientation) as the corresponding actual video camera, said imaging properties including focal length, field of view and distortion parameters, zoom and focus. In exemplary embodiments of the present invention means can be provided to generate an augmented view for microscopic navigation by overlaying the video images from the camera, or cameras, as the case may be, on the microscope with virtual rendered images of the patient's 3D anatomical structures generated by the computer according to the corresponding virtual microscope camera model in response to the position and orientation data of the microscope from the tracking device as well as magnification and focus data obtained from the microscope itself, by, for example, an integrated sensor.

[0031] In exemplary embodiments of the present invention there can also be a video camera integrated with a probe, such as, for example, is described in the Camera-probe Application. As described in the Camera-probe Application, a virtual model of the video camera having the same imaging properties and pose (position and orientation) as the actual video camera, said imaging properties including focal length, field of view and distortion parameters, can be provided. Further, means can be provided to generate an augmented view for macroscopic navigation by overlaying video images from the camera in the probe with rendered images of the patient's 3D anatomical structures generated by the computer according to the virtual camera model in response to the position and orientation data of the probe from the tracking device.

[0032] In exemplary embodiments of the present invention an augmented

microscopic view can be digitally zoomed so that a magnified view of microscopic navigation can be obtained without requiring a change of the position and settings (magnification and focus) of the microscope. An anatomic structure outside of the optical field of the microscope at its current settings can thus be displayed in such a zoomed-out display, overlaid only partly by the real time video image coming from the microscope's camera in the center of the display. Additionally, in exemplary embodiments of the present invention a user need not change the setting of or move the microscope away to obtain a macroscopic navigation view. A user need only move the probe, which can image the surgical field from any arbitrary viewpoint.

As noted above, the microscopic image can be digitally zoomed. This is next described. Change of magnification or zoom in an AR image works by changing the field of view of the virtual camera (*i.e.* its frustum shape) together with the real image by ensuring that the video image plane is aligned along the frustum of virtual camera. This concept is illustrated with reference to Figs. 1A-1C. It is noted that the original figures were in color, and the following description makes reference to those colors. However, the referents are easily discernable even in greyscale images.

Fig. 1A depicts a virtual camera (red axes at left of left image), and its frustum, represented by a near plane (dark blue; left side of left image) connected to a far plane (dark grey; right edge of left image), together with a virtual object.

The video image, (pink rectangle), has its image centers aligned to the center of frustum. In this setting, for example, the video image size is set to be the same as the

near plane. Thus, the full video image covers the screen-view (or viewport), and there is no zooming effect.

In Fig. 1B the frustum has been changed such that a virtual object is projected with a magnification or zooming-in effect. Such change in frustum causes a change in what is visible in the screen space for the video image. Because now only some parts of the video image are inside the projection plane (near-plane), covering the screen view, there is a zooming-in effect also in the video image.

In Fig. 1C the frustum is changed such that the virtual object is projected with a zooming-out effect (appearing smaller). This change in frustum causes the whole video image inside the projection plane (near-plane) to cover only a part of the screen-view, thus the video image appears smaller in the screen view.

In the exemplary embodiment of the present invention, the change of frustum can be achieved by changing the parameters of the perspective matrix of the virtual camera that produce the perspective projection. Specifically, a perspective projection matrix of 4x4 matrix defined in an OpenGL context can, for example, be defined with the following parameters:

$$\begin{aligned} \text{ProjMat}[0] &= 2 * \text{Near} / (\text{Right} - \text{Left}) * \text{zoomFactor} \\ \text{ProjMat}[2] &= (\text{Right} + \text{Left}) / (\text{Right} - \text{Left}) \\ \text{ProjMat}[5] &= 2 * \text{Near} / (\text{Top} - \text{Bottom}) * \text{zoomFactor} \\ \text{ProjMat}[6] &= (\text{Top} + \text{Bottom}) / (\text{Top} - \text{Bottom}) \\ \text{ProjMat}[10] &= - (\text{Far} + \text{Near}) / (\text{Far} - \text{Near}) \\ \text{ProjMat}[11] &= -2 * \text{Far} * \text{Near} / (\text{Far} - \text{Near}) \\ \text{ProjMat}[14] &= -1 \\ \text{ProjMat}[15] &= 0 \end{aligned}$$

with element 1,3,4,7,8,9,12, and 13 having value of 0 (read from left to right, top to bottom rule).

The parameters Left, Right, Top, Bottom are functions of the microscope model based on the intrinsic camera calibration parameters together with focus and zoom setting of the microscope. The parameter for Near and Far can be, for example, set at constant values.

The parameter *zoomFactor* is the factor that determines the zooming-in or zooming-out effects. When its value is below 1, the effect is zooming-out, and when greater than 1, the effect is zooming-in. No zoom effect is operative when the value is 1.

In exemplary embodiments of the present invention, the video image can be displayed as a texture map with the orthographic projection. To enable a correct and consistent overlay of the virtual object in the video image during zooming-in or zooming-out, an OpenGL viewport can be adjusted by following parameters:

```

GLfloat cx = fabs (Left) / (Right-Left)
GLfloat cy = fabs (Bottom) / (Top -Bottom)

glViewport ( (1 - zoomFactor) * screenWidth * cx + originX ,
             (1 - zoomFactor) * screenHeight * cy + originY ,
             screenWidth * zoomFactor ,
             screenHeight * zoomFactor );

```

which is, basically, scaling the size of screen view with a *zoomFactor*, and shifting the origin of the viewport according to the *zoomFactor*, video-image

centers (cx, and cy), and the origin of OpenGL window such that the visible video image is overlaid correctly with the virtual image.

[0033] In exemplary embodiments of the present invention a probe can be used during microscopic surgery to obtain navigational views from varying orientations and locations. The anatomic structures around the surgical field, together with the focal points and optical axis of the microscope can be displayed from the point of view of the probe camera. The anatomic structures around the surgical area from various view points can, for example, thus be presented to the surgeon without the need of changing the microscope.

[0034] With reference to Fig. 1D, a surgical navigation system as used in performing a neurosurgical procedure according to an exemplary embodiment of the present invention is shown. In the figure the surgery is in the microscopic mode. Operation microscope 115 has a camera 105, which can, for example, be a color camera, installed on its imaging port and reference markers 110 can be mounted to it. The microscope 115 can, for example, have a built-in sensor to detect changes in imaging parameters of the microscope occurring as a result of adjustment of the microscope wherein said imaging parameters include parameters comprising microscope magnification and focus. Such a sensor can be, for example, an encoder. The adjustment of focus and zoom involves mechanical movement of the lenses and such an encoder can, for example, measure such movement. The parameters can be available from a serial port of the microscope. The data format can be, for example, of the form Zoom: +120; Focus: 362. The microscope can also have an optical axis 111 and a focal point 112 which is defined as the intersection point of the optical axis and the focus

plane of the microscope. A focus plane is perpendicular to the optical axis. On focus plane you can get the clearest image. A focal plane changes with focus adjustment. In exemplary embodiments of the present invention a focal point's position relative to reference markers 110 can be calibrated in the full range of microscope focus and therefore can be depicted from the tracking data.

[0035] In Fig. 1D the microscope is being viewed by a surgeon and in the microscope's light path there is a patient's head 152. The exemplary patient has a tumor 155 (which is the target object of the operation) and a blood vessel structure 150 (which should be avoided during the operation) close to tumor 155. A position tracking system 100 (such as, for example, NDI Polaris) can receive commands and can send tracking data to a computer 120, either, for example, wirelessly or through a cable linked with the computer.

[0036] Computer 120 can have 3D models 125 of the tumor 155 and blood vessel structure 150 stored in its memory prior to the navigation, such as for example, after pre-operative scanning and processing of such scan data into a volumetric data set containing various segmentations and planning data. A probe 140 can, for example, contain a video camera 135, and a pointer with a tip 136 can be attached to its front end. The probe 140 can be placed within easy reach of a surgeon to facilitate its use during the surgery. The probe can, for example, be of the type as disclosed in the Camera-probe Application. The position tracking system 100 can provide continual real time tracking data of the microscope 115 to the computer. When the probe 140 is introduced into the surgical field, the position tracking system 100 can also provide continual real time tracking data of the probe 140 to the computer. The computer can be connected to (i) a display 130, (ii) a camera and sensor of microscope 115, and

(iii) a mini camera of the probe. The system can further include software to detect position and orientation data of the microscope and probe from the tracking data, and from such position data to automatically select one (probe or microscope) to be used as a basis of images for navigation and/or visualization. Such automatic selection can be according to defined priority rules or various algorithms as may be appropriate to a given application and a given user's preferences.

[0037] For example, a given user may prefer to get his general bearings via a macroscopic view, and then when he gets close to delicate structures, use a microscopic view. If an operation has multiple stages, it can easily be seen that such a surgeon would cycle through using the probe, then the microscope, then again the probe and then again the microscope. For such a surgeon, the system could realize that for an initial period the main implement is a probe, and then once a microscope has been engaged it is the main implement until a new microscope position has been chosen, when the probe is once again used at the beginning of another stage. The system could, as a result, generate a combined image on the display corresponding to a view from whichever implement was then prioritized. Many alternative rules could be implemented, and a surgeon could always override such priority settings by actuating a switch or voice controlled interface.

[0038] Continuing with reference to Fig. 1D, the computer 120 can receive a real-time video image of a surgical scene acquired by microscope camera 105. Microscope camera 105 can, for example, have a microscope virtual camera model which can be provided and stored in computer 120.

[0039] In exemplary embodiments of the present invention a microscope virtual camera model can have a set of intrinsic parameters and extrinsic parameters wherein said intrinsic parameters can include, for example, focal length, image center and distortion, and said extrinsic parameters can include, for example, position and orientation of the virtual microscope camera model in relative to a reference coordinate system.

[0040] In exemplary embodiments of to the present invention a reference coordinate system can be, for example, the coordinate system of markers 110 which are rigidly linked to microscope 115.

[0041] In exemplary embodiments of the present invention the intrinsic and extrinsic parameters of the microscope camera model can change according to changes of the microscope's magnification and focus.

[0042] In exemplary embodiments according to the present invention the intrinsic and extrinsic parameters of the microscope camera model can be described as bivariate polynomial functions of the microscope magnification and focus. For example, a parameter ρ (ρ represents one of the intrinsic and extrinsic parameters) can be modeled as a qth order bivariate polynomial function of the values of focus (f) and zoom (z) of the microscope, as follows:

$$\rho(z, f) = \sum_{m,n} a_{m,n} z^m f^n \quad (m,n \geq 0; m+n \leq q)$$

[0043] To solve for coefficients $a_{m,n}$, the microscope can be calibrated as a number of fixed cameras (with fixed focal length) across the full range of the

microscope focus and zoom range. After a sufficient number of fixed camera calibrations, under different zoom and focus settings, a group of calibration data can be obtained. The coefficients $a_{m,n}$ of the polynomial functions can then be solved, for example, by bivariate polynomial fitting.

[0044] An exemplary microscope camera model for an exemplary microscope in an augmented reality microscope system can be as follows:

Intrinsic Parameters

Image Size: $N_x = 768$, $N_y = 576$

Image Center: $C_x = 384$, $C_y = 288$

Focal Length:

$$f_x = -0.000000008 * F * Z^3 + (-0.000004613) * F * Z^2 + (-0.001289058 * F * Z + (-0.022283345) * F + 0.000039765 * Z^3 + 0.042230380 * Z^2 + 21.010557606 * Z + 4970.548674307$$

$$f_y = 0.000000010 * F * Z^3 + (-0.000001564) * F * Z^2 + (-0.001287695) * F * Z + (-0.020680795) * F + 0.000034475 * Z^3 + 0.040391899 * Z^2 + 20.227847227 * Z + 4767.037899857$$

Extrinsic Parameters

$$O_{wcx} = 0.000008797 * F + (-0.058476064)$$

$$O_{wcy} = -0.000016119 * F + (-0.781894036)$$

$$O_{wcz} = -0.000004200 * F + (-0.078145268)$$

$$T_{wcx} = 0.000000000 * F^2 * Z + (-0.000000747) * F^2 + (-0.000002558) * F * Z + (-0.006475870) * F + 0.000141871 * Z + 0.271534556$$

$$T_{wcy} = -0.000000001 * F^2 * Z + (-0.000001826) * F^2 + (0.000002707) * F * Z + (-0.004741056) * F + (-0.003616348) * Z + 5.606256436$$

$$T_{wcz} = 0.000000302 * F^2 * Z + 0.000014187 * F^2 + (-0.000088499) * F * Z + (-0.018100412) * F + 0.061825291 * Z + 422.480480324$$

Where O_{wcx} , O_{wcy} , O_{wcz} are rotation vectors from which the rotation matrix from the microscope camera to the reference coordinate system can be calculated, and T_{wcx} , T_{wcy} , and T_{wcz} are transforms in x, y and z and from them the transform matrix to the reference coordinate system can be constructed.

Thus, for any given zoom and focus value of the microscope, a corresponding virtual microscope camera can be created and can be used to generate a virtual image of the virtual objects.

[0045] As is illustrated in Fig. 1D, computer 120 receives the current magnification and focus values for the microscope. Intrinsic and extrinsic parameters of a virtual microscope camera can thus be calculated from the stored microscope camera model. The virtual microscope camera position and orientation in the position tracking system can be depicted using the tracking data of the markers on the microscope.

[0046] As is illustrated in Fig. 1D, the microscope has an optical axis 111 and

a focal point 112. In exemplary embodiments according to the present invention the position of the focal point changes in relative to the reference markers accordingly to the changes of the microscope focus.

[0047] In exemplary embodiments according to the present invention the position of the focal point of the microscope relative to the reference markers can be calibrated before navigation. An exemplary calibrated result of the focal point for an exemplary microscope from an augmented reality microscope system is presented below.

[0048] FocusPoint (x, y, z) = (Fpx, Fpy, Fpz), wherein

[0049] $F_{px} = -0.000001113 * F^2 + 0.001109120 * F + 116.090108990$;

[0050] $F_{py} = 0.000002183 * F^2 + (-0.000711078) * F + (-27.066366422)$;

[0051] $F_{pz} = -0.000073468 * F^2 + (-0.154217215) * F + -369.813473763$; and

[0052] F represents focus.

The calibration result of the focal point can be stored in the computer. Thus, for any given focus value of the microscope, a position of focal point can be depicted from the tracking data of the reference markers.

In exemplary embodiments according to the present invention the optical axis can be, for example, a line linking the focal points of various microscope focal values.

[0053] In exemplary embodiments of the present invention image data of a patient can be mapped to the patient using one of the generally known registration techniques. For example, one such registration technique maps the

image data of a patient to the patient using a number of anatomical features (at least 3) on the body surface of the patient by matching their positions identified and located in the scan images and their corresponding positions on the patient determined using a tracked probe. The registration accuracy may be further improved by mapping a surface of a body part of the patient generated from the imaging data to the surface data of the corresponding body part generated on the operating table. For example, this method is described in detail in PCT/SG2005/00244, entitled "Systems and Methods For Mapping A Virtual Model Of An Object To The Object ("Multipoint Registration")" filed on 20 July 2005 by Applicant hereof. The registration method described in this PCT application can be used directly for microscope navigation in exemplary embodiments hereof. The aim of registration is to make the patient imaging data align with the patient, and it can be done, for example, in a macroscopic stage when the microscope is not involved yet, and the registration result used in microscopic navigation. After registration, the image data of the patient, including all the segmented objects and other objects generated in surgical planning associated with the imaging data, are registered to the physical patient. For example, in Fig. 1D the model of the tumor and blood vessel stored in computer 120 are registered with the actual tumor 155 and blood vessel 150 in the head of the patient.

[0054] The position and orientation of the patient head 152 and the position and orientation of the microscope video camera 105 can be transformed into a common coordinate system, for example the coordinate system of the position tracking system. The relative position and orientation between the head 152 and the microscope video camera 105 can thus be determined dynamically using the position tracking system 100.

[0055] As is illustrated in Fig. 2, in exemplary embodiments of the present invention the microscope camera can capture a video image of patient head 152. The tumor 155 and blood vessel 150 may not be visible in the video image (as they may be visually occluded by an as yet closed portion of the head).

[0056] As illustrated In Fig. 3, in exemplary embodiments of the present invention the computer can generate a virtual image of tumor 155 and blood vessel 150 based on the intrinsic and extrinsic parameters of the virtual microscope camera and the stored model of the tumor and blood vessel.

[0057] As is illustrated in Fig. 4, in exemplary embodiments of the present invention real image 201 and virtual image 301 can be combined to generate an augmented reality image. The augmented reality image can then, for example, be on display device 130. Display 130 can be a monitor, a HMD, a display build in the microscope for “image injection”, etc..

[0058] The 3D model of tumor and blood vessel may be generated from three-dimensional (3D) images of the patient. For example, from MRI or CT images of the patient head. In exemplary embodiments according to the present invention, such data can be generated using hardware and software provided by Volume Interactions Pte Ltd., such as, for example, the Dextroscope system running RadioDexter software.

[0059] In exemplary embodiments according to the present invention the augmented reality image can be displayed in various ways. The real image can be overlaid on the virtual image (real image is on the virtual image), or be overlaid by the virtual image (the virtual image is on the real image). The

transparency of the overlay image can be changed so that the augmented reality image can be displayed in various ways, with the virtual image only, real image only, or a combined view. At the same time, for example, axial, coronal and sagittal planes of the 3D models according to the position changing of the focal point can be displayed in three separate windows.

[0060] In exemplary embodiments according to the present invention the augmented reality in microscopic navigation can be in various microscope settings across the full magnification and focus range.

[0061] Fig. 5 shows an exemplary augmented reality view of the patient head in a different (greater, relative to Figs. 3-4) magnification setting.

[0062] In exemplary embodiments according to the present invention digital zoom can be used to virtually change the magnification of the augmented reality image. The zoom ratio can be an input of a user. The zoomed field of view can, for example, be centered at the center of the window by default.

[0063] Fig. 6 shows an exemplary virtual image only navigation view of the surgical field through the microscope at a higher magnification. The surgeon is operating on the tumor so part of the tumor is visible in the optical view of the microscope. However, most of the tumor and all of the blood vessel are either hidden under the exposed surface or out of the field of view of the microscope so that the surgeon cannot see directly. A rendered image of tumor and blood vessel generated by the computer can be displayed to the surgeon, but because of the magnification, only a small part of the tumor and blood vessel can be shown.

[0064] It may be crucial to know the exact 3D structure and location of the tumor and blood vessel beyond the field of view of the microscope without changing the microscope magnification and position. Thus, Fig. 7 shows a virtually enlarged view of the microscope in which the whole structure of the tumor and blood vessel are visible. In exemplary embodiments of the present invention this can be achieved by digital zooming. Digital zooming virtually changes the field of view of the virtual microscope camera model, so that the 3D models in the virtual camera's field of view can be rendered from the same viewpoint but a different field of view. Digital zooming enables the surgeon to see beyond of the microscope's field of view without changing the microscope's actual settings. In exemplary embodiments of the present invention the video signal can also be zoomed, and thus a zoomed image can have video (real) images, virtual images or any combination of both, with varying transparency of either. Fig. 7 is zoomed-out relative to the view of Fig. 6, but obviously of a much greater magnification (zoom-in) relative to the view of Fig. 5 and of course that of Fig. 3. Thus, a user may frequently change zoom values, zooming in and out repeatedly over the course of a given procedure or operation.

[0065] In a neurosurgical application scenario, a surgeon may, for example, use the probe 140 to do registration, and to select the entrance point by navigating with the probe. Then the microscope can be brought in for refined navigation and guidance. During surgery, the surgeon may need from time to time to navigate using the probe 140, as navigation by moving the probe 140 is much easier to handle than navigation by moving the microscope. In such an exemplary application scenario, the system allows swift and smooth shift between the two navigation methods.

[0066] FIG. 8 depicts the exemplary scene of FIG. 7 from the point of view of the mini-camera inside the probe. The focal point as well as the optical path of the microscope can be shown together with the tumor and blood vessels, indicating the 3D relationship of the microscope, the surgical field and the virtual objects (tumor and blood vessels).

[0067] Figs. 9-11 are actual screen shots from an exemplary embodiment of the present invention. Fig. 9 shows an exemplary navigational view from a surgical microscope according to an exemplary embodiment of the present invention.

[0068] Fig. 10 shows the exemplary view of Fig. 9 after digitally zooming-out according to an exemplary embodiment of the present invention, using the techniques described above as in connection with Fig. 7.

[0069] Fig. 11 shows an exemplary augmented reality navigational view from an exemplary probe according to an exemplary embodiment of the present invention, corresponding somewhat to that shown in Fig. 8, without the optical path and focal point of the microscope.

[0070] In exemplary embodiments according to the present invention the selection between the microscope and probe can be performed automatically. The automatic selection can be based upon (*i.e.*, be a function of) the tracking data. In exemplary embodiments according to the present invention this can be achieved by setting a higher priority to the probe. If only the microscope tracking data is available, the microscope will be selected as the navigation instrument

and its AR image will be displayed. If both the microscope and probe are tracked, the probe will be selected and its AR view be displayed. The microscope in such situation can, for example, be ignored. When the probe is not tracked, the microscope can, for example, be selected automatically for navigation. The video image can also be automatically changed accordingly.

[0071] The system, methods and apparatus of the present invention thus enable a user to see "beyond the normal field of view" both during macroscopic surgery as well as microscopic surgery. This allows a user to always be aware just how near he or she is to highly sensitive or important hidden structures.

WHAT IS CLAIMED:

1. An integrated surgical navigation and visualization system, comprising:
a microscope;
at least one video camera affixed to the microscope;
a computer;
a microscope camera model is installed in the computer;
a probe;
a video camera affixed to the probe;
a probe camera model stored in the computer;
a tracking device which determines the poses (positions and orientations) of the probe and the microscope;
three dimensional patient image data pre-stored in the computer; and
a display;
wherein the computer automatically selects the pose data and video image associated with the probe or the microscope for surgical navigation.
2. The system of claim 1, wherein the automatic selection is based on the tracking data and a defined relative priority algorithm of the probe view and the microscopic view.
3. The system of claim 3, wherein the microscope's magnification and focus are adjustable, and wherein a sensor detects the values of the magnification and focus and communicates this data to the computer.
4. The system of claim 1, wherein a virtual microscope camera which has imaging properties, position and orientation matching of the video camera affixed to

the microscope can be generated from the microscope camera model, the microscope tracking data, and the microscope zoom and focus values.

5. The system of claim 1, wherein the microscope has a focal point. The position of the focal point in relative to the patient can be depicted from the microscope focus value and tracking data of microscope.

6. The system of claim 4, where the video image from the video camera affixed to the microscope is augmented by the virtual image generated by the computer from the three dimensional patient image data according to the virtual microscope camera and displays a composite image on the display.

7. The system of claim 1, wherein a virtual probe camera which has imaging properties, position and orientation matching of the video camera affixed to the probe can be generated from the probe camera model and the probe tracking data.

8. The system of claim 4, where the video image from the video camera affixed to the probe is augmented by the virtual image generated by the computer from the three dimensional patient image data according to the virtual probe camera and displays a composite image on the display.

9. The system of claim 2, wherein the selection can be overridden by a user by actuating a physical or vocal interface.

10. A method of surgical navigation and visualization, comprising: acquiring three dimensional image data from a patient; storing said three dimensional image data in a data processor; registering the three dimensional image

data to the patient; acquiring real-time video images of the patient from a video camera affixed to a microscope; tracking the positions and orientations of the microscope; receiving the zoom and focus values of the microscope; constructing a virtual microscope camera according to microscope camera model, the tracking data, zoom and focus value and the microscope; generating a virtual image of the three dimensional image data of the patient; generating an augmented reality view by superimposing the real-time video images upon the virtual image; and displaying augmented reality view on one or more displays.

11. The method of claim 10, wherein the augmented reality view can be digitally zoomed without changing the position, zoom or focus value(s) of the microscope.

12. The method of claim 11, wherein the real image and virtual image are geometrically co-aligned in the digitally zoomed augmented reality view.

13. The method of claim 12, wherein the augmented reality view is zoomed out, the virtual image of three dimensional image data of the patient outside the field of view of the real image is generated and displayed; overlaid partly on the real image from the video camera.

14. The method of claim 13, including automatically selecting a probe with a video camera affixed to replace the microscope for surgical navigation.

15. The method of claim 14, including acquiring real-time video images of the patient from the video camera affixed to the probe; tracking the positions and orientations of the probe; constructing a virtual probe camera according to probe

camera model and the tracking data; generating a virtual image of the three dimensional image data of the patient according to the virtual probe camera; generating an augmented reality view by superimposing the real-time video images upon the virtual image.

16. The method of claim 15, wherein the augmented reality view can be zoomed digitally with out changing the position of the probe.

17. The method of claim 16, including acquiring a real time video image of the patient from the camera affixed to the probe with the microscope remaining at the surgical operation condition; generating a virtual image of the focal point and optical axis and the three dimensional image data of the patient according to the virtual probe camera; generating an augmented reality view by superimposing the real-time video images upon the virtual image.

18. The method of claim 10, including positioning the probe during microscopic surgery to obtain navigational views from varying orientation and location.

19. The method of claim 18, wherein the anatomic structures around the surgical field, together with the focal points and optical axis of the microscope, can be displayed from the point of view of the probe camera.

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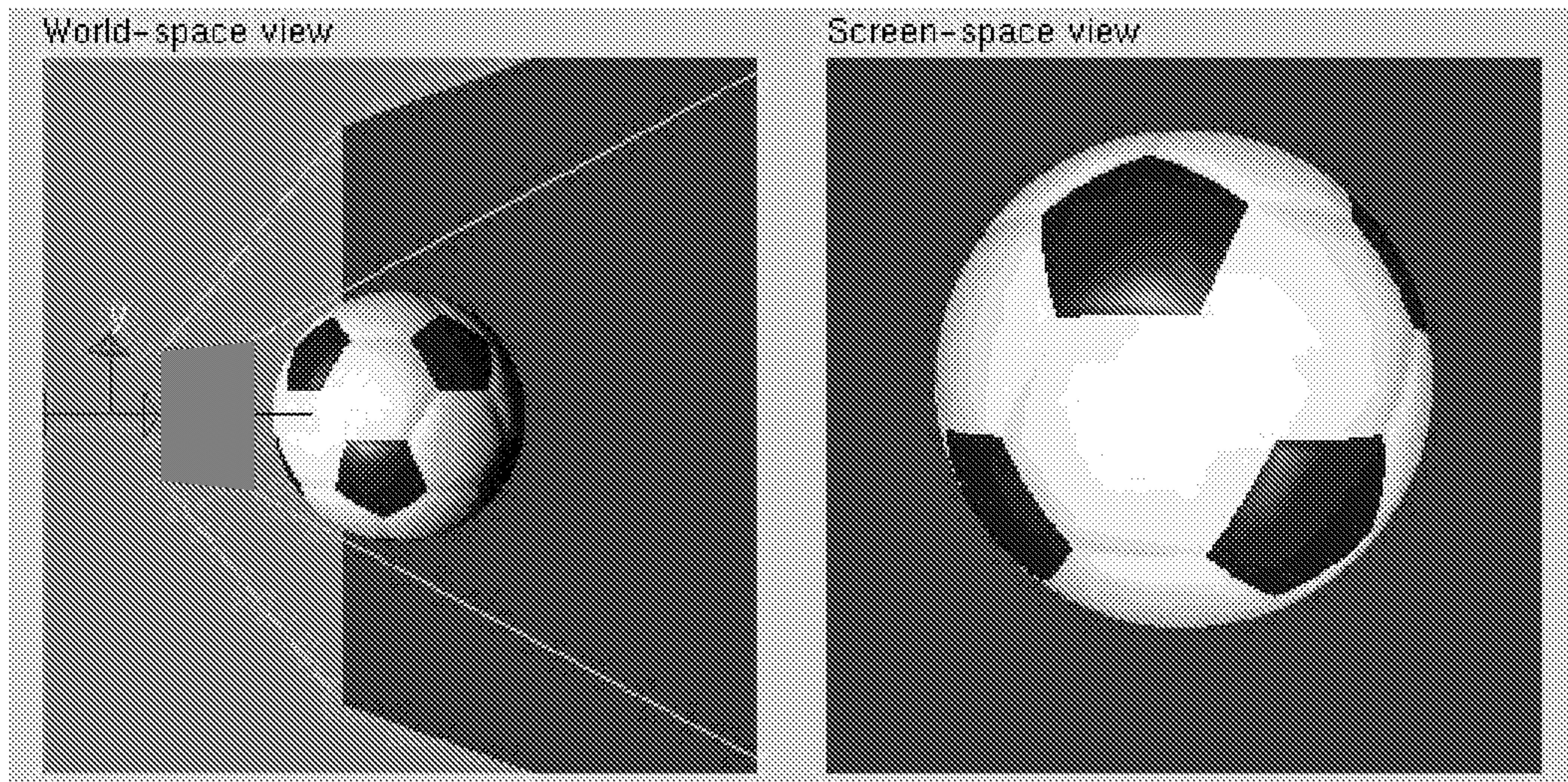


Fig 1A - A virtual camera and its frustum in world space view (left). A virtual object as seen by the virtual camera (right).

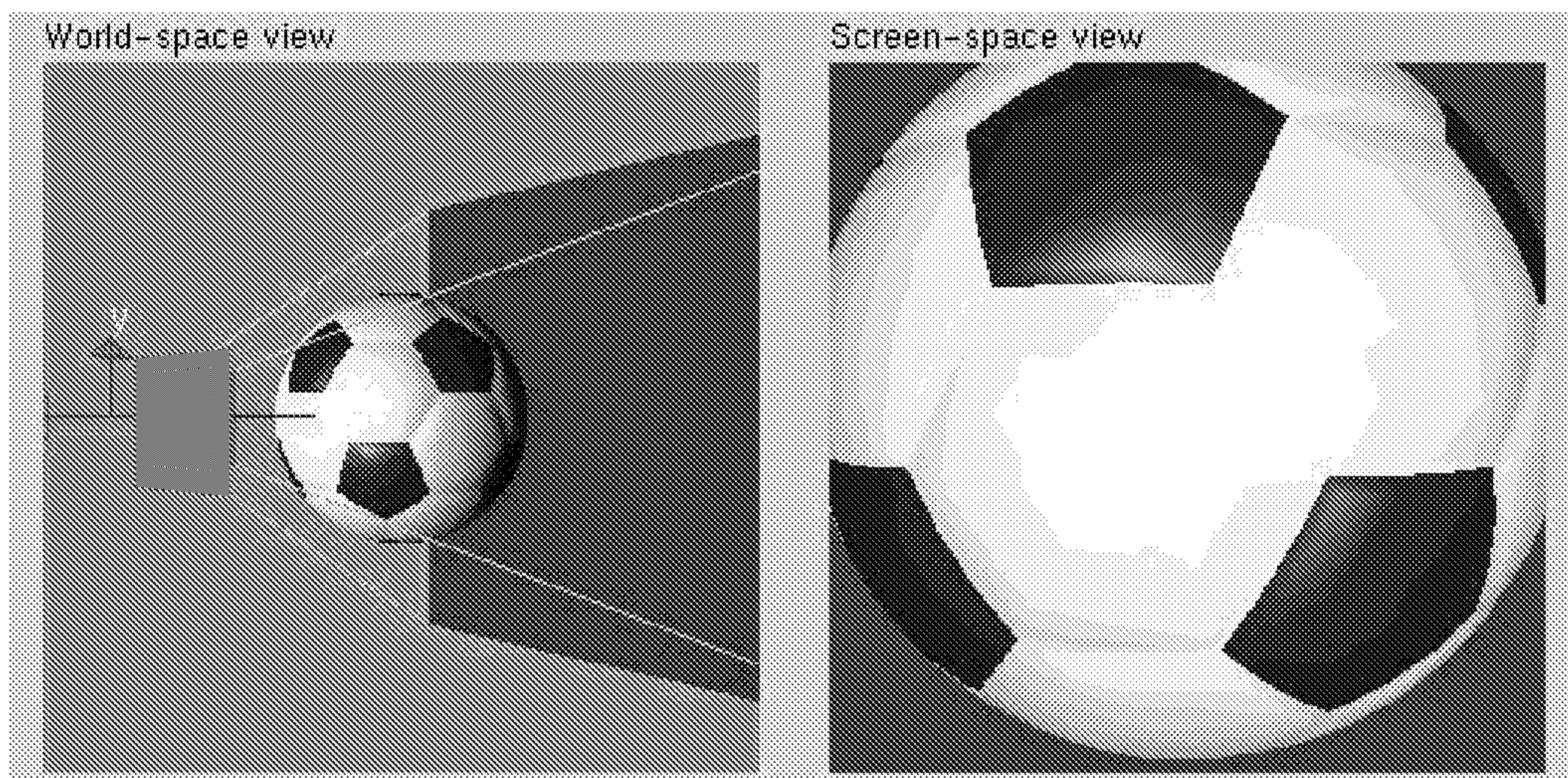


Fig 1B - For zooming in effect, the frustum is changed by increasing the separation between the far (dark-grey; right side of figure) and near (dark blue; left side of figure) planes (left). The virtual object appears closer/magnified (right).

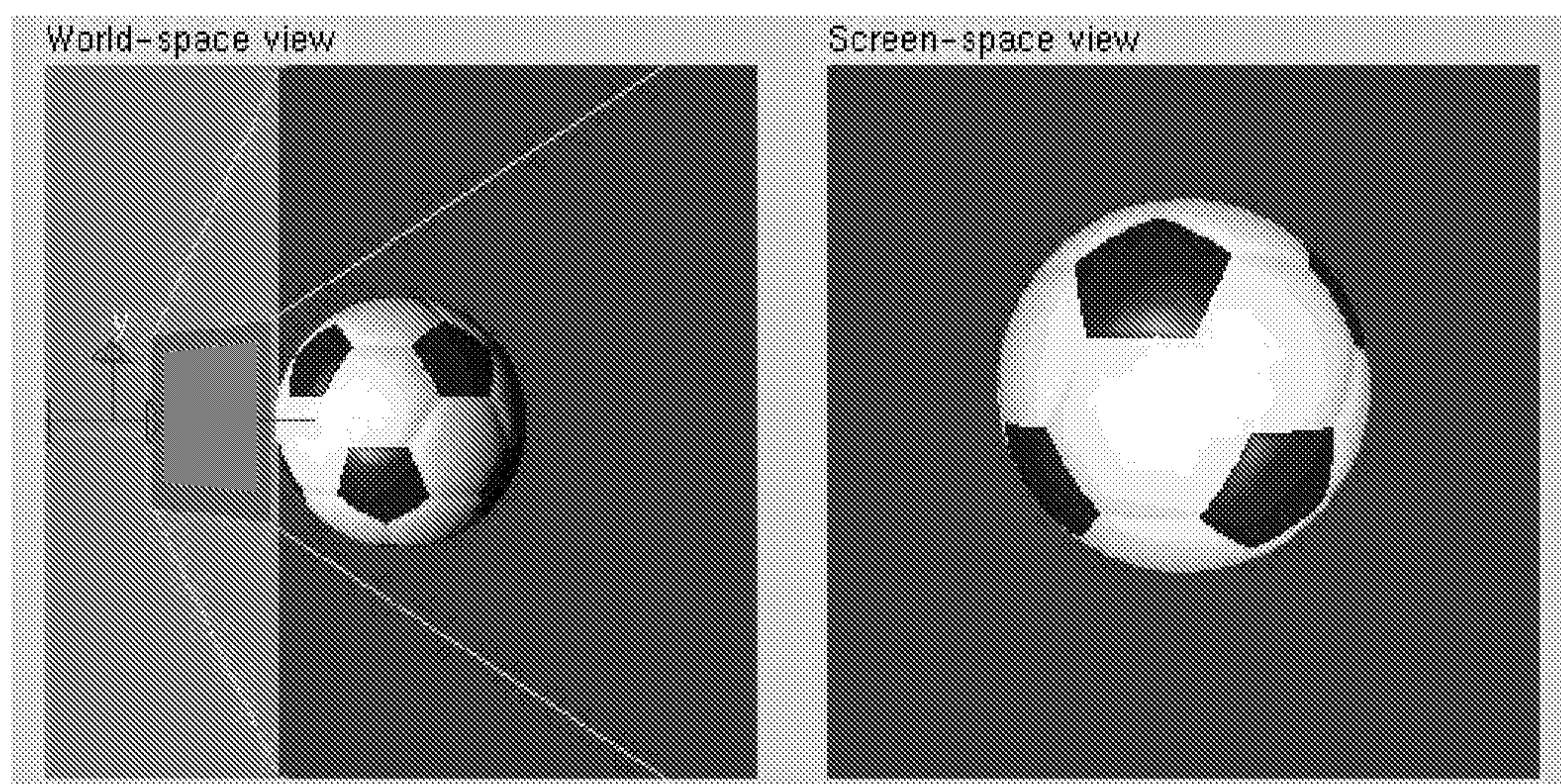


FIG. 1C - For zooming out effect, the frustum can be changed by decreasing the separation of the far (dark-grey; right side of figure) and near (dark blue; left side of figure) planes (left). The virtual object thus appears smaller / further (right).

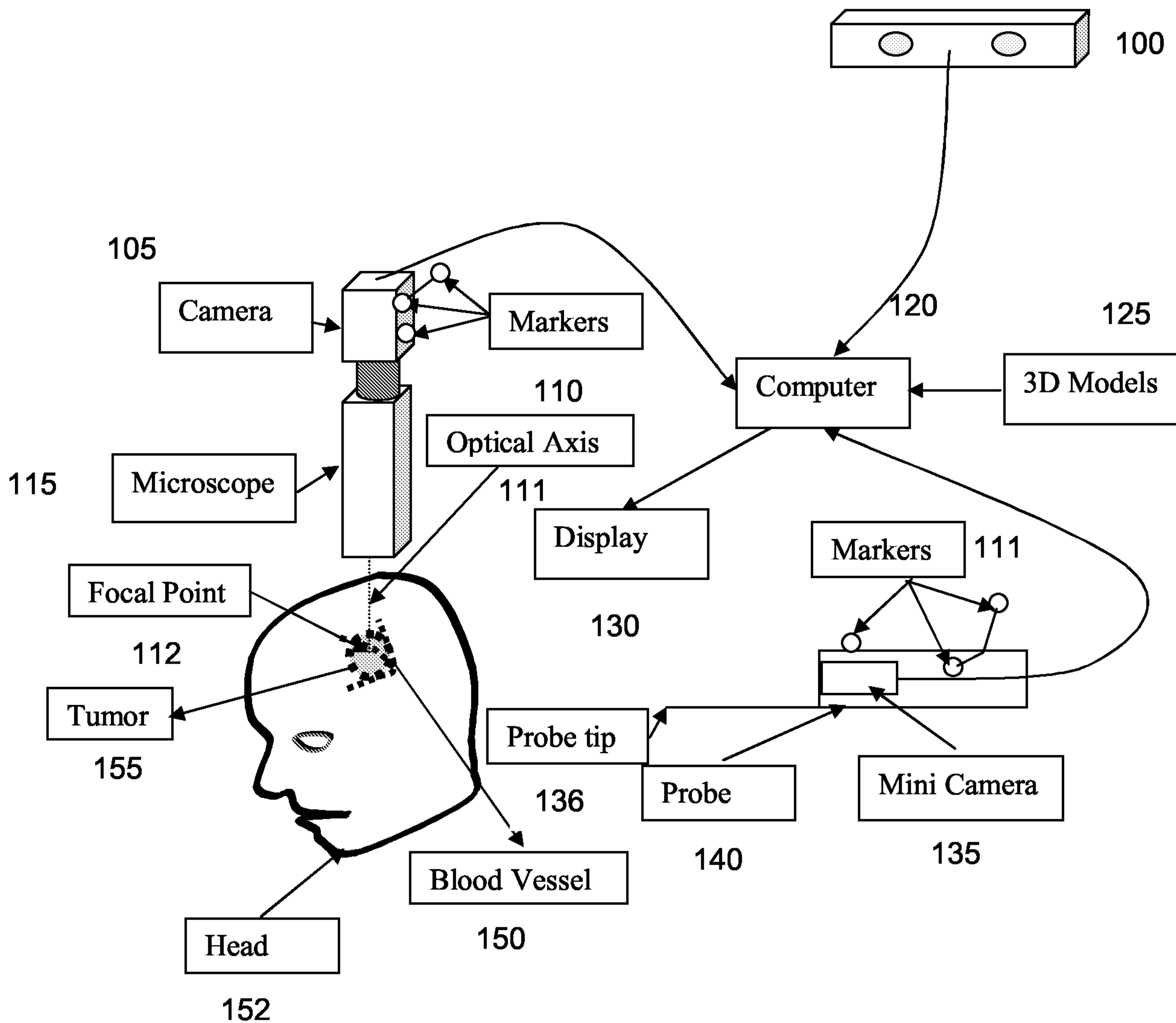


FIG. 1D
Exemplary Navigation system

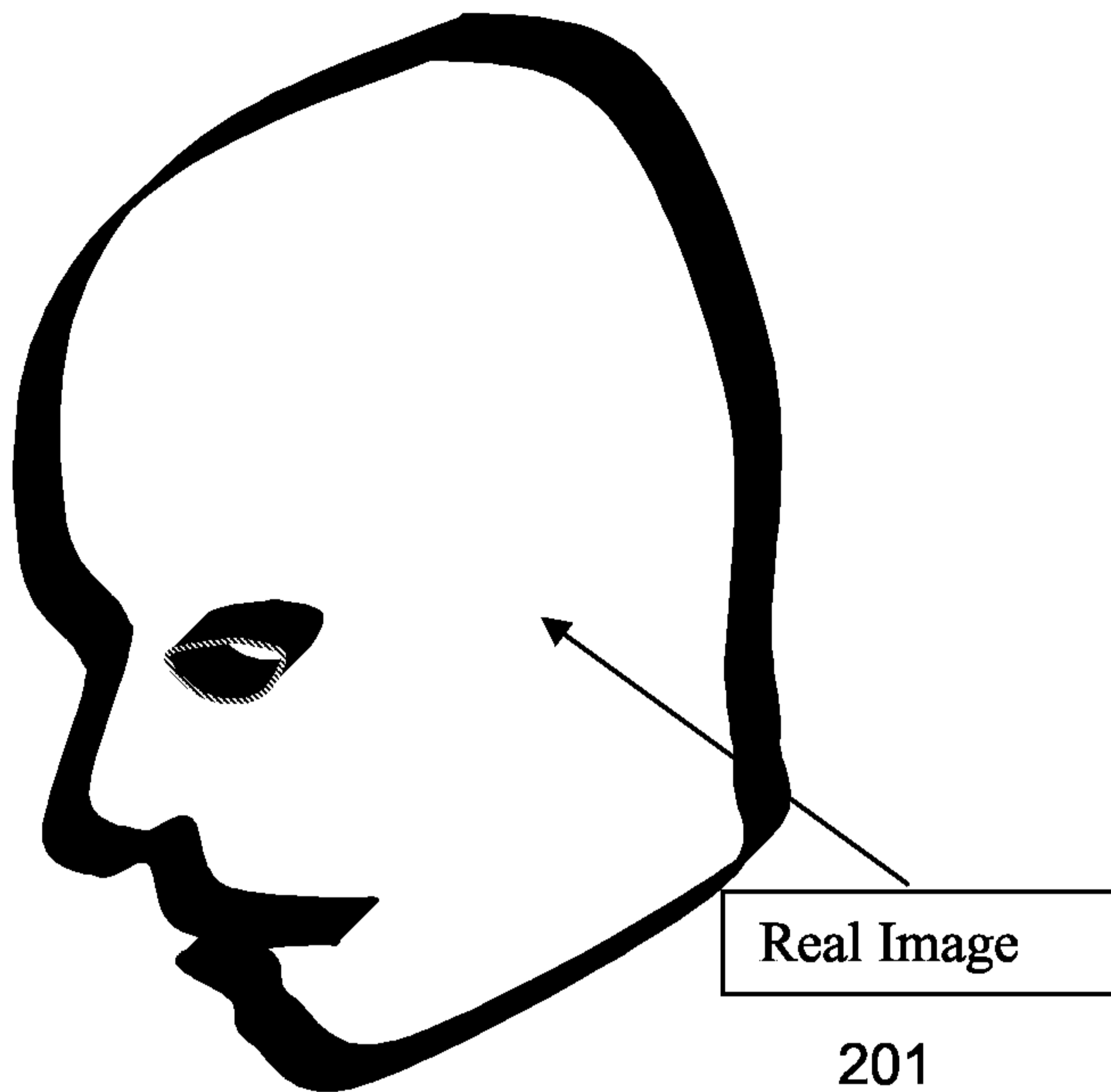


FIG. 2 - A real image of a patient head captured by the microscope video camera

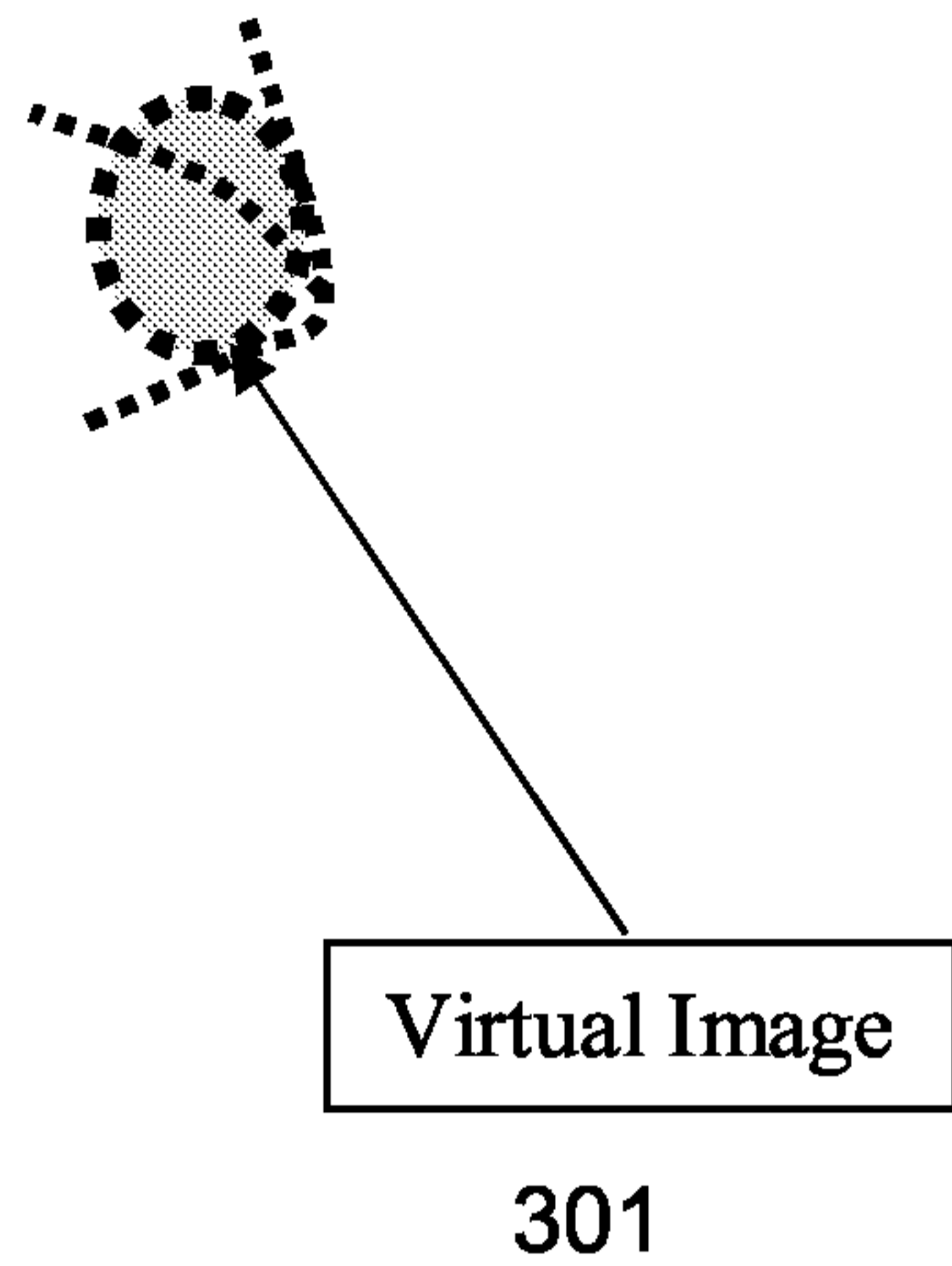


FIG. 3 - A virtual image of a tumor and blood vessel generated by the computer

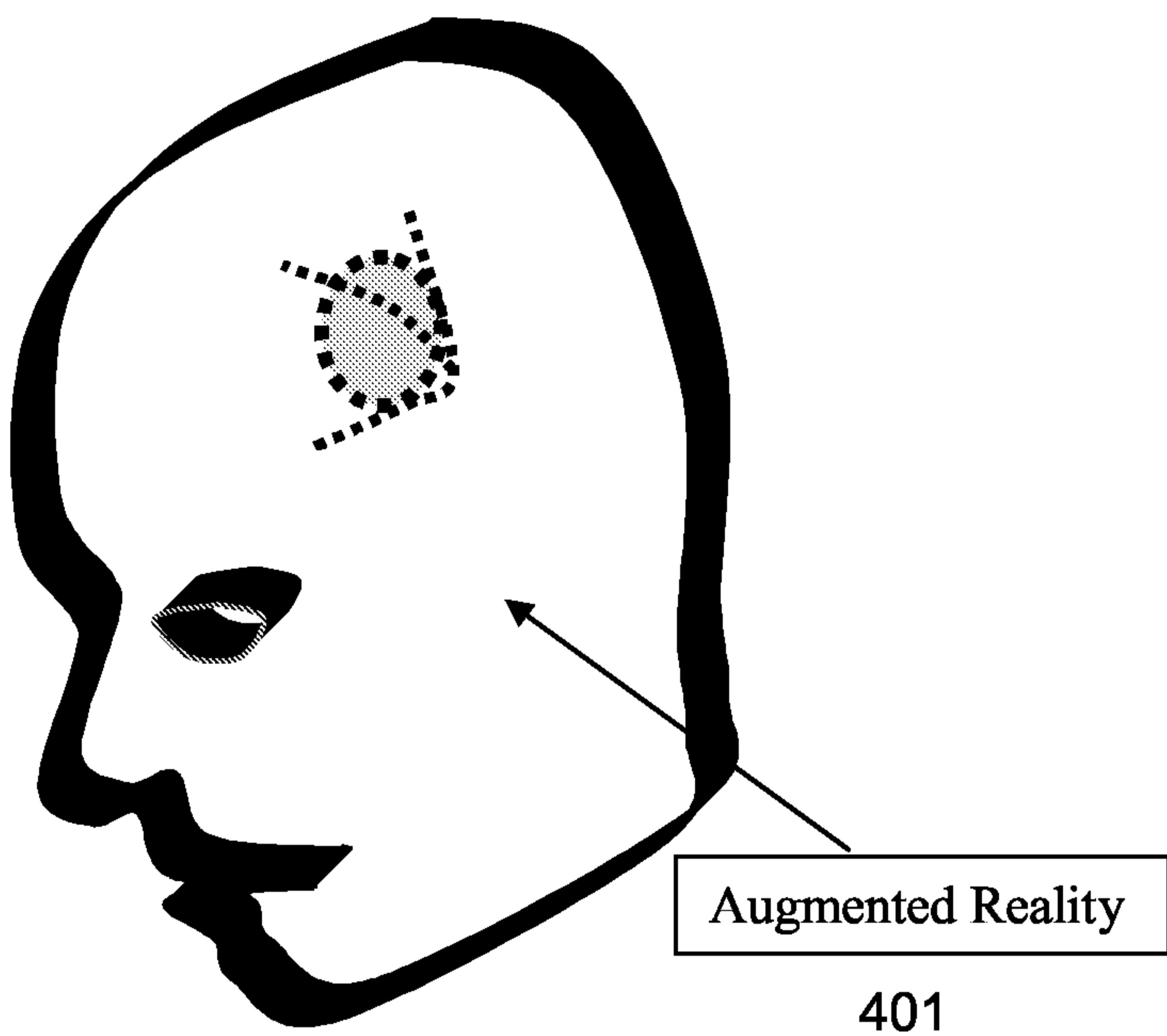


FIG. 4 - A combined image (augmented image) of real and virtual images.

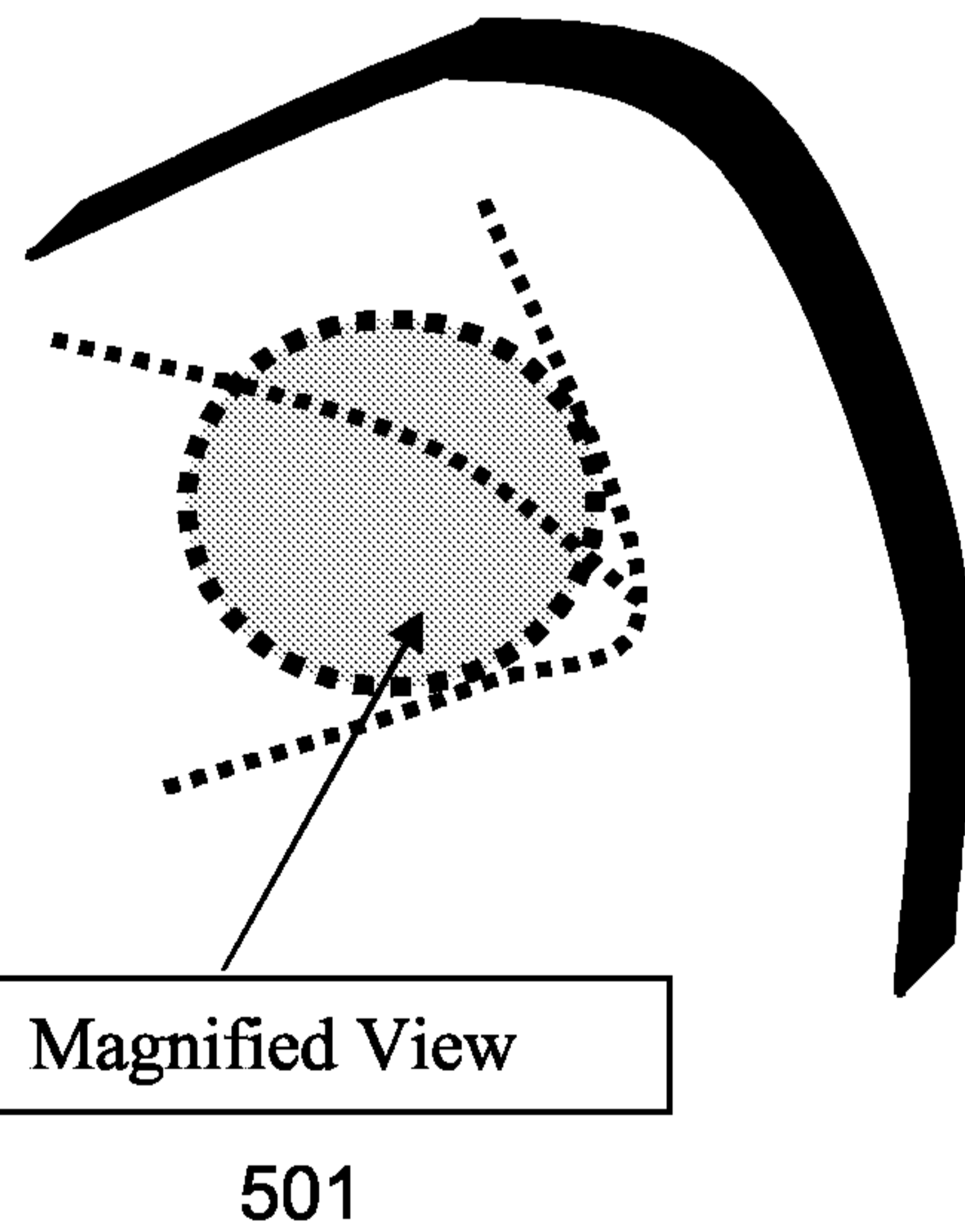


FIG. 5 - A magnified augmented reality view

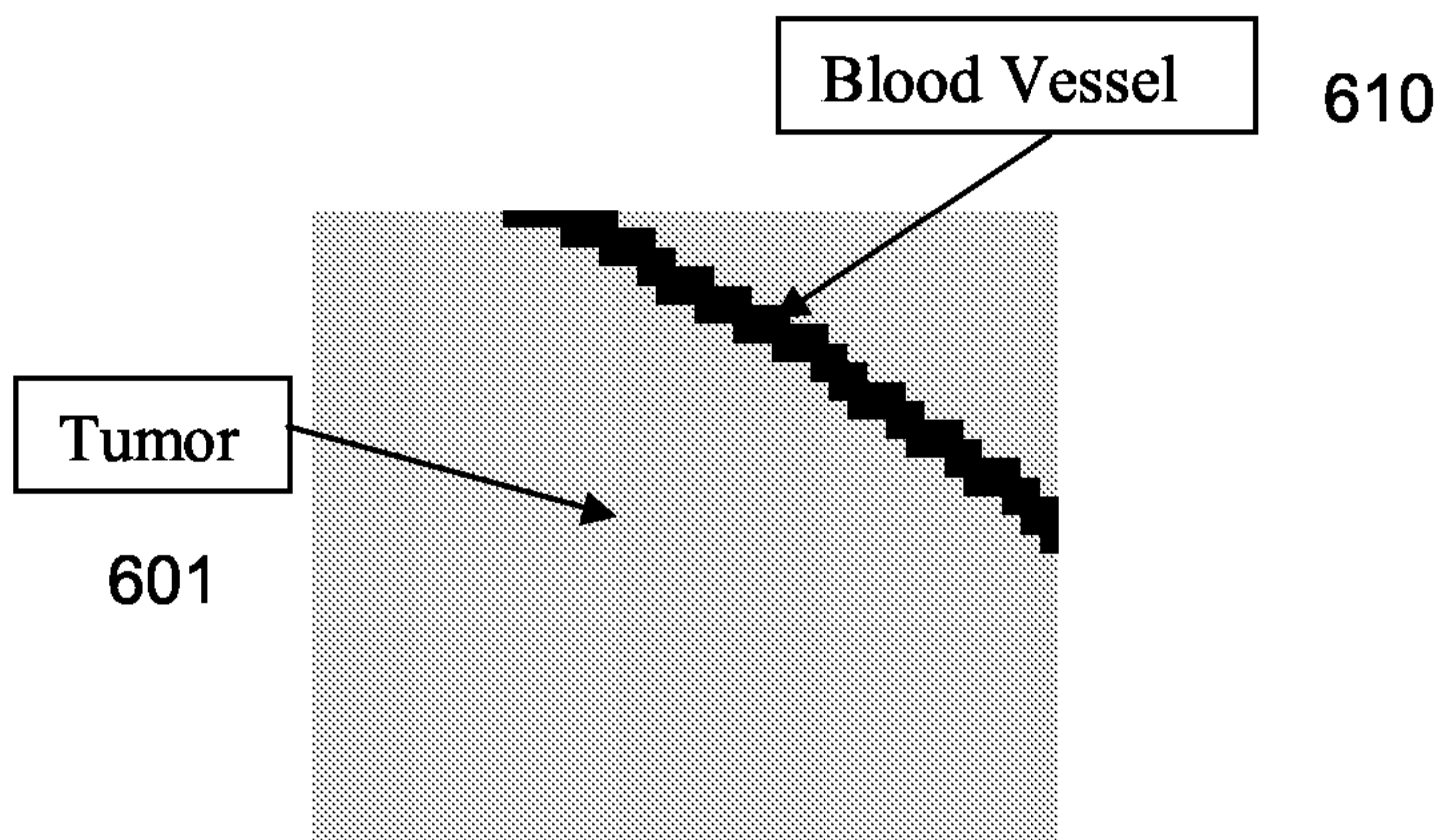


FIG. 6: A microscopic magnified view (without real image)

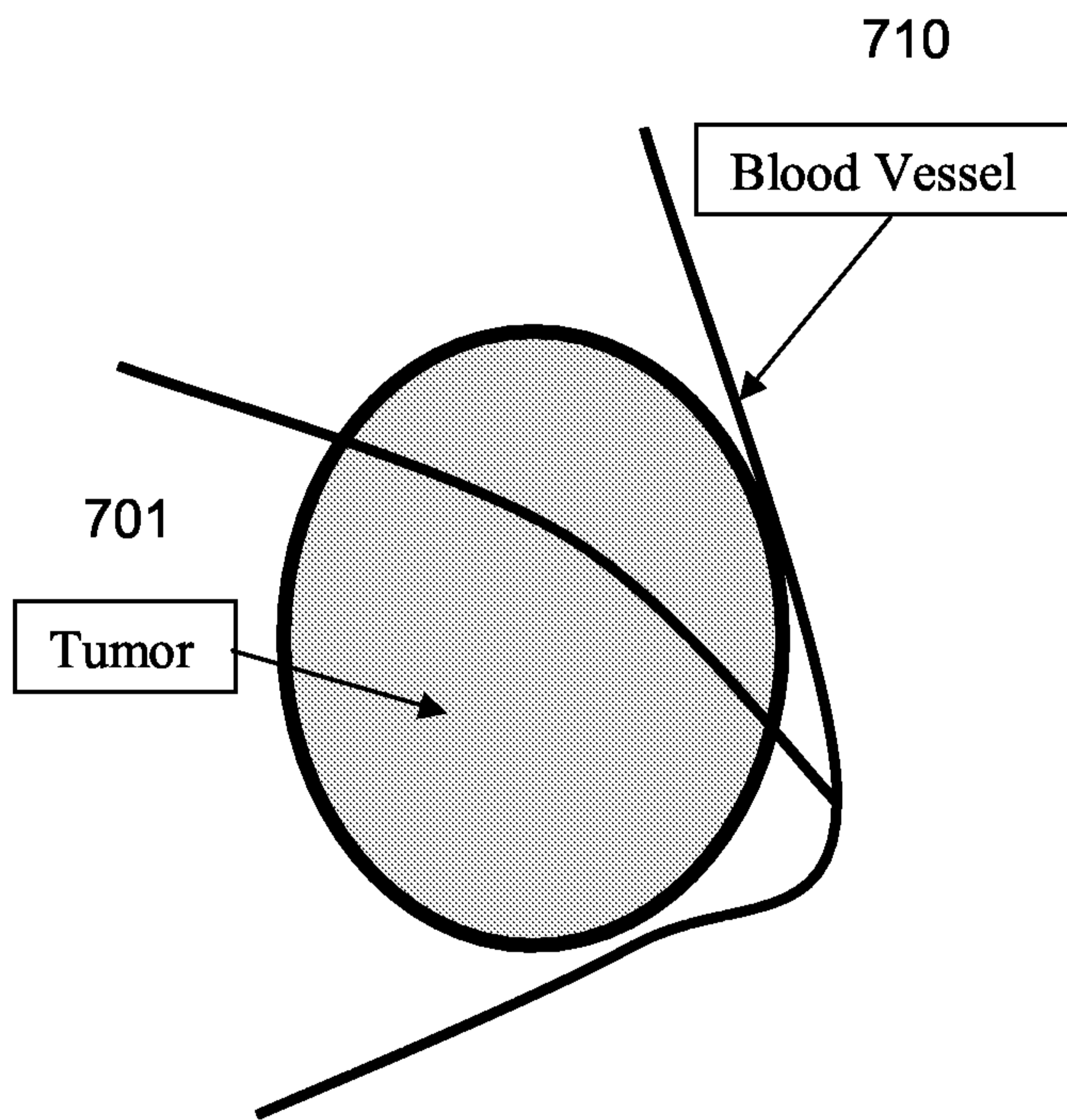


FIG. 7: A digitally zoomed-out microscopic magnified view (virtual image without real image)

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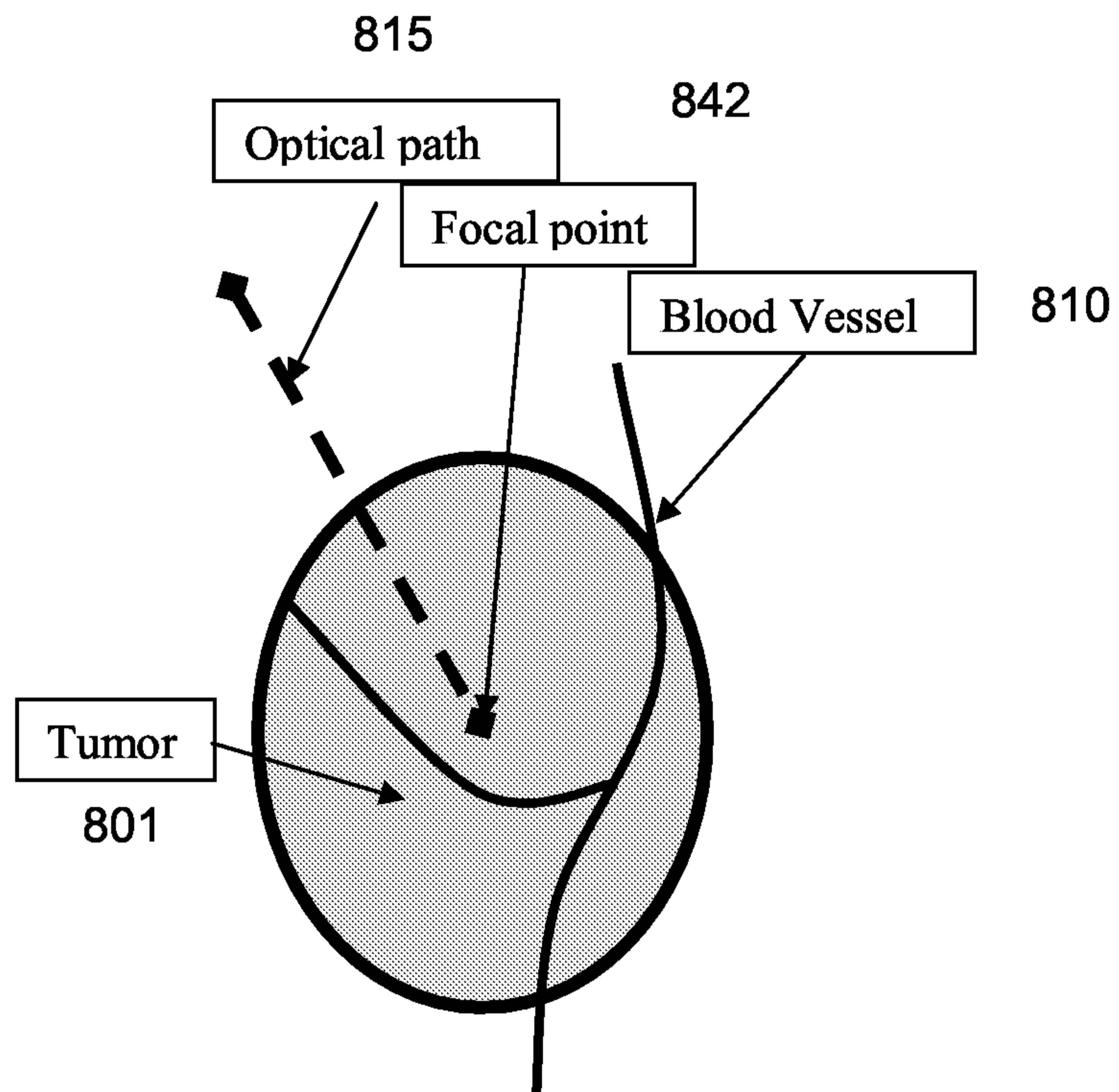


FIG. 8 - A navigational view from a probe (virtual image without real image)

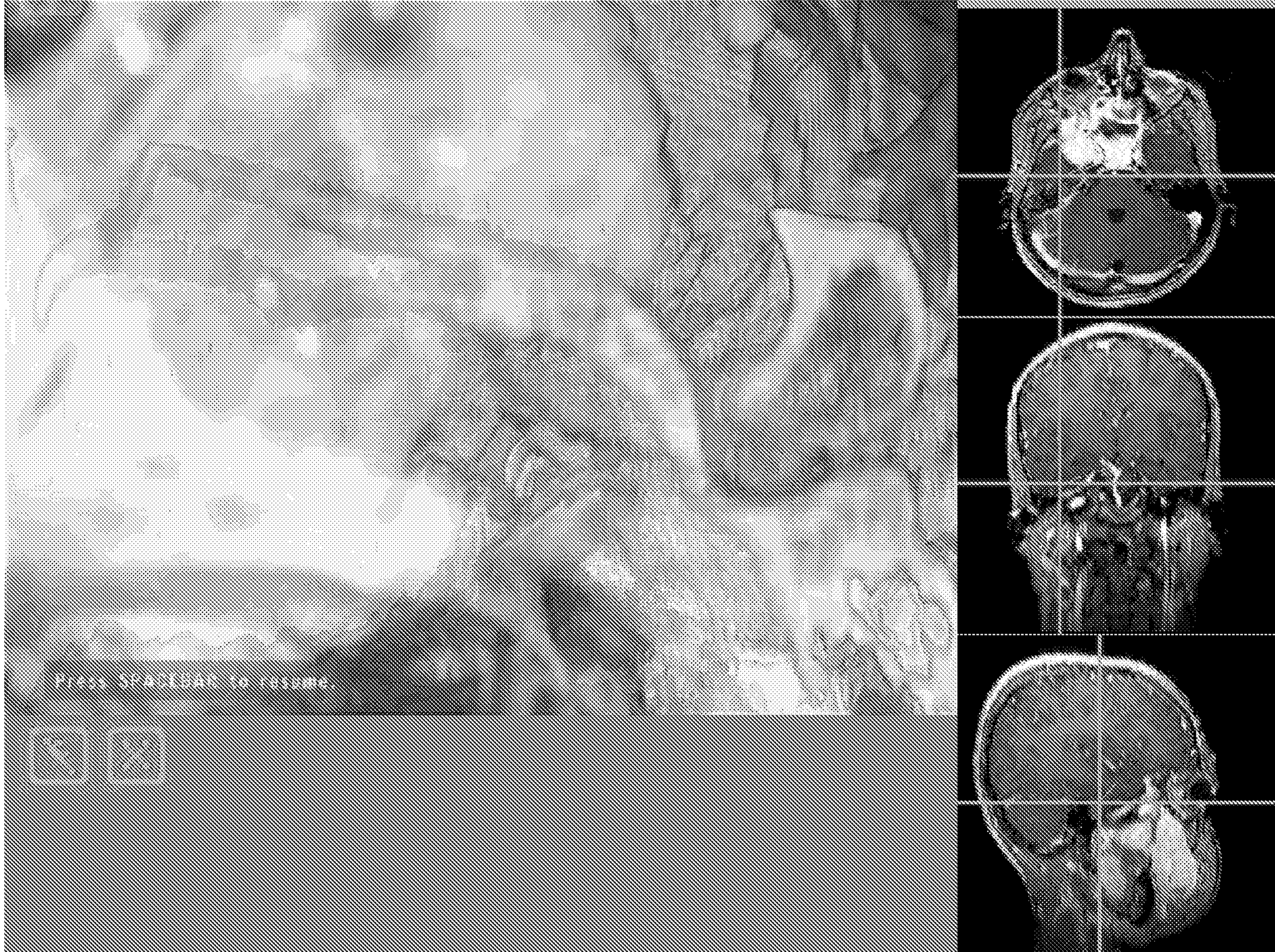


Fig. 9 – An Exemplary Normal AR View Without Digital Zoom

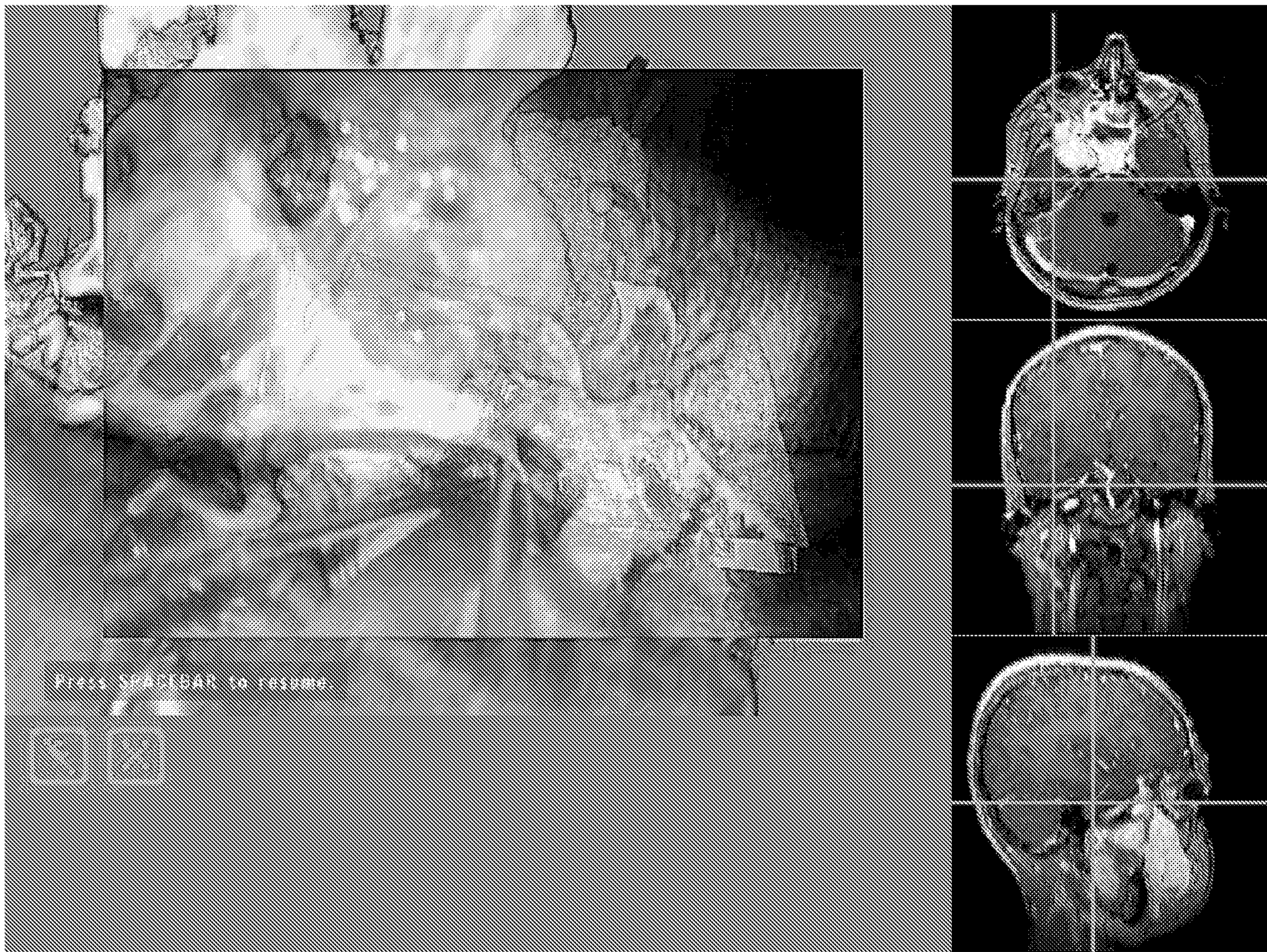


Fig. 10 – An Exemplary Digital Zoom-Out View

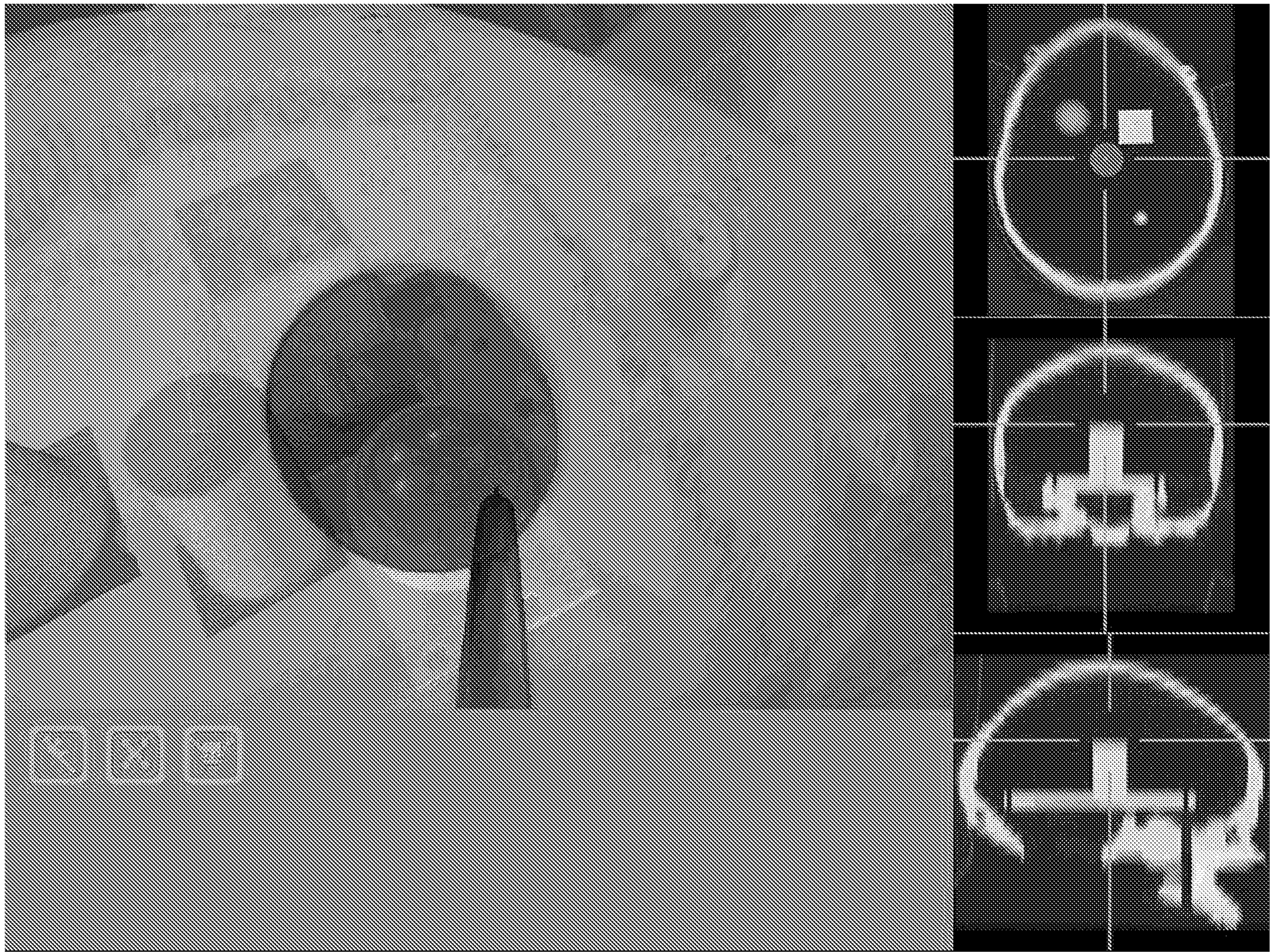


Fig. 11 – An Exemplary AR View From The Viewpoint Of A Camera Affixed To A Probe

