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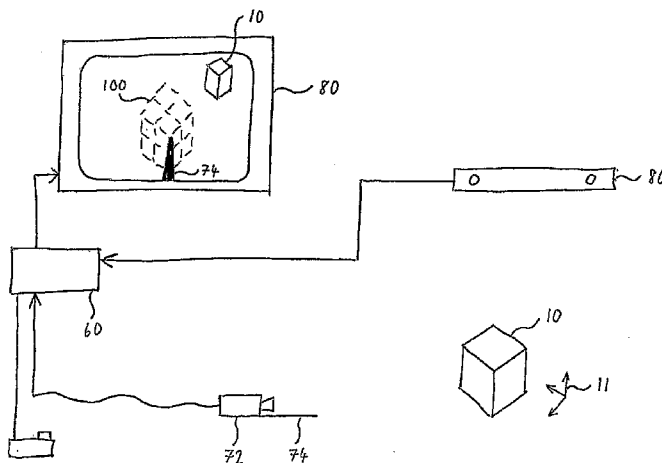
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(57) Abstract: A method of and apparatus for mapping a virtual model (100) formed from a scanned image of a part (10) of a patient to that part 10 of the patient. A camera (72) with a probe (74) fixed thereto is moved relative to the part (10) of the patient until a video image of that part (10) captured by the camera (72) appears to coincide on a video screen (80) with the virtual model which is shown fixed on that screen (80). The position of the camera (72) in a real coordinate system (11) is sensed. The position in a virtual coordinate system (110) of the virtual model (100) relative to a virtual camera by which the view of the virtual model (100) on the screen (80) is notionally captured is predetermined and known. From this, the position of the virtual model (100) relative to the part (10) of the patient 10 can be mapped and a transform generated to position the part (10) of the patient in the virtual coordinate system (110) to approximately coincide with the virtual model (100).

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A METHOD OF AND APPARATUS FOR MAPPING A VIRTUAL MODEL OF AN OBJECT TO THE OBJECT

FIELD OF THE INVENTION

This invention relates to a method of mapping the position of a virtual model of an object in a virtual coordinate system to the position of the object in a real coordinate system. More specifically, but not exclusively, this invention relates to the mapping of a virtual model generated from scanned images of part of a patient's body.

BACKGROUND TO THE INVENTION

Techniques such as magnetic resonance imaging (MRI) and computerised axial tomography (CAT) allow three-dimensional (3-D) images of the bodies or body parts of patients to be generated in a manner that allows those images to be viewed and manipulated using a computer. For example, it is possible to take a MRI scan or a CAT scan of a patient's head, and then to use a computer to generate a 3-D virtual model of the head from the scan and to display views of the model. The computer may be used to seemingly rotate the 3-D virtual model of the head so that it can be seen from another point of view; to remove parts of the model so that other parts become visible, such as removing a part of the head to view more closely a brain tumour; and to highlight certain parts of the head, such as soft tissue, so that those parts become more visible. Viewing virtual models generated from scanned data in this way can be of considerable use in the diagnosis and treatment of medical conditions, and in particular in preparing for and planning surgical operation. For example, such techniques can allow a surgeon to decide upon the point and direction from which he or she should enter a patient's head to remove a tumour so as to minimise damage to surrounding structure.

International Publication No. WO-A1-02/100284 discloses an example of apparatus which may be used to view in 3-D and to manipulate virtual models produced from an MRI scan or a CAT scan. Such apparatus is manufactured and sold under the name DEXTROSCOPE (RTM) by the proprietors of the invention described in WO-A1-02/100284, who are also the proprietors of the invention described herein.

Virtual Models produced from MRI and CAT scanning are also used during surgery. For example, it can be useful to provide a video screen that shows to a surgeon real time video images of part of a patients body, together with a representation of a corresponding virtual model of that part superimposed thereon. This enables the surgeon to see, for example, sub-surface structure shown in views of the virtual model positioned correctly with respect to the real time video images. It is as if the real time video images can see below the surface of the body part. Thus, the surgeon has an improved view of the body part and may consequently be able to operate with more precision.

An improvement of this technique is described in WO-A1-2005/000139 which also describes an invention owned by the proprietors of the present invention. In WO-A1-2005/000139 apparatus that includes a moveable video camera is disclosed. The position of the camera within a 3-D coordinate system is trackable by tracking means, with the overall arrangement being such that the camera can be moved so as to display on a video display screen different views of a body part, but with a corresponding view of a virtual model of that body part being displayed thereon.

In order for an arrangement such as that described in WO-A1-2005/000139 to work, it will be appreciated that it is necessary to achieve some sort of registry between images of the virtual model and the real time video images. More specifically, a way is needed of mapping the virtual model, which exists in a virtual coordinate system inside a computer, to the actual object of which it is a model, that object existing as a real object in a real coordinate system in the real world. This can be done in a number of ways. It may, for example, be carried out as a two-stage process. Firstly, an initial alignment process is carried out that substantially maps the virtual model to the real object. Then, a refined alignment is carried out which aims to bring the virtual model into complete alignment with the real object.

One way of carrying out the initial registration is to fix to a patient's body a number of markers, known as "fiducials". In the example of a head, fiducials in the form of small spheres might be fixed to the head such as by screwing them into the patient's skull. These fiducials are fixed in place before scanning and thus appear in the virtual model produced from the scan. Tracking apparatus can then be used to track a probe that is

brought into contact with each fiducial in the operating theatre to record the real position of that fiducial in a real coordinate system in the operating theatre. From this information, and as long as the patient's head remains still, the virtual model of the head can be mapped to real head.

A clear disadvantage of this technique of initial alignment is the need to fixed fiducials to the patient. This is an uncomfortable experience for the patient and a time-consuming operation for those fitting the fiducials. One advantage, however, of this technique is that it can result in a very accurate alignment between the virtual model and the body part such that no further alignment is necessary.

An alternative approach for achieving the initial registration is to specify a set of points on the virtual model produced from the scan. For example, a surgeon or a radiographer might use appropriate computer apparatus, such as the DEXTROSCOPE referred to above, to select easily-identifiable points, referred to as "anatomical landmarks", of the virtual model that correspond to points on the surface of the body part. These selected points fulfil a similar role to that of the fiducials. The person selecting the points might, for example, select on the virtual model the tip of the nose and each ear lobe. In the operating theatre, the surgeon would then select using tracking equipment the same points on the actual body part of the patient that correspond to the points selected on the virtual model. It is then possible for a computer to map the virtual model to the real body part.

A disadvantage of this alternative approach to the initial registration is that the selection of points on the virtual model to act as anatomical landmarks, and the selection of the corresponding points on the patient, is time consuming. It is also possible that either the person selecting the points on the virtual model, or the person selecting the corresponding points on the body, may make a mistake. There are also problems in determining precisely points such as the tip of a person's nose and the tip of an ear lobe.

Once the initial registration has been carried out, a refined registration may be performed to more closely align the virtual model with the real body part. One method of doing this is to select individually with tracking equipment a number of spaced-apart points on the surface of the body part. The surgeon can, for example, place a probe of

the tracking equipment in place on the surface of the body part and then operates an associated computer to record the position of the probe. He repeats this until a sufficient number of points on the surface of the body part have been recorded to allow accurate mapping of the virtual model to the body part.

It is therefore an object of this invention to address one or more of these problems with initial registration and refined registration.

SUMMARY OF THE INVENTION

According to a first aspect of this invention, there is provided a method of mapping a model of an object, the model being a virtual model positioned in a virtual 3-D coordinate system in virtual space, substantially to the position of the object in a real 3-D coordinate system in real space:

- a) computer processing means accessing information indicative of the virtual model;
- b) the computer processing means displaying on video display means a virtual image that is a view of at least part of the virtual model, the view being as if from a virtual camera fixed in the virtual coordinate system; and also displaying on the display means real video images of the real space captured by a real video camera moveable in the real coordinate system; wherein the real video images of the object at a distance from the camera in the real coordinate system are shown on the display means as being substantially the same size as the virtual image of the virtual model when the virtual model is at that same distance from the virtual camera in the virtual coordinate system;
- c) the computer processing means receiving an input indicative of the camera having been moved in the real coordinate system into a position in which the display means shows the virtual image of the virtual model in virtual space to be substantially coincident with the real video images of the object in real space;
- d) the computer processing means communicating with sensing means to sense the position of the camera in the real coordinate system;

e) the computer processing means accessing model position information indicative of the position of the virtual model relative to the virtual camera in the virtual coordinate system;

f) the computer processing means responding to the input to ascertain the position of the object in the real coordinate system from the sensed position of the camera sense in step (d) and the model position information of step (e); and then mapping the position of the virtual model in the virtual coordinate system substantially to the position of the object in the real coordinate system.

This method allows a user to perform an initial alignment between a 3-D model of an object and the actual object in a convenient manner. The virtual image of the 3-D model appears on the video display means and does not move on those means when the camera is moved. By moving the real camera, however, real video images of objects in the real space may move across the display means. Thus, the user may move the camera until the virtual image appears on the display means to coincide with the real video images of the object as seen by the real camera. For example, where the virtual image is of a human head, the user may look to align prominent and easily-recognisable features of the virtual image shown on the display means, such as ears or a nose, with the corresponding features in the video images captured by the camera. When this is done, the input to the computer processing means fixes the position of the virtual image relative to the head

Preferably, the object is a part or whole of the body of a human or of an animal.

The method may include the step of positioning at least one of the virtual model and the object such that they are substantially coincident in one of the coordinate systems.

Preferably, the mapping includes generating a transform that maps the position of the virtual model to the position of the object. The method may include the subsequent step of applying the transform to position the object in the virtual coordinate system so as to be substantially coincident with the virtual model in the virtual coordinate system. The method may include the subsequent step of applying the transform to position the virtual model in the real coordinate system so as to be substantially coincident with the object in the real coordinate system.

The method may include the step of positioning the virtual model relative to the virtual camera in the virtual coordinate system so as to be a predefined distance from the virtual camera. The step of positioning the virtual model may also include the step of orientating the virtual model relative to the virtual camera. The positioning step may include selecting a preferred point of the virtual model and positioning the virtual model relative to the virtual camera such that the preferred point is at the predefined distance from the virtual camera. Preferably the preferred point is on the surface of the virtual image. Preferably the preferred point substantially coincides with a well-defined point on the surface of the object. The preferred point may be an anatomical landmark. For example, the preferred point may be the tip of the nose, the tip of an ear lobe or one of the temples. The orientating step may include orientating the virtual model such that the preferred point is viewed by the virtual camera from a preferred direction. The step of positioning and/or the step of orientating may be performed automatically by the computer processing means, or may be carried out by a user operating the computer processing means. Preferably a user specifies a preferred point on the surface of the virtual model. Preferably, the user specifies a preferred direction from which the preferred point is viewed by the virtual camera. Preferably, the virtual model and/or the virtual camera are automatically positioned such that the distance therebetween is the predefined distance.

The method may include the subsequent step of displaying on the video display means real images of the real space captured by the real camera, and virtual images of the virtual space as if captured by the virtual camera, the virtual camera being moveable in the virtual space with movement of the real camera in the real space such that the virtual camera is positioned relative to the virtual model in the virtual coordinate system in the same way as the real camera is positioned relative to the object in the real coordinate system. The method may therefore include the step of the computer processing means communicating with the sensing means to sense the position of the camera in the real coordinate system. The computer processing means may then ascertain therefrom the position of the real camera relative to the object. The computer processing means may then move the virtual camera in the virtual coordinate system so as to be at the same position relative to the virtual model.

By relating movement of the virtual camera with movement of the real camera in this way, the real camera may be moved so as to display real images of the object on the display means from a different point of view and the virtual camera will be moved correspondingly such that corresponding virtual images of the virtual model from the same point of view are also displayed on the display means. Thus, embodiments of the invention may be used by a surgeon in the operating theatre to view a body part from many different directions and have the benefit of seeing a scanned image of that part overlaid on real video images thereof.

According to a second aspect of this invention, there is provided mapping apparatus for mapping a model of an object, the model being a virtual model positioned in a virtual 3-D coordinate system in virtual space, substantially to the position of the object in a real 3-D coordinate system in real space;

wherein the apparatus includes computer processing means, a video camera and video display means;

the apparatus arranged such that: the video display means is operable to display real video images captured by the camera of the real space, the camera being moveable within the real coordinate system; the computer processing means is operable to display also on the video display means a virtual image that is a view of at least part of the virtual model, the view being as if from a virtual camera fixed in the virtual coordinate system,

wherein the apparatus further includes sensing means to sense the position of the video camera in the real coordinate system and to communicate camera position information indicative of this to the computer processing means, and the computer processing means is arranged to access model position information indicative of the position of the virtual model relative to the virtual camera in the virtual coordinate system and to ascertain from the camera position information and the model position information the position of the object in the real coordinate system, and

wherein the computer processing means is arranged to respond to an input indicative of the camera having been moved in the real coordinate system into a position in which the

video display means shows the virtual image of the virtual model in virtual space to be substantially coincident with a real video image of the object in real space by mapping the position of the virtual model in the virtual coordinate system substantially to the position of the object in the real coordinate system.

The computer processing means may be arranged and programmed to carry out the method defined above in the first aspect of this invention.

The computer processing means may include a navigation computer processing means for positioning in an operating theatre for use in preparation for or during a medical operation. The computer processing means may include planning computer processing means to receive data generated by a body scanner, to generate the virtual model therefrom and to display that image and allow manipulation thereof by a user.

Preferably, the real camera includes a guide fixed thereto and arranged such that when real camera is moved such that the guide contacts the surface of the object, the object is at a predefined distance from the real camera that is known to the computer processing means. The guide may be an elongate probe that projects in front of the real camera.

The specification and arrangement of the real camera may be such that, when the object is at the predefined distance from the real camera, the size of the real image of that object on the display means is the same as the size of the virtual image displayed on those display means when the virtual model is at the predefined distance from the virtual camera. For example, the position and focal length of a lens of the real camera may be selected such that this is the case. Alternatively, or additionally, the computer processing means may be programmed such that the virtual camera has the same optical characteristics as the real camera such that the virtual image displayed on the display means when the virtual model is at the predefined distance from the virtual camera appears the same size as real images of the object at the predefined distance from the real camera.

The mapping apparatus may be arranged such that the computer processing means receives an output from the real camera indicative of the images captured by that

camera and such that the computer processing means displays the real images on the video display means.

The apparatus may include input means operable by the user to provide the input indicative of the camera having been the position in which the video display means shows the virtual image to be substantially coincident with the real image of the object. The input means may be a user-operated switch. Preferable the input means is a switch that can be placed on the floor and operated by the foot of the user.

According to a third aspect of this invention, there is provided a method of more closely aligning a model of an object, the model being a virtual model positioned in a 3-D coordinate system in space, with the object in the coordinate system, the virtual model and the object having already been substantially aligned, the method including the steps of:

- a) computer processing means receiving an input indicating that a real data collection procedure should begin;
- b) the computer processing means communicating with sensing means to ascertain the position of a probe in the coordinate system, and thereby the position of a point on the surface of the object when the probe is in contact with that surface;
- c) the computer processing means responding to the input to record automatically and at intervals respective real data indicative of each of a plurality of positions of the probe in the coordinate system, and hence indicative of each of a plurality of points on the surface of the object when the probe is in contact with that surface;
- d) the computer processing means calculating a transform that substantially maps the virtual model to the real data.
- e) the computer processing means applying the transform to more closely align the virtual model with the object in the coordinate system.

At step (c), the method may record respective real data indicative of each of at least 50 positions of the probe and may record, for example, respective real data indicative of each of 100, 200, 300, 400, 500, 600, 700 or 750 positions of the probe.

Preferably, the method is such that the real data indicative of the position of the probe is indicative of the position of a tip of the probe that can be used to contact the object.

Preferably, the computer processing means automatically records the respective real data such that the position of the probe at periodic intervals is recorded. Preferably, the method includes the step of the computer processing means displaying on video display means one more or all of the positions of the probe for which real data is recorded.

Preferably the method includes displaying the positions of the probe together with the virtual model to show the relative positions thereof in the coordinate system. Preferably, the method displays each position of the probe substantially as the respective data indicative thereof is collected. Preferably each position of the probe is displayed in this manner in real time.

The method of the first aspect of this invention may include in subsequent steps the method of the third aspect of this invention.

The mapping apparatus may be further programmed and arranged to carry out the method of the third aspect of this invention.

According to a fourth aspect of this invention, there is provided computer processing means arranged and programmed to carry out one or more of the methods defined hereinabove.

The computer processing means may include a personal computer.

According to a fifth aspect of this invention, there is provided a computer program including code portions which are executable by computer processing means to cause those means to carry out one or more of the methods defined hereinabove.

According to a sixth aspect of this invention, there is provided a record carrier including therein a record of a computer program having code portions which are executable by

computer processing means to cause those means to carry out one or more of the methods defined hereinabove.

The record carrier may be a computer-readable record product, such as one or more: optical disk, such as a CD-ROM or DVD; magnetic disk, such as a floppy disk; or solid state record device, such as an EPROM or EEPROM. The record carrier may be a signal transmitted over a network. The signal may be an electrical signal transmitted over wires. The signal may be a radio signal transmitted wirelessly. The signal may be an optical signal transmitted over an optical network.

It will be appreciated that references herein to the "position" of items such as the virtual model, the object, the virtual camera and the real camera are references to the location and the orientation of those items.

BRIEF DESCRIPTION OF THE DRAWINGS

Specific embodiments of this invention are described below with reference to the accompanying drawings, in which:

Figure 1 shows is schematic form apparatus of first embodiment of this invention;

Figure 2 shows a simplified representation of the head of a human patient;

Figure 3 shows a simplified representation of a virtual model of the head;

Figure 4 shows the representation of the virtual model in a virtual coordinate system, with a point of the image being selected;

Figure 5 shows part of the apparatus that is located in an operating theatre, that part of the apparatus being used at the beginning of an initial alignment procedure;

Figure 6 shows the apparatus of Figure 5 being used later in the initial alignment procedure;

Figure 7 shows the apparatus of Figure 5 and Figure 6 at the completion of the initial alignment procedure;

Figure 8 shows a video screen and a camera probe of the apparatus during a refined alignment procedure carried out subsequently to the initial alignment procedure; and

Figure 9 shows images displayed on the video screen at the completion of the refined alignment procedure.

SPECIFIC DESCRIPTION OF CERTAIN EXEMPLARY EMBODIMENTS

It is intended that the embodiment now described is for mapping a virtual model of a patient existing on a computer, such as produced as a result of an MRI scan, to the position of the actual patient in an operating theatre. This allows views of the virtual model to be overlaid on real time video images of the patient and so acts as an aid to surgery. The description of this embodiment will include a description of an initial registration procedure in which the virtual model is substantially mapped to the position of the actual patient, and a refined registration procedure in which the aim is for the virtual model to be exactly mapped to the patient.

Figure 1 shows, in schematic form, apparatus 20 used in this embodiment. The apparatus 20 includes an MRI scanner 30 that is in data communication with a planning station computer 40. The MRI scanner 30 is arranged to perform an MRI scan of a patient and to send scanned data produced from that scan to the planning station computer 40. The planning station computer 40 is arranged to produce a 3-D model of the patient from the scanned data that can be viewed and manipulated by an operator of the planning station computer 40, such as a radiographer. As the 3-D model exists only inside the computer, it is referred to herein as a "virtual model".

With continued reference to Figure 1, the apparatus 20 further includes theatre apparatus 50 that is located in an operating theatre (not shown). The theatre apparatus 50 includes a navigation station computer 60 that is in data communication with the planning station computer 40. The theatre apparatus 50 further includes a foot switch 65, a camera probe 70, tracking equipment 90 and a monitor 90. The foot switch 65 is positioned on the floor and connected to the navigation station computer 60 so as to

provide an input thereto when depressed by the foot of an operator. The camera probe 70 is made up of a video camera 72 with a long, thin, probe 74 projecting therefrom into the centre of the field of view of the camera 72. The video camera 72 is compact and light such that it can easily be held without strain in the hand of an operator and easily moved between positions. A video output of the camera 72 is connected as an input to the navigation station computer 40. The tracking equipment 90 is arranged to track the position of the camera probe 70 in a known manner and is connected to the navigation station computer 40 so as to provide data thereto indicative of the position of the camera probe 70 relative thereto.

In this embodiment, it should be understood that the part of the patient's body that is of interest is the head. Specifically, it should be understood that an MRI scan has been performed of a patient's head and a 3-D virtual model of the patient's head has been constructed from data gleaned from that scan. The model, which is viewable on computer means in the form of a planning station computer, shows, in this exemplary embodiment, there to be a tumour in the region of the patient's brain. The intention is that the patient should undergo surgery with a view to removing the tumour.

In an attempt to simplify the following description of this embodiment, the shape of the patient's head is represented by a cube. The cube representing the patient's head is shown at 10 in Figure 2.

As a preliminary procedure, an MRI scan is performed of the patient's head using the MRI scanner 30. Scan data from that scan is sent from the MRI scanner 30 to the planning station computer 40. The planning station computer 40 runs planning software that uses the scan data to create a virtual model that can be viewed and manipulated using the planning station computer 40. The virtual model is shown at 100 in Figure 3.

With reference to Figure 4, the virtual model is made up of a series of data points positioned in a 3-D coordinate system 110 inside the planning station computer 40. As this coordinate system exists only in the planning station computer 40 and, as yet, has no frame of reference in the real world, this coordinate system 110 will be referred to as the "virtual coordinate system" 110 and will be referred to as being in "virtual space".

By interacting with the planning station computer 40 and the planning software running thereon, a user, such as a radiographer, selects a point of view from which the virtual model 100 should be viewed in the virtual space. To do this, he first selects a point 102 on the surface of the virtual model 100. It is preferable to select a point that is comparatively well defined such as, in the case of a model of a head, the tip of the nose or ear lobe. The radiographer then selects a line of sight 103 leading to the selected point. This point 102 and the line of sight 103 are saved, together with the data from which the virtual model is generated, as virtual model data by the planning software. The virtual model data is saved so as to be available to the navigation station computer 60. In this embodiment, the virtual model data is made available to the navigation station computer 60 by virtue of each station computer 40, 60 being connected to a local area network (LAN).

Activity then moves to the operating theatre. Figure 5 shows a schematic representation of the arrangement in the operating theatre. The patient is prepared for surgery and positioned such that his head 10 (still represented by a cube) is fixed in a real coordinate system 11 defined by the position of the tracking equipment 80. In the operating theatre, a user, such as a surgeon, then operates navigation software running on the navigation computer station 60 to access the virtual model data saved by the planning computer station 40. With continued reference to Figure 5, the navigation software displays the virtual model 100 on the monitor 80. The virtual model 100 is displayed as if viewed by a virtual video camera fixed so as to view the virtual model from the point of view specified using the planning station computer 40, and at a distance from the virtual camera specified by the navigation software. Simultaneously, the navigation software receives data indicative of the real time video output from the video camera 72 and displays video images corresponding to that output on the monitor 80. The displayed video images will be referred to as "real images" and the video camera 72 will be referred to as the "real camera" 72 in order to distinguish these clearly from images of the virtual model 100 and virtual camera. The navigation software and the real camera 72 are calibrated such that the displayed image of a virtual model at a distance x in the virtual coordinate system 110 from the virtual camera is shown as the same size on the monitor 80 as a real image of the corresponding object at a distance x in the real world from the real camera 72. (It will be understood that references to the distance of an object or model from a camera may more properly be referred to as the distance from

the focal plane of that camera. However, for clarity of explanation, reference to focal planes is omitted herein.)

Furthermore, the navigation software is arranged to display images of the virtual model as if the point 102 selected previously were at a distance from the virtual camera that is equal to the distance of the tip of the probe 74 from the real camera 72 to which it is attached. Whilst the real camera 72 is moveable in the real world such that moving the real camera 72 causes different real images to appear on the monitor 80, moving the real camera 72 has no effect on the position of the virtual camera in the virtual coordinate system 110. The image of the virtual model 100 therefore remains static on the monitor 80 regardless of whether or not the real camera 72 is moved. As the probe 74 is fixed to the real camera 72 and projects into the centre of the camera's field of view, the probe 72 is also always visible projecting into the centre of the real images shown on the monitor 80. As a result of all this, images of the virtual model appear fixed on the monitor 80 with the point 102 previously selected appearing fixed at the end of the probe 72. This remains the case even when the real camera 72 is moved around and different real images pass across the monitor 80.

Thus, Figure 5 shows the virtual model 100 displayed on the monitor 80 and positioned so that the selected point 102 is at the tip of the probe 72 and the view of the virtual model 100 is that previously selected using the planning stage computer 40. In the arrangement shown in Figure 5, the camera probe 70 is some distance from the patient's head 10. As a result the real image of the head 10 on the monitor is shown as being in the distance.

Also visible in Figure 5 is the tracking equipment 90. During operation of the theatre apparatus 50, the navigation software receives camera probe position data from the tracking equipment 90 indicative of the position and orientation of the camera probe 70 in the real coordinate system 11.

In order to begin an initial registration procedure in which the position of the virtual model is substantially mapped to the position of the patient's head 10 in the real coordinate system 11, the surgeon moves the camera probe 70 towards the patient's head 10. As the camera probe 70, which includes the real camera 72, approaches the

patient's head 10, the real image of the head 10 on the monitor grows. The surgeon moves the camera probe 70 towards the patient's head such that the tip of the probe touches the point on the head 10 that corresponds to the point 102 selected on the surface of the virtual model. As stated above, a convenient point might be the tip of the patient's nose. The monitor 80 would then show a real image of the head 10 positioned with the tip of the nose at the tip of the probe 74. This arrangement is shown in Figure 6. As the image of the virtual model 100 would not have moved from its static position, the tip of the nose on the virtual model 100 would therefore appear to coincide with the tip of the nose on the real image of the head 10. The remainder of the image of the virtual model 100 may, however, not coincide with the remainder of the real image.

In order to bring the rest of the real image of the head 10 into alignment with the image of the virtual model 100, the surgeon moves the camera around, whilst keeping the tip of the probe on the tip of the patient's nose. By looking at the monitor 80 the surgeon receives visual feedback as to whether or not he is bringing the real image into alignment with the image of the virtual model 100. Once he has succeeded in achieving the closest alignment that he is able to achieve, such as that shown in Figure 7, the surgeon depresses the foot switch 65. The foot switch 65 sends an input to the navigation station computer 60 that is taken by the navigation software to mean that the real image is substantially aligned with the image of the virtual model 100. Upon receiving this input, the navigation software records the position and orientation of the camera probe 70 in the real coordinated system 11.

As the navigation software now knows:

- a) that the present position of the camera probe 70 results in the real image being coincident with the image of the virtual model 100 on the monitor; and
- b) the arrangement is such that the virtual camera shows on the monitor an image of a virtual model of an object that appears on the monitor to be the same size as the real image of the object captured by the real camera, when the each of the virtual model and real object is the same distance from its respective camera,

it can conclude that the patient's head 10 must be positioned in front of the real camera 72 in the same way as the virtual model 100 of the head 10 is positioned in front of the virtual camera.

Furthermore, as the navigation software also knows the location and orientation of the virtual model relative to the virtual camera, it can ascertain the location and orientation of the patient's head relative to the real camera 72; and as it also knows the location and orientation of the camera probe 70 and hence the real camera 72 in the real coordinate system, it can calculate the location and orientation of the patient's head 10 in that real coordinate system.

Upon calculating the location and orientation of the patient's head 10 in the real coordinate system, the navigation software can then map the position of virtual model in the virtual coordinate system to the position of the patient's head 10 in the real coordinate system. The navigation software causes the navigation station computer to carry out the necessary calculations to generate a mathematical transform that maps between these two positions. That transform is then applied to position the patient's head in the virtual coordinate system so as to be substantially in alignment with the virtual model of the head therein. An alternative way of thinking of this is to think of the virtual coordinate system becoming fixed relative to the real coordinate system and located and orientated relative thereto such that the virtual model 100 coincides with the head 10.

The navigation software then unfixes the virtual camera from its previously fixed position in the virtual space and fixes it to the real camera 72 such that it is moveable with the real camera 72 to move through the virtual space as the real camera moves through the real space. In this way, pointing the real camera 72 at the head 10 from different points of view results in different real views being displayed on the monitor 80, each with a corresponding view of the virtual model overlaid thereon and in substantial alignment therewith.

That completes the initial alignment procedure.

It is unlikely, however, that the initial alignment procedure will result in accurate alignment. Any slight unsteadiness in the hand of the surgeon may lead to imperfect alignment between the head and the virtual model 100. Inaccurate alignment may also result from difficulty in placing the tip of the probe 74 at the very same point on the patient as was selected using the planning station computer. In the present example, it may be difficult to decide a single point that represents the tip of the nose. Thus, it is likely that, following the initial registration, there is some misalignment between the head 10 and the virtual model 100. In order to improve the alignment, a procedure of refined registration is carried out.

With reference to Figure 8, the surgeon begins the refined registration by indicating to the navigation software that the refined registration is to begin. He then moves the camera probe 70, such that the tip of the probe 74 traces a route across the surface of the patient's head 10. At the same time, the navigation software receives data from the tracking equipment 90 indicative of the position of the camera probe 70, and hence the tip of the probe 74, in the real coordinate system. From this data, and by using the mathematical transform calculated towards the end of the initial alignment procedure, the computer is able to calculate the position of the camera probe, and hence the tip of the probe, in the virtual coordinate system. The navigation software is arranged to periodically record position data indicative of the position of each of a series of real points on the surface of the head in the virtual coordinate system. Upon recording a real point, the navigation software is such that the real point is displayed on the monitor 80. This helps to ensure that the surgeon only moves the tip of the probe 74 across parts of the patient that are included in the virtual model and hence for which there is virtual model data. Moving the tip of the probe 74 outside the scanned region may reduce the registration accuracy as this would result in a real point being recorded for which there is no corresponding point making up the surface of the virtual model.

As can be seen in Figure 8, the tip of the probe 74 is traced evenly over the surface of the scanned part of the patient's body, which in this example is the head 10. The tracing continues until the navigation software has collected data for enough real points. In this embodiment, the software collects data for 750 real points. After the data for the 750th real point has been collected, the navigation software notifies the surgeon, such as by

causing the navigation station computer to make a sound, and stops recording data for real points.

It will be appreciated that the navigation software now has access to data representing 750 points that are positioned in the virtual coordinate system to as to be precisely on the surface of the patient's head 10.

The navigation software then accesses the virtual model data that makes up the virtual model. The software isolates the data representing the surface of the patient's head from the remainder of the data. From the isolated data, a cloud point representation of the skin surface of the patient's head 10 is extracted.

The navigation software then causes the navigation station computer to begin a process of iterative closest point (ICP) measure. In this process, the computer finds, for each of the real points, a closest one of the points making up the cloud point representation. Once a pair has been established for each of the real points, the computer calculates a transformation that would shift, as closely as possible, each of the paired points of the cloud point representation to the real point in the respective pair. The computer then applies this transformation to move the virtual model into closer alignment with the head in the virtual coordinate system. The computer then repeats this operation of pairing-off each real point with the closest point in the cloud point representation, finding a transformation, and then applying the transformation. Subsequent iterations are carried out until the position of the virtual model 100 settles into a final position in the virtual coordinate system, as shown in Figure 9. The software then fixes the virtual model 100 in that final position. Whilst the final position of the virtual model 100 may not be in exact alignment with the patient's head 10, it would most likely be in closer alignment than following the initial registration and be sufficiently aligned to be of assistance during surgery.

In an alternative embodiment of this invention, the initial registration is carried out in the manner described hereinabove up to the point at which the surgeon depresses the foot switch 65 indicating that the camera probe 70 has been positioned on the patient's head and orientated such that the real images on the monitor 80 have been brought into substantial alignment with the image of the virtual model 100 thereon. In this alternative

embodiment, the navigation software reacts to the input from the foot switch 65 to freeze the real image of the head 10 on the monitor 80. The navigation software of this embodiment, in common with the first embodiment described, also senses and records the position of the real camera 72. With the real images of the head 10 frozen, the real camera 72 can be put down. The surgeon then operates the navigation station computer 60 to move the position of the virtual camera relative to the virtual model such that the image of the virtual model 100 shown on the monitor 80 is shown from a different point of view. This is done such that the image of the virtual model 100 shown on the monitor 80 is brought into closer alignment with the frozen real image of the head 10. It is envisaged that this alternative embodiment may be advantageous in that very fine movement of the virtual camera relative to the virtual model may be achieved, whereas such fine movement of the real camera relative to the head 10 may be difficult. Thus, it may be possible to achieve a more accurate initial alignment in this alternative embodiment than is possible in the first embodiment. Once satisfactory alignment has been achieved, an input indicative of this is provided to the navigation station computer such that the navigation software then proceeds with mapping the position of the virtual model to position of the head 10 in the manner of the first embodiment.

If the initial registration as performed by either the first embodiment or the alternative embodiment described hereinabove results in an accuracy of alignment between the virtual model and the real image that is satisfactory for the intended subsequent medical procedures, then the procedure of refined alignment described above may be omitted.

The accuracy of the registration may be assessed by moving the real camera around the patient's head 10 to see whether or not there is apparent misalignment between the virtual model 100 and the real images of the head 10.

It is envisaged that the apparatus disclosed in each of WO-A1-02/100284 and WO-A1-2005/000139 may be modified in accordance with the foregoing description so as to amount to the apparatus described hereinabove and thereby to embody the present invention. Accordingly, the contents of those two earlier publications are hereby incorporated herein in their entirety.

CLAIMS

1. A method of mapping a model of an object, the model being a virtual model positioned in a virtual 3-D coordinate system in virtual space, substantially to the position of the object in a real 3-D coordinate system in real space:

- a) computer processing means accessing information indicative of the virtual model;
- b) the computer processing means displaying on video display means a virtual image that is a view of at least part of the virtual model, the view being as if from a virtual camera fixed in the virtual coordinate system; and also displaying on the display means real video images of the real space captured by a real video camera moveable in the real coordinate system; wherein the real video images of the object at a distance from the camera in the real coordinate system are shown on the display means as being substantially the same size as the virtual image of the virtual model when the virtual model is at that same distance from the virtual camera in the virtual coordinate system;
- c) the computer processing means receiving an input indicative of the camera having been moved in the real coordinate system into a position in which the display means shows the virtual image of the virtual model in virtual space to be substantially coincident with the real video images of the object in real space;
- d) the computer processing means communicating with sensing means to sense the position of the camera in the real coordinate system;
- e) the computer processing means accessing model position information indicative of the position of the virtual model relative to the virtual camera in the virtual coordinate system;
- f) the computer processing means responding to the input to ascertain the position of the object in the real coordinate system from the sensed position of the camera sense in step (d) and the model position information of step (e); and then mapping the position of the virtual model in the virtual coordinate system substantially to the position of the object in the real coordinate system.

2. A method according to claim 1 including the subsequent step of applying the mapping to position at least one of the virtual model and the object such that they are substantially coincident in one of the coordinate systems.
3. A method according to claim 1 or claim 2, wherein the mapping includes generating a transform that maps the position of the virtual model to the position of the object and the method includes the subsequent step of applying the transform to position the object in the virtual coordinate system so as to be substantially coincident with the virtual model in the virtual coordinate system.
4. A method according to claim 1 or 2, wherein the mapping includes generating a transform that maps the position of the virtual model to the position of the object and the method includes the subsequent step of applying the transform to position the virtual model in the real coordinate system so as to be substantially coincident with the object in the real coordinate system.
5. A method according to an preceding claim and including the step of positioning the virtual model relative to the virtual camera in the virtual coordinate system so as to be a predefined distance from the virtual camera.
6. A method according to claim 5, wherein the step of positioning the virtual model also includes the step of orientating the virtual model relative to the virtual camera.
7. A method according to claim 5 or claim 6, wherein the positioning step includes selecting a preferred point of the virtual model and positioning the virtual model relative to the virtual camera such that the preferred point is at the predefined distance from the virtual camera.
8. A method according to claim 7, wherein the preferred point substantially coincides with a well-defined point on the surface of the object.

9. A method according to any one of claims 6 to 8, wherein the orientating step includes orientating the virtual model such that the preferred point is viewed by the virtual camera from a preferred direction.

10. A method according to any one of claims 7 to 9, wherein a user specifies a preferred point of the virtual model.

11. A method according to any one of claims 5 to 10, wherein a user specifies a preferred direction from which the preferred point is viewed by the virtual camera.

12. A method according to any one of claims 5 to 11, wherein the virtual model and/or the virtual camera are automatically positioned such that the distance therebetween is the predefined distance.

13. A method according to any preceding claim and including the subsequent step of displaying on the video display means real images of the real space captured by the real camera, and virtual images of the virtual space as if captured by the virtual camera, the virtual camera being moveable in the virtual space with movement of the real camera in the real space such that the virtual camera is positioned relative to the virtual model in the virtual coordinate system in the same way as the real camera is positioned relative to the object in the real coordinate system.

14. A method according to claim 13, and including the steps of: the computer processing means communicating with the sensing means to sense the position of the camera in the real coordinate system; the computer processing means then ascertaining therefrom the position of the real camera relative to the object; and the computer processing means displaying a virtual image on the display means as if the virtual camera has been moved in the virtual coordinate system so as to be at the same position relative to the virtual model.

15. Mapping apparatus for mapping a model of an object, the model being a virtual model positioned in a virtual 3-D coordinate system in virtual space, substantially to the position of the object in a real 3-D coordinate system in real space;

wherein the apparatus includes computer processing means, a video camera and video display means;

the apparatus arranged such that: the video display means is operable to display real video images captured by the camera of the real space, the camera being moveable within the real coordinate system; and the computer processing means is operable to display also on the video display means a virtual image that is a view of at least part of the virtual model, the view being as if from a virtual camera fixed in the virtual coordinate system,

wherein the apparatus further includes sensing means to sense the position of the video camera in the real coordinate system and to communicate camera position information indicative of this to the computer processing means, and the computer processing means is arranged to access model position information indicative of the position of the virtual model relative to the virtual camera in the virtual coordinate system and to ascertain from the camera position information and the model position information the position of the object in the real coordinate system, and

wherein the computer processing means is arranged to respond to an input indicative of the camera having been moved in the real coordinate system into a position in which the video display means shows the virtual image of the virtual model in virtual space to be substantially coincident with a real video image of the object in real space by mapping the position of the virtual model in the virtual coordinate system substantially to the position of the object in the real coordinate system.

16. Apparatus according to claim 13, wherein the computer processing means is arranged and programmed to carry out a method according to any one of claims 1 to 14.

17. Apparatus according to claim 13 or 14, wherein the camera is of a size and weight such that it can be held in the hand of a user and thereby moved by the user.

18. Apparatus according to any one of claims 15 to 17, wherein the real camera includes a guide fixed thereto and arranged such that when real camera is moved such that the

guide contacts the surface of the object, the object is at a predefined distance from the real camera that is known to the computer processing means.

19. Apparatus according to claim 18, wherein the guide is an elongate probe that projects in front of the real camera.

20. Apparatus according to any one of claims 15 to 19, wherein the specification and arrangement of the real camera are such that the real video images of the object at the distance from the camera in the real coordinate system are shown on the display means as being substantially the same size as the virtual image of the virtual model when the model is at that same distance from the virtual camera in the virtual coordinate system

21. Apparatus according to any one of claims 15 to 20, wherein the computer processing means is programmed such that the virtual camera has the same optical characteristics as the real camera such the real video images of the object at the distance from the camera in the real coordinate system are shown on the display means as being substantially the same size as the virtual image of the virtual model when the model is at that same distance from the virtual camera in the virtual coordinate system.

22. Apparatus according to any one of claims 15 to 21 and including input means operable by the user to provide the input indicative of the camera having been the position in which the video display means shows the virtual image of the virtual model to be substantially coincident with the real image of the object.

23. Apparatus according to claim 22, wherein the input means includes a user-operated switch that can be placed on the floor and operated by the foot of a user.

24. A method of more closely aligning a model of an object, the model being a virtual model positioned in a 3-D coordinate system in space, with the object in the coordinate system, the virtual model and the object having already been substantially aligned, the method including the steps of:

a) computer processing means receiving an input indicating that a real data collection procedure should begin;

b) the computer processing means communicating with sensing means to ascertain the position of a probe in the coordinate system, and thereby the position of a point on the surface of the object when the probe is in contact with that surface;

c) the computer processing means responding to the input to record automatically and at intervals respective real data indicative of each of a plurality of positions of the probe in the coordinate system, and hence indicative of each of a plurality of points on the surface of the object when the probe is in contact with that surface;

d) the computer processing means calculating a transform that substantially maps the virtual model to the real data.

e) the computer processing means applying the transform to more closely align the virtual model with the object in the coordinate system.

25. A method according to claim 24, wherein, at step (c), the method records respective real data indicative of each of positions of the probe.

26. A method according to claim 23 or claim 24, wherein the computer processing means automatically records the respective real data such that the position of the probe at periodic intervals is recorded.

27. A method according to any one or claims 24 to 26 and including the step of the computer processing means displaying on video display means one more or all of the positions of the probe for which real data is recorded.

28. A method according to claim 27 and including displaying the positions of the probe together with the virtual image of the virtual model on the video display means to show the relative positions thereof in the coordinate system.

29. A method according to claim 27 or 28, wherein each position of the probe is displayed in real time.

30. Computer processing means arranged and programmed to carry out a method according to any one of claims 1 to 14 and/or a method according to any one of claims 24 to 29.

31. A computer program including code portions which are executable by computer processing means to cause those means to carry a method according to any one of claims 1 to 14 and/or a method according to any one of claims 24 to 29.

32. A record carrier including therein a record of a computer program having code portions which are executable by computer processing means to cause those means to carry out a method according to any one of claims 1 to 14 and/or a method according to any one of claims 24 to 29.

33. A record carrier according to claim 32, wherein the record carrier is a computer-readable record product.

34. A record carrier according to claim 32, wherein the record carrier is a signal transmitted over a network.

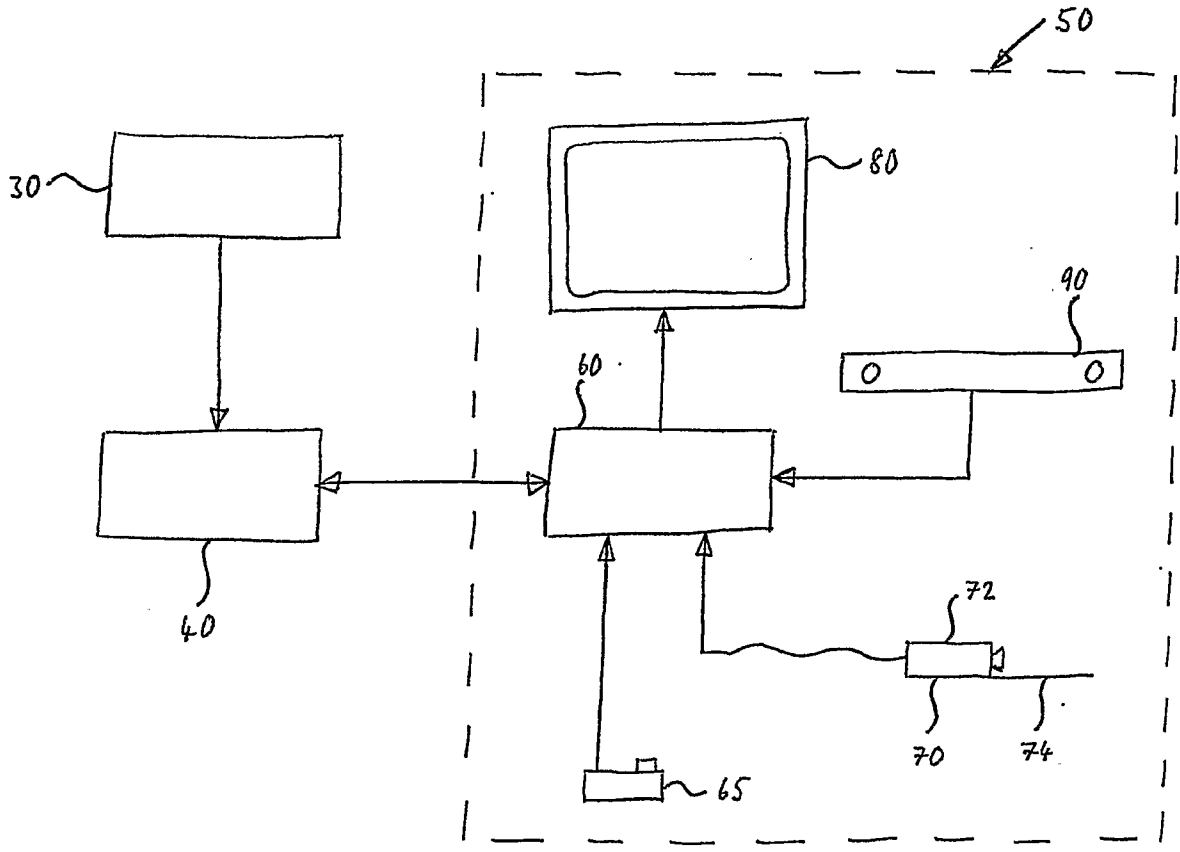


FIG. 1

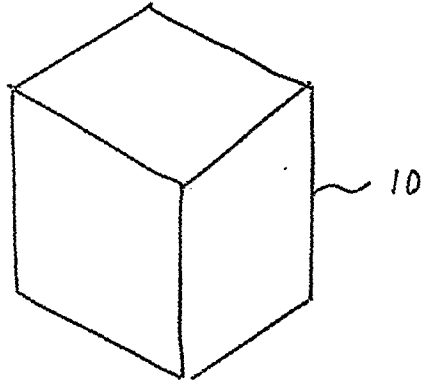


FIG. 2

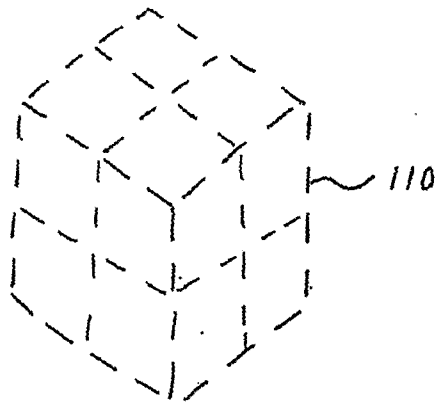


FIG. 3

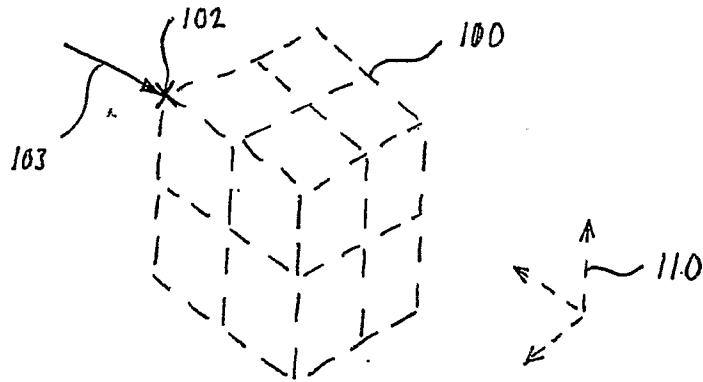


FIG. 4

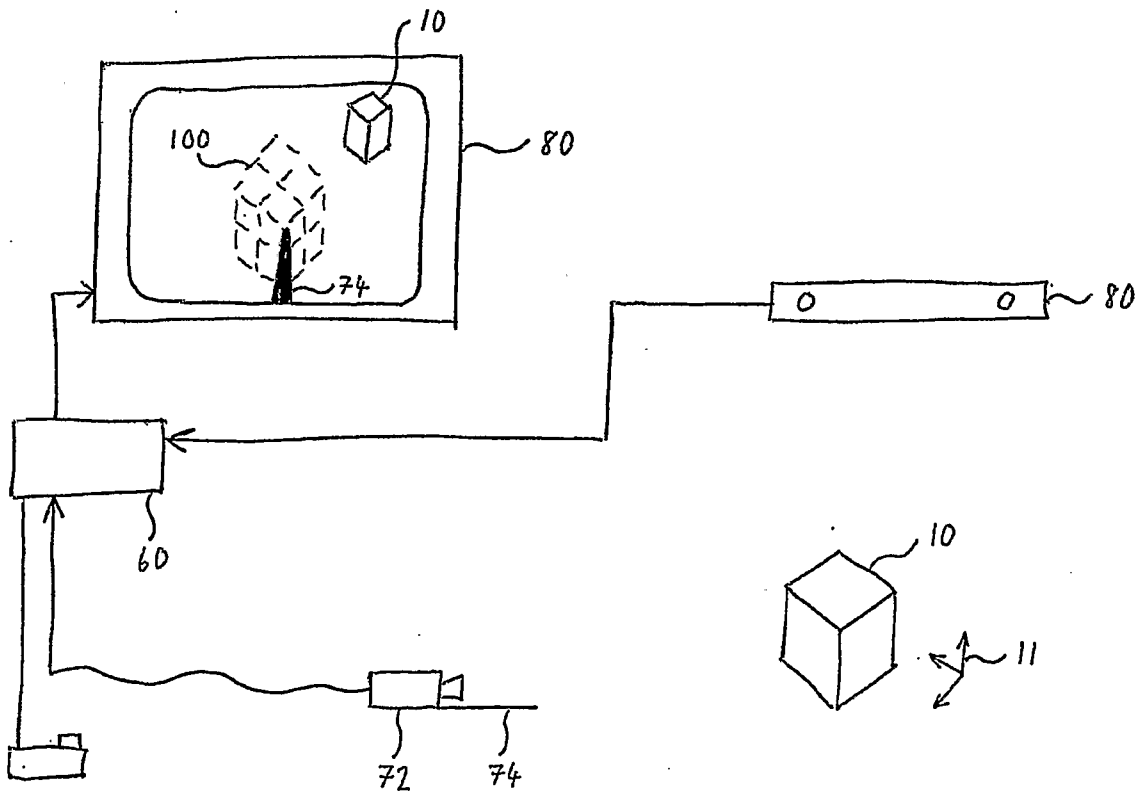
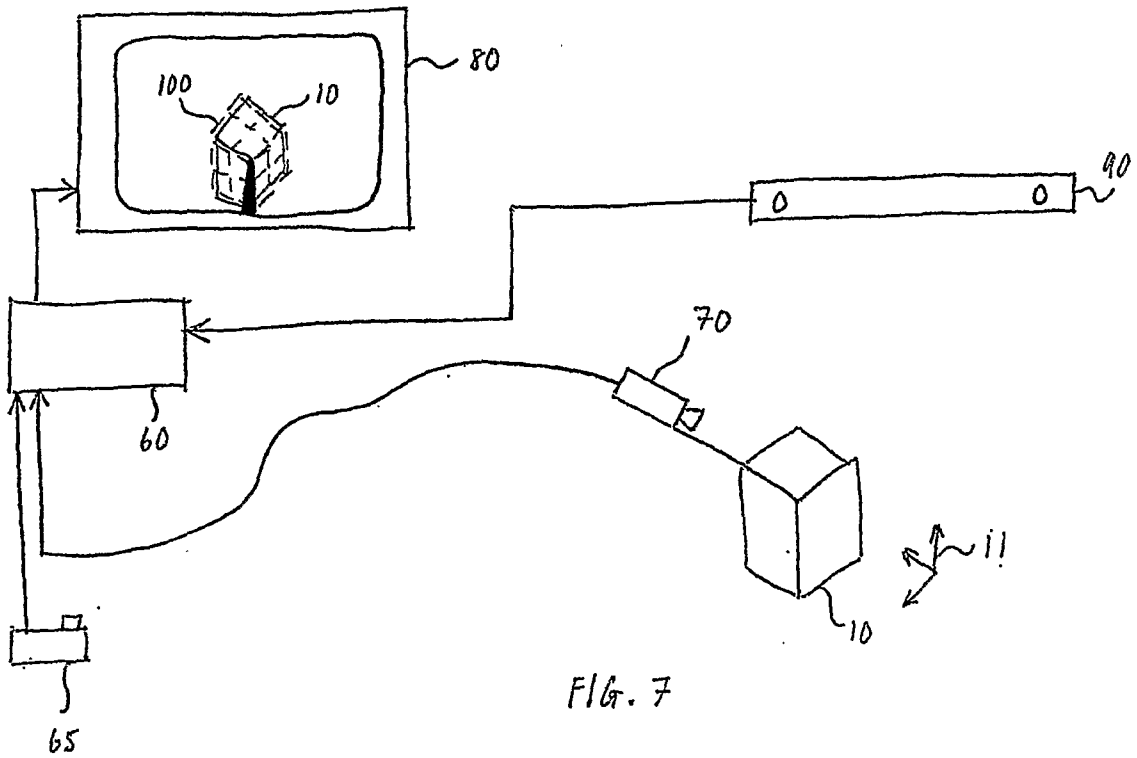
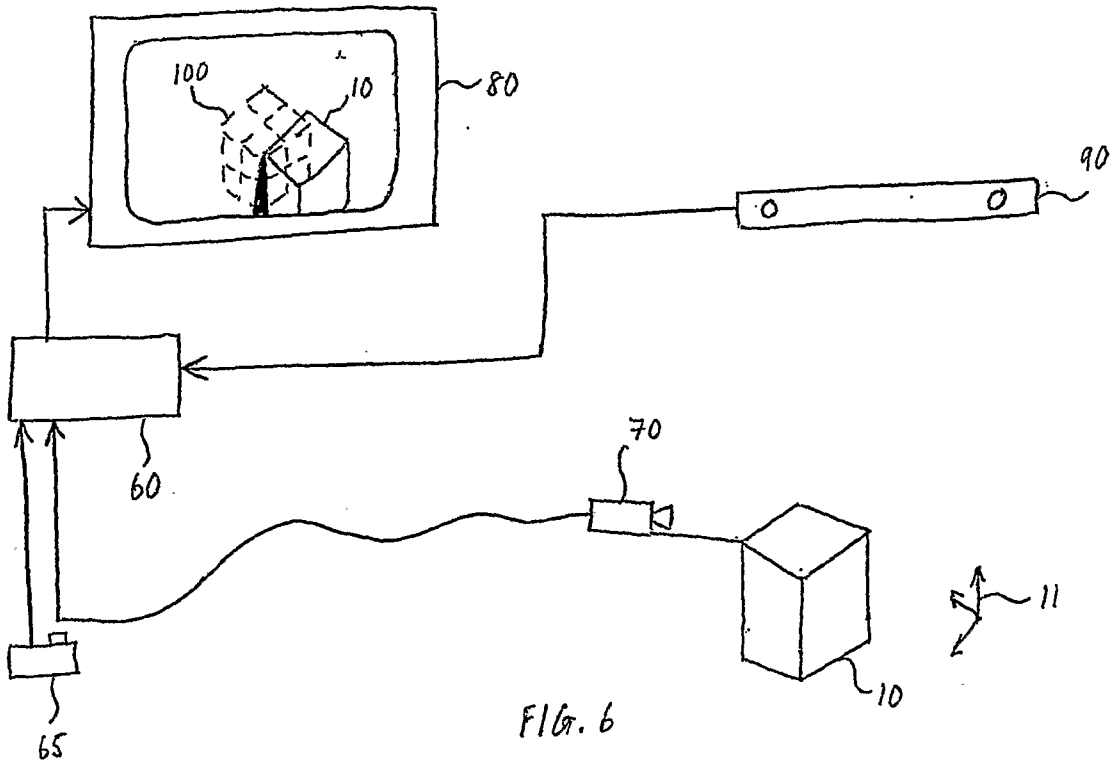


FIG. 5



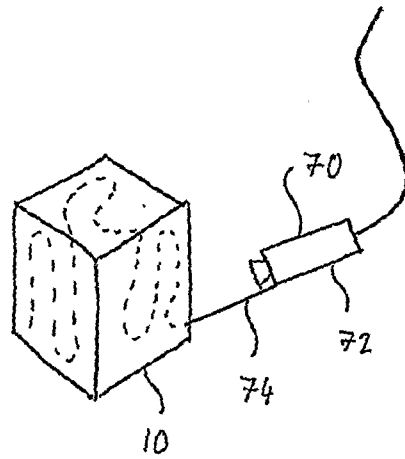
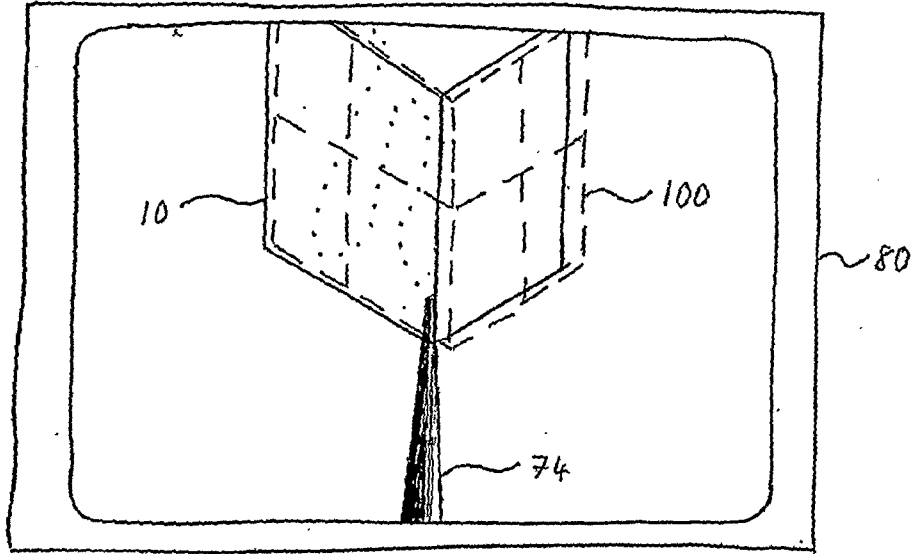


FIG. 8

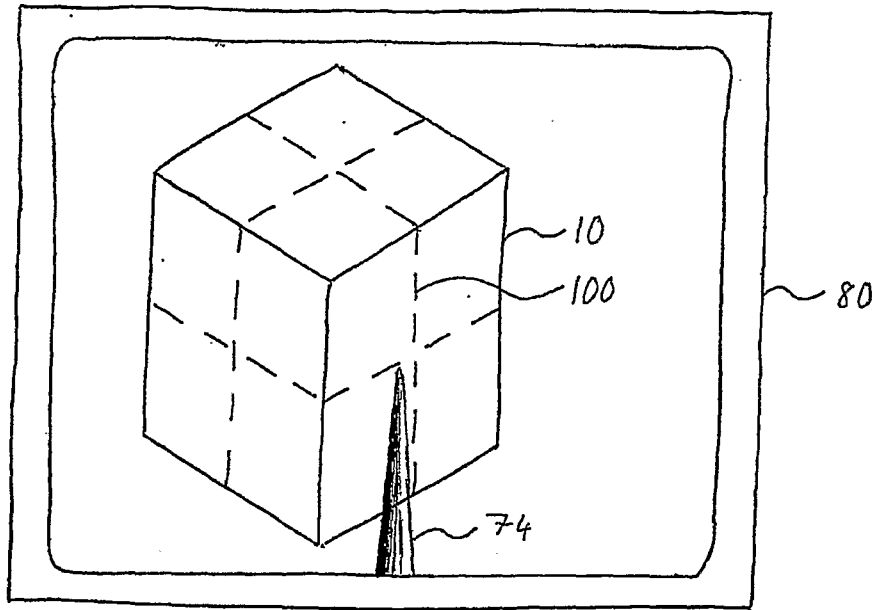


Fig. 9