US 20030187345A1

(19) United States

(12) Patent Application Publication (10) Pub. No.: US 2003/0187345 A1

Mochizuki (43) Pub. Date: Oct. 2, 2003

(54) ULTRASONIC MEDICAL SYSTEM

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(21) Appl. No.: **10/397,788**

(22) Filed: **Mar. 26, 2003**

(30) **Foreign Application Priority Data**

Mar. 27, 2002 (JP) 2002-88154
Mar. 7, 2003 (JP) 2003-61120

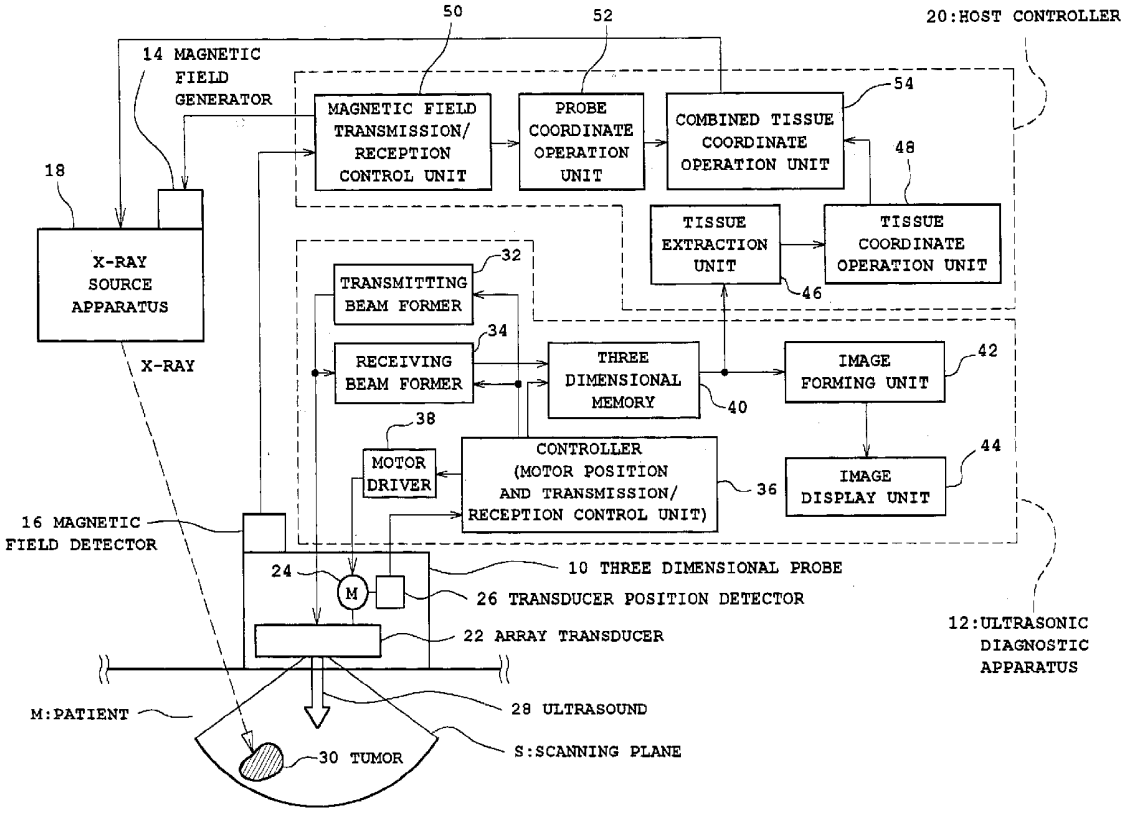
Publication Classification

(51) **Int. Cl.**[7] **A61B 5/05**; A61B 8/00

(52) **U.S. Cl.** **600/407**; 600/439

(57) ABSTRACT

An ultrasonic diagnostic apparatus **12** outputs echo data to a host controller **20**. In the host controller **20**, a tissue coordinate operation unit **48** computes coordinate information of a tumor **30** using a three dimensional probe **10** as an origin; a probe coordinate operation unit **52** computes coordinate information of the three dimensional probe **10** using, as its origin, an X-ray source apparatus **18** which functions as a reference position; and a combined tissue coordinate operation unit **54** uses the coordinate information of the tumor using the three dimensional probe **10** as its origin and the coordinate information of the three dimensional probe **10** using the X-ray source apparatus **18** as its origin to compute coordinate information of the tumor **30** using the X-ray source apparatus as its origin, and outputs the computed coordinate information to the X-ray source apparatus **18.**



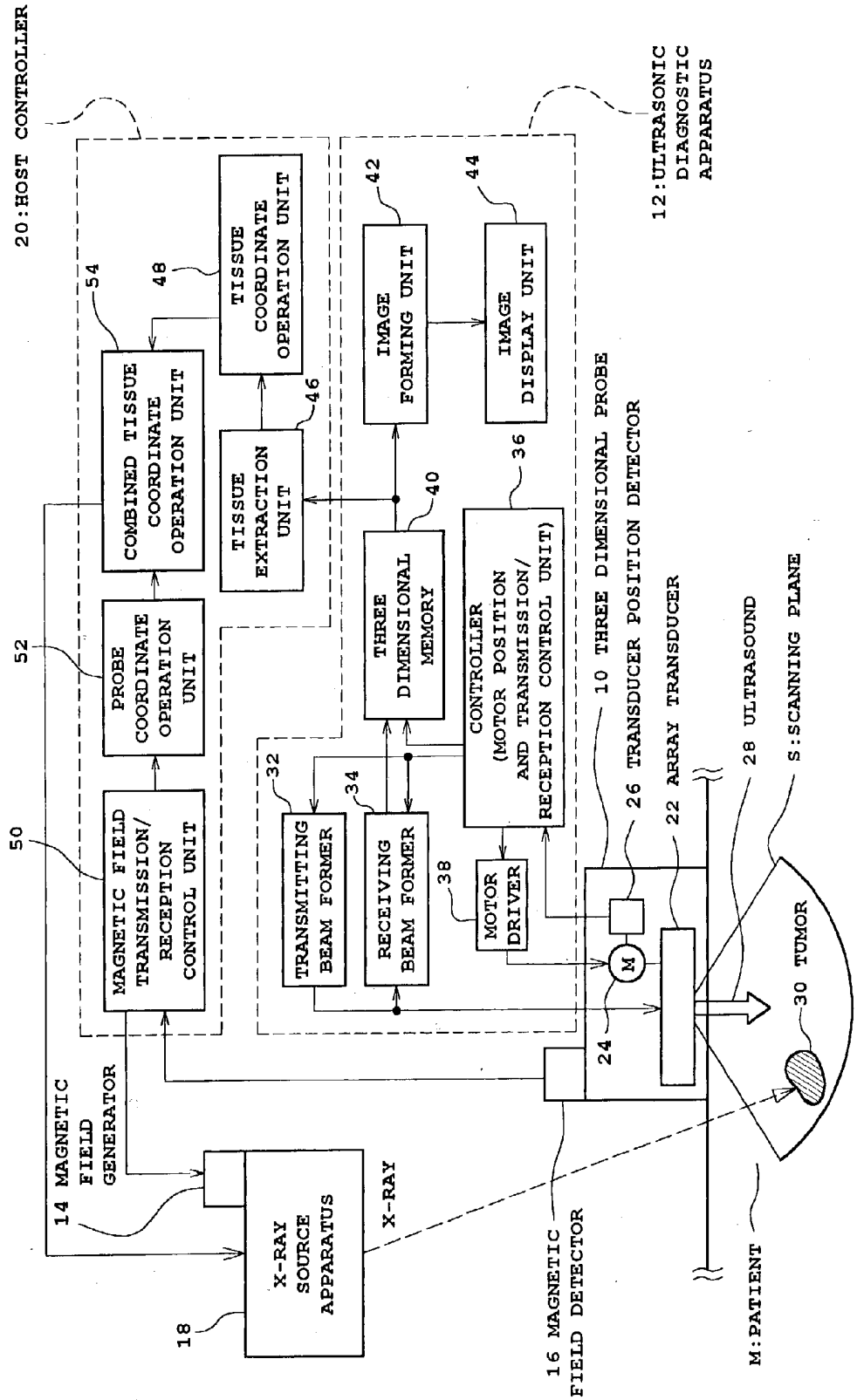

20:HOST CONTROLLER
12:ULTRASONIC DIAGNOSTIC APPARATUS
TISSUE COORDINATE OPERATION UNIT
48
IMAGE FORMING UNIT
42
IMAGE DISPLAY UNIT
44
54
COMBINED TISSUE COORDINATE OPERATION UNIT
46
TISSUE EXTRACTION UNIT
36
40
THREE DIMENSIONAL MEMORY
CONTROLLER (MOTOR POSITION AND TRANSMISSION/ RECEPTION CONTROL UNIT)
52
PROBE COORDINATE OPERATION UNIT
32
34
TRANSMITTING BEAM FORMER
RECEIVING BEAM FORMER
38
MOTOR DRIVER
50
MAGNETIC FIELD TRANSMISSION/ RECEPTION CONTROL UNIT
10 THREE DIMENSIONAL PROBE
26 TRANSDUCER POSITION DETECTOR
22 ARRAY TRANSDUCER
28 ULTRASOUND
S:SCANNING PLANE
30 TUMOR
24
M
14 MAGNETIC FIELD GENERATOR
X-RAY SOURCE APPARATUS
18
X-RAY
16 MAGNETIC FIELD DETECTOR
M:PATIENT

Fig.1

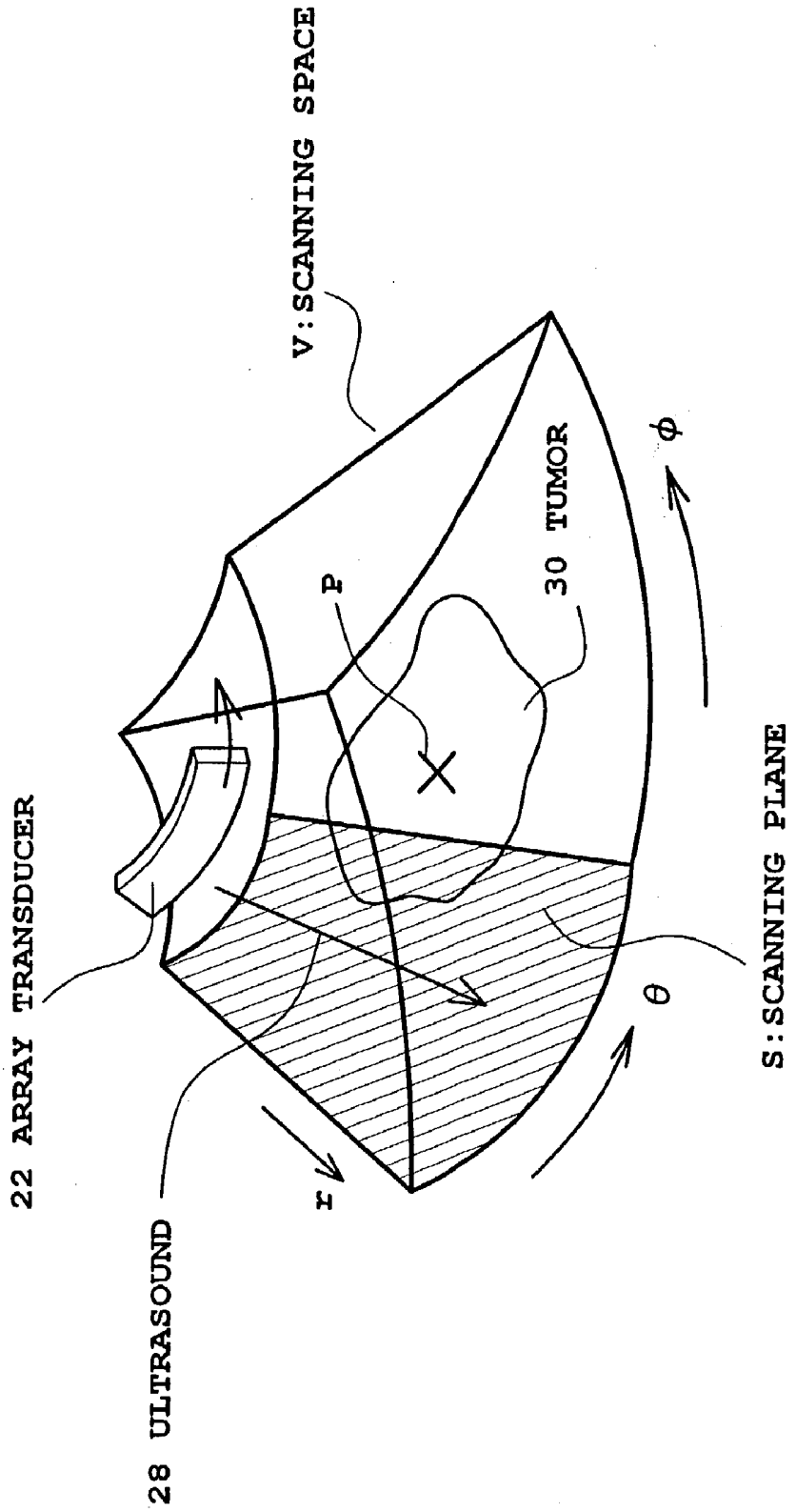

V:SCANNING SPACE
30 TUMOR
P
22 ARRAY TRANSDUCER
28 ULTRASOUND
S:SCANNING PLANE
r
θ
φ

Fig.2

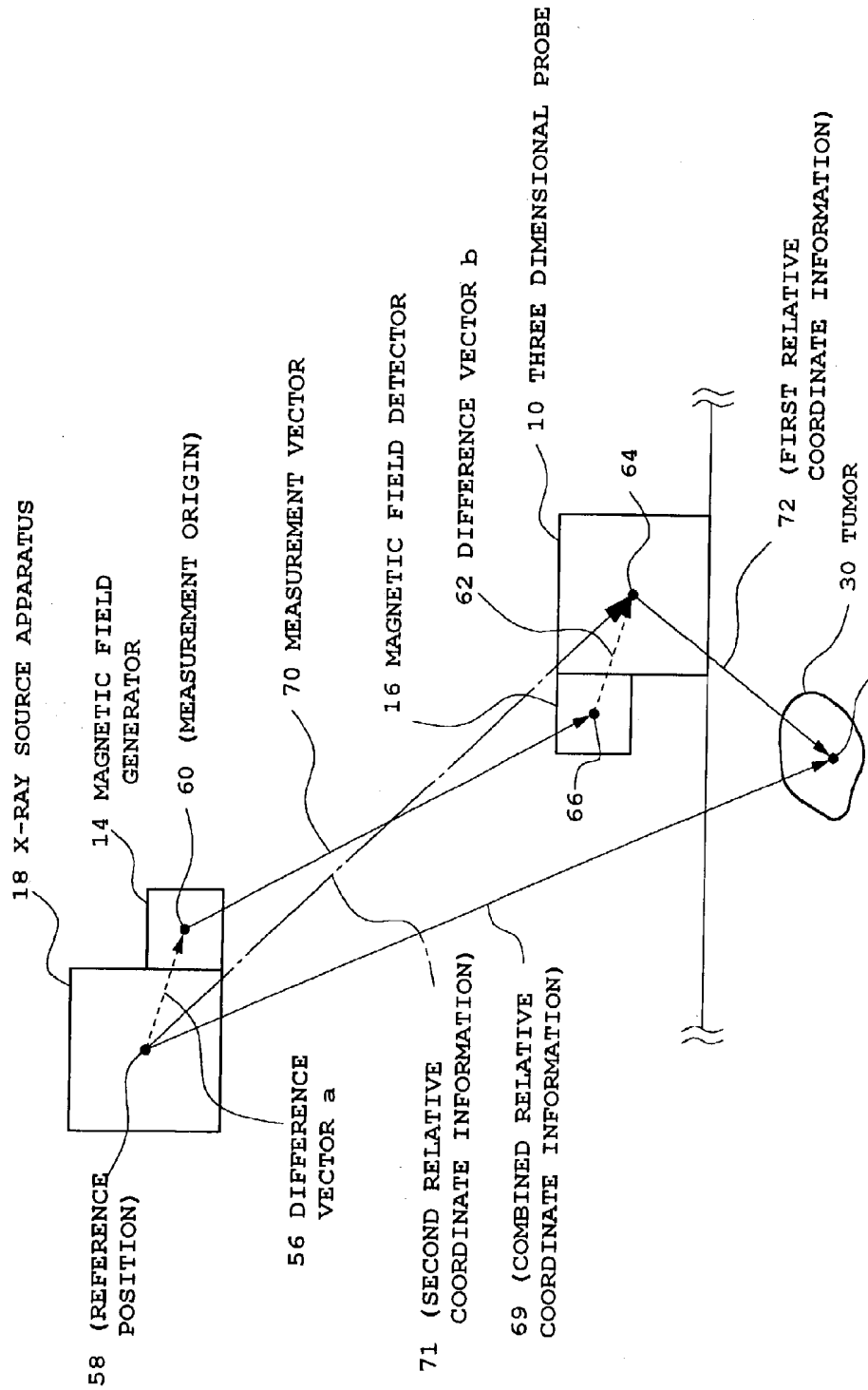

18 X-RAY SOURCE APPARATUS
14 MAGNETIC FIELD GENERATOR
60 (MEASUREMENT ORIGIN)
70 MEASUREMENT VECTOR
16 MAGNETIC FIELD DETECTOR
62 DIFFERENCE VECTOR b
10 THREE DIMENSIONAL PROBE
64
72 (FIRST RELATIVE COORDINATE INFORMATION)
30 TUMOR
68
66
58 (REFERENCE POSITION)
56 DIFFERENCE VECTOR a
71 (SECOND RELATIVE COORDINATE INFORMATION)
69 (COMBINED RELATIVE COORDINATE INFORMATION)

Fig.3

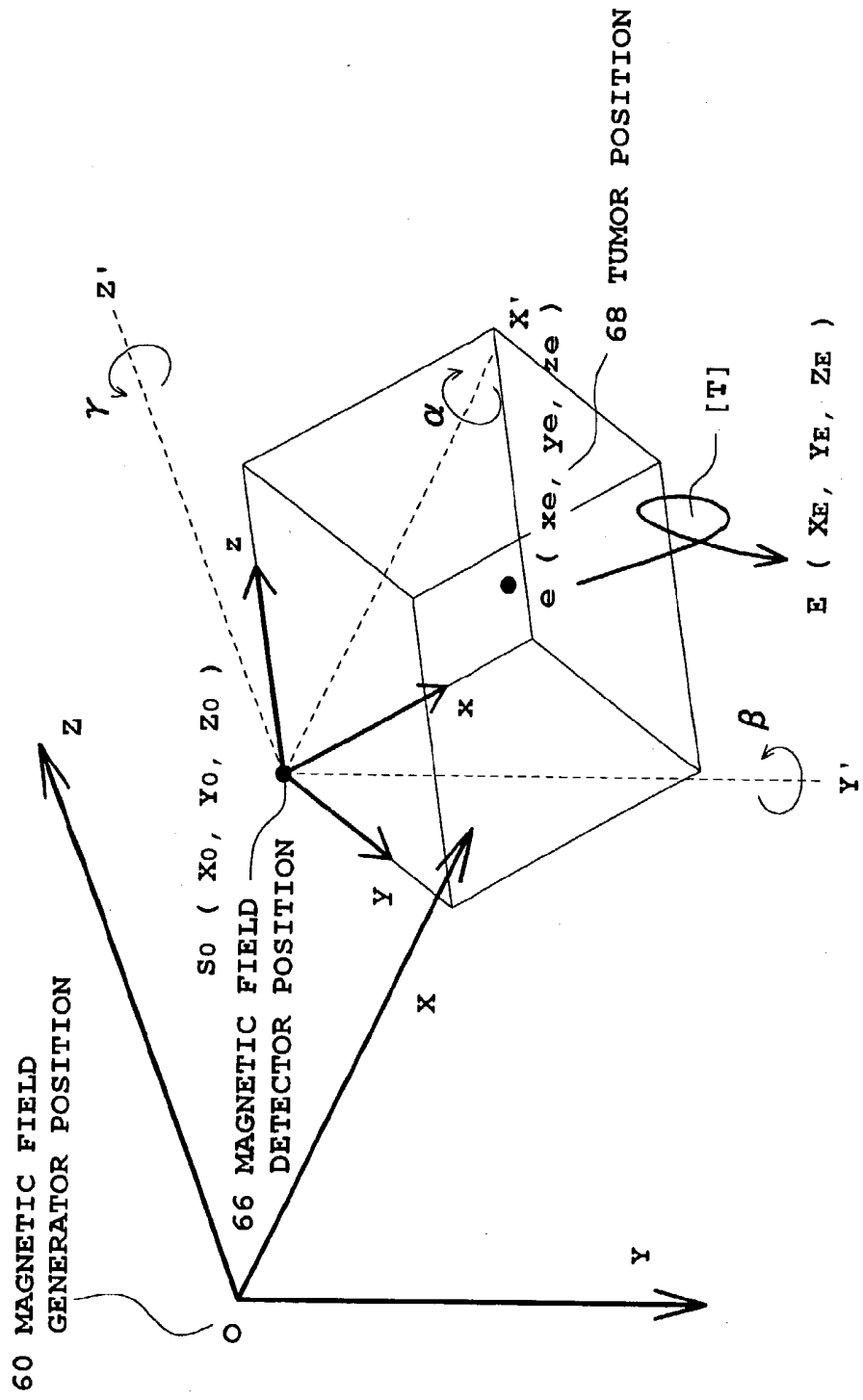

60 MAGNETIC FIELD GENERATOR POSITION
66 MAGNETIC FIELD DETECTOR POSITION
68 TUMOR POSITION
So (Xo, Yo, Zo)
e (xe, ye, ze)
E (XE, YE, ZE)
[T]
O
X
Y
Z
x
y
z
x'
y'
z'
α
β
γ

Fig. 4

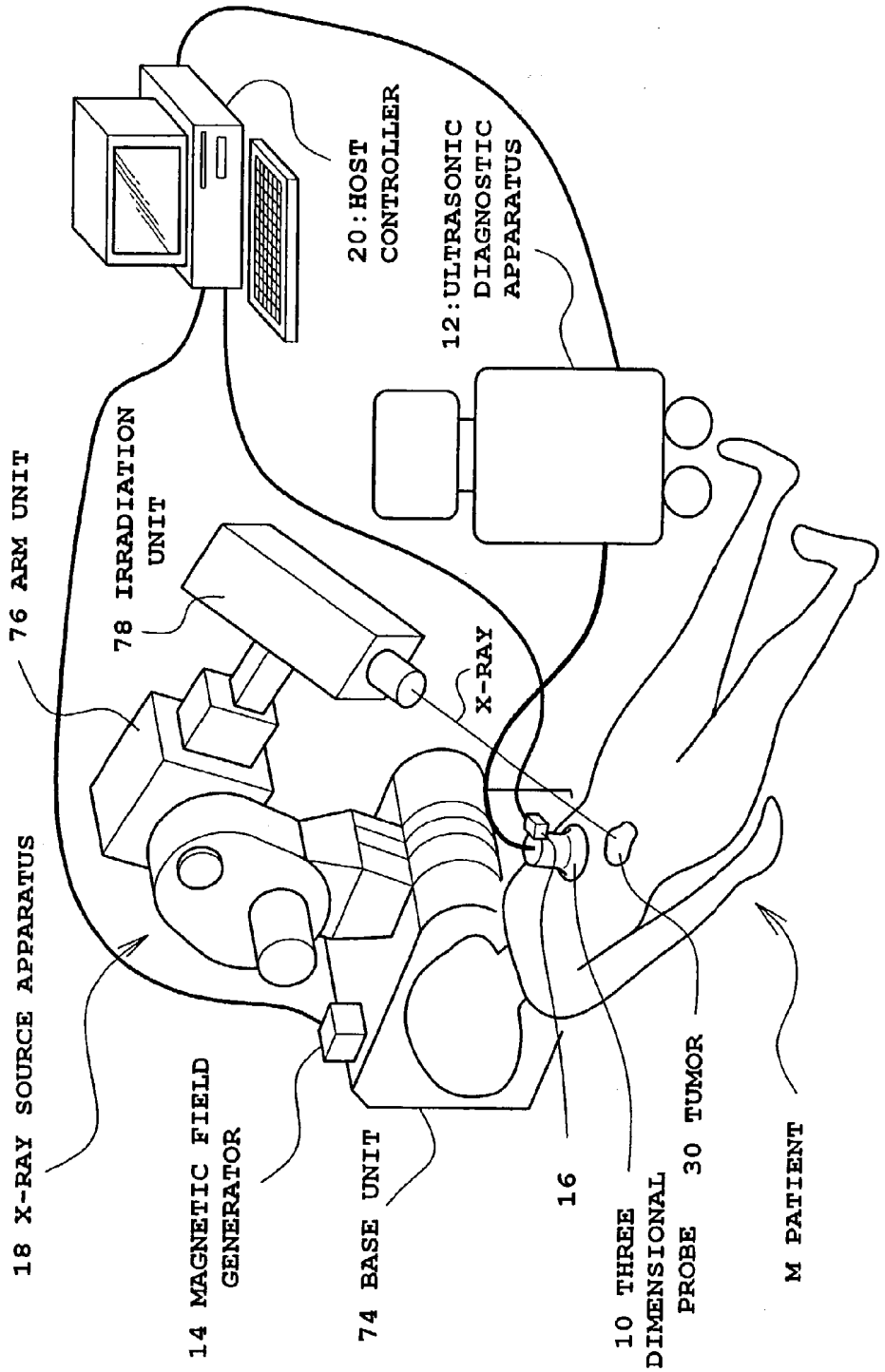

18 X-RAY SOURCE APPARATUS
76 ARM UNIT
78 IRRADIATION UNIT
14 MAGNETIC FIELD GENERATOR
74 BASE UNIT
X-RAY
16
10 THREE DIMENSIONAL PROBE
30 TUMOR
M PATIENT
12:ULTRASONIC DIAGNOSTIC APPARATUS
20:HOST CONTROLLER

Fig.5

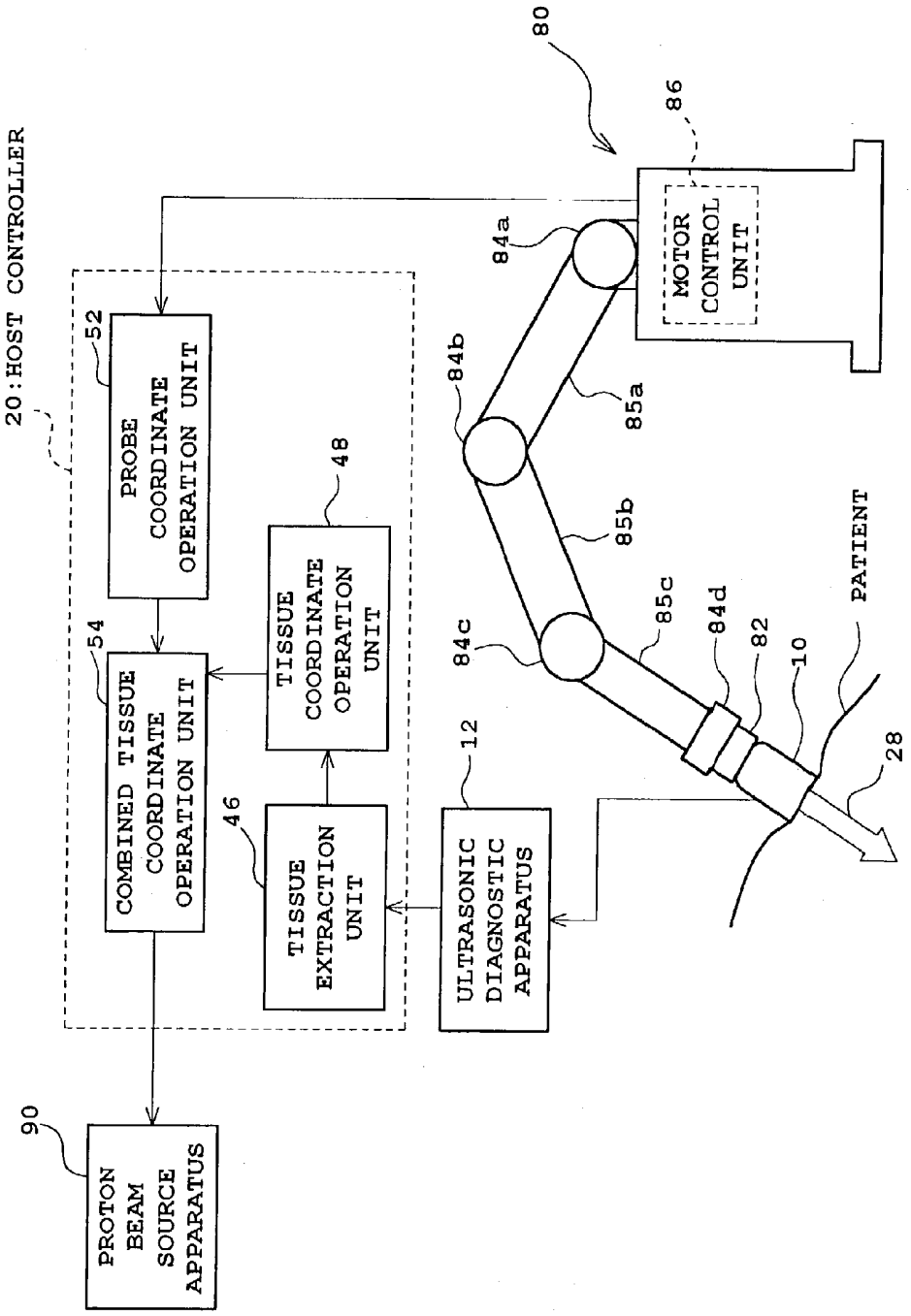

20:HOST CONTROLLER
PROBE COORDINATE OPERATION UNIT
52
COMBINED TISSUE COORDINATE OPERATION UNIT
54
TISSUE COORDINATE OPERATION UNIT
48
TISSUE EXTRACTION UNIT
46
ULTRASONIC DIAGNOSTIC APPARATUS
12
PROTON BEAM SOURCE APPARATUS
90
80
86
MOTOR CONTROL UNIT
84a
84b
85a
85b
85c
84c
84d
82
10
PATIENT
28

Fig. 6

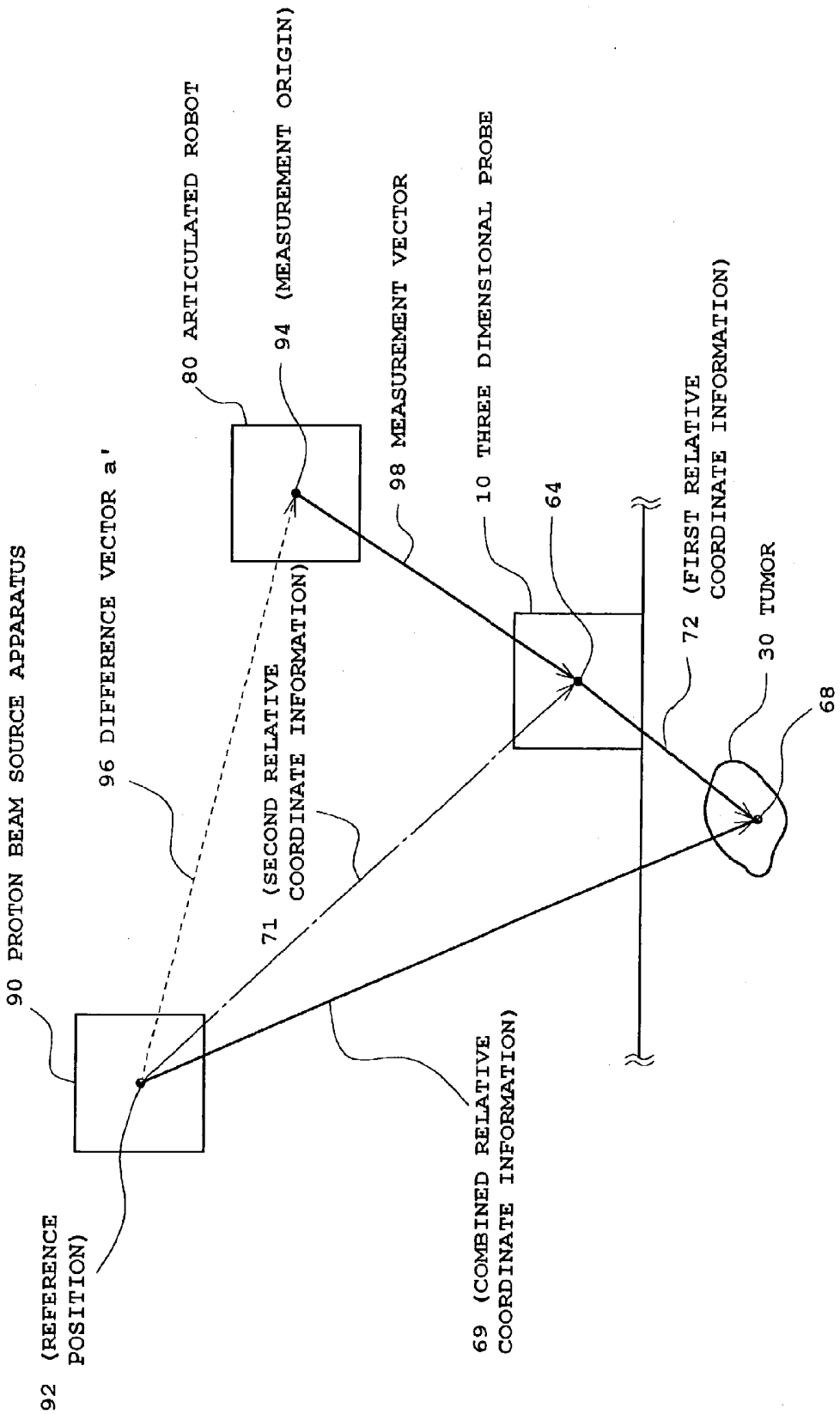

90 PROTON BEAM SOURCE APPARATUS
92 (REFERENCE POSITION)
96 DIFFERENCE VECTOR a'
80 ARTICULATED ROBOT
94 (MEASUREMENT ORIGIN)
71 (SECOND RELATIVE COORDINATE INFORMATION)
98 MEASUREMENT VECTOR
10 THREE DIMENSIONAL PROBE
64
69 (COMBINED RELATIVE COORDINATE INFORMATION)
72 (FIRST RELATIVE COORDINATE INFORMATION)
30 TUMOR
68

Fig. 7

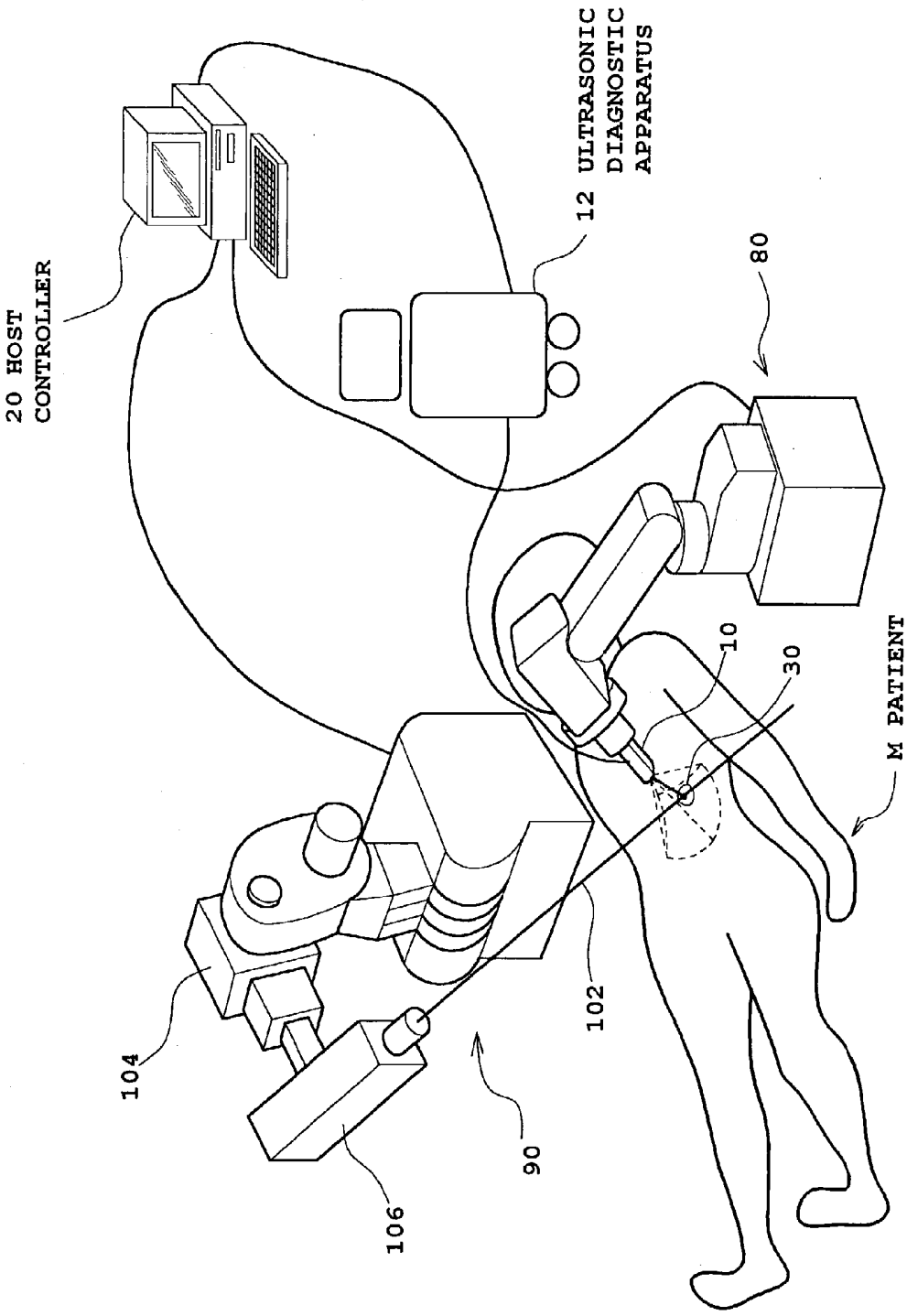

20 HOST CONTROLLER
12 ULTRASONIC DIAGNOSTIC APPARATUS
80
10
30
M PATIENT
102
104
106
90

Fig. 8

ULTRASONIC MEDICAL SYSTEM

BACKGROUND OF THE INVENTION

[0001] 1. Field of the Invention

[0002] The present invention relates to an ultrasonic medical system, and more particularly to an ultrasonic medical system for detecting a target tissue through transmission and reception of ultrasound, and computing information regarding the position of the detected target tissue.

[0003] 2. Description of Related Art

[0004] Ultrasonic diagnostic apparatuses are actively utilized in medical diagnosis and treatment. Medical methods which use an ultrasonic diagnostic apparatus so as to specify the position of a tissue to be treated include, as one example, radiation treatment involving irradiation of cancerous tumors.

[0005] In radiation treatment, intense radiation is applied to cancerous tissue to kill the tissue. Because it is desirable to minimize irradiation of normal tissue when performing such a radiation treatment, it is important that the position of a tumor tissue be precisely ascertained so as to focus the radiation accurately to the tumor tissue. In order to ascertain the tumor position, image diagnosis by means of radiography, CT (Computed Tomography), or MRI (Magnetic Resonance Imaging) is performed prior to the radiation treatment, so that the position of a tumor tissue is ascertained in advance for determining the position or range for irradiation. With such a method, however, accurate irradiation of a tumor tissue cannot be performed if the position of tumor tissue is moved due to, for example, shifting of the patient's position or the influence of breathing.

[0006] In order to overcome the above disadvantage, a radiation treatment in which the position of a tissue is ascertained using an ultrasonic diagnostic apparatus is also proposed. More specifically, in this method, radiation is directed toward a tumor tissue as the position of the tissue is being detected by an ultrasonic diagnostic apparatus. For example, Japanese Patent Laid-Open Publication No. Hei 8-24263 discloses an apparatus which uses an ultrasonic image for shock wave irradiation.

[0007] However, the above method also suffers from a problem. Specifically, since conventional ultrasonic diagnostic apparatuses obtain information regarding a tissue position using an ultrasonic probe as a reference, it may be difficult to obtain appropriate information regarding the position of the tissue, depending on the conditions in which the ultrasonic probe is used. For example, in a case wherein a doctor or other health professional holds an ultrasonic probe in their hand so as to detect a movement of a tumor tissue on a display screen of the ultrasonic diagnostic apparatus, it is not possible to determine whether detected movement is caused by a shift of the tumor tissue itself, or by a shift of the ultrasonic probe while the tumor remains still, or by combination of such movement.

[0008] Because information regarding the tissue position obtained by conventional ultrasonic diagnostic apparatuses is based on the ultrasonic probe which functions as a reference as described above, information regarding the position of a target tissue depends on the position of the ultrasonic probe.

[0009] It is therefore an advantage of the present invention to provide an ultrasonic medical system capable of outputting appropriate information regarding the tissue position.

SUMMARY OF THE INVENTION

[0010] The present invention was conceived in view of the aforementioned problems of the related art and provides an ultrasonic medical system comprising a wave transceiver for transmitting and receiving ultrasound with regard to a space including a target tissue and outputting a reception wave signal; first relative coordinate operation means for computing first relative coordinate information of the target tissue using the wave transceiver as an origin, based on the reception wave signal; second relative coordinate operation means for computing second relative coordinate information of the wave transceiver using a reference position as an origin; and combined relative coordinate operation means for computing combined relative coordinate information of the target tissue using the reference position as an origin, based on the first relative coordinate information and the second relative coordinate information, and outputting the combined relative coordinate information.

[0011] With the above configuration, because the coordinate information of the target tissue can be obtained using a desired reference position as an origin, the coordinates of the target tissue can be specified independently of the coordinates of the wave transmitter/receiver. For example, even when the wave transceiver moves or when the coordinates of the wave transceiver is not specified, the coordinates of the target tissue can be ascertained as relative coordinates with regard to the known reference position. In the above configuration, each of the first relative coordinate information and the second relative coordinate information may be synthesized information regarding a plurality of coordinate systems. For example, the second relative coordinate information may be coordinate information obtained by synthesis of the second (first) relative coordinate information and the second (second) relative coordinate information. Thus, it is possible to compute the combined relative coordinate information from three or more items of coordinate information including the third relative coordinate information, the fourth relative coordinate information, and the like, based on the same principle as used for computing the combined relative coordinate information from the first and second relative coordinate information.

[0012] Preferably, the wave transceiver transmits and receives ultrasound with regard to a three dimensional space including the target tissue, and each of the first relative coordinate information, the second relative coordinate information, and the combined relative coordinate information is three dimensional relative coordinate information. More preferably, the second relative coordinate information includes position information and direction information of the wave transceiver using the reference position as an origin.

[0013] Preferably, the above ultrasonic medical system further includes a generator which is provided at either one of a measurement origin whose positional relationship with the reference position is known and the wave transceiver, for generating a measurement signal, and a detector which is provided at the other of the measurement origin and the wave transceiver, for detecting the measurement signal, and

the second relative coordinate operation means computes the second relative coordinate information of the wave transceiver using the reference position as an origin, based on the detection result by the detector. With such a configuration in which a non-contact coordinate detection configuration is achieved by the generator and the detector, the movement of the wave transceiver is not limited during coordinate detection. It should be noted that the measurement signal is a signal used for measuring the coordinates of, for example, the position of the wave transceiver. Preferably, the generator is a magnetic field generator for generating a magnetic field, and the detector is a magnetic field detector for detecting the magnetic field. With this configuration, because the magnetic field can be detected by the magnetic field detector without being blocked by a human body, it is possible to maintain the accuracy in computing the coordinates of the wave transceiver irrespective of the body position of a doctor or an examiner. Further, because magnetic fields and ultrasound do not interact with each other, influence of the magnetic field generated by the magnetic field generator on the ultrasound by the wave transceiver, or influence of the ultrasound on the magnetic fields can be disregarded.

[0014] Preferably, the first relative coordinate operation means computes the first coordinate information of the target tissue using the wave transceiver as an origin, based on coordinate information specified by an examiner by using an ultrasonic image formed based on the reception wave signal.

[0015] Preferably, the above ultrasonic medical system further comprises a holder mechanism for holding the wave transceiver and a measurement information operation unit for outputting measurement information regarding the wave transceiver which is held by the holder mechanism, and the second relative coordinate operation means computes the second relative coordinate information of the wave transceiver using the reference position as an origin, based on the measurement information. More preferably, the measurement information is coordinate information of the wave transceiver relative to a measurement origin whose positional relationship with the reference position is known. Still more preferably, the holder mechanism is an articulated robot, and the measurement information is information based on length data and angle data regarding each movable section of the articulated robot. Further preferably, the wave transceiver is brought into contact with a body surface of a patient, and the holder mechanism includes a pressure sensor for measuring a contact pressure exerted to the patient by the wave transceiver, for controlling the contact pressure to a predetermined value based on the output from the pressure sensor.

[0016] Preferably, the above ultrasonic medical system comprises a radiation source apparatus for performing irradiation with radiation while controlling an aim based on the combined relative coordinate information. With this configuration, it is possible to apply radiation intensely to the target tissue, while minimizing irradiation of tissues other than the target tissue by controlling an aim such that radiation is accurately applied to the target tissue. Therefore, the tumor can be killed while irradiation of normal tissues is reduced. As radiation, electromagnetic radiation such as X-rays and gamma-rays, and particle beams such as proton beams and deuteron beams may be used.

[0017] Preferably, the radiation source apparatus controls the aim in accordance with a movement of the target tissue based on the combined relative coordinate information. With this configuration, even when, or even as, the target tissue moves, it is possible to apply radiation intensively to the target tissue while minimizing irradiation of tissues other than the target tissue, by controlling the aim such that radiation is accurately applied to the target tissue. Therefore, the tumor can be killed while irradiation of normal tissues is reduced.

[0018] The above ultrasonic medical system may further comprise a puncture apparatus for controlling a puncture position based on the combined relative coordinate information. With such a configuration, it is possible to cause a puncture needle to reach the target tissue accurately, by introducing the puncture needle while controlling an aim such that the puncture is focused on the target tissue.

[0019] Further, in accordance with another aspect of the present invention, there is provided an ultrasonic medical system comprising an ultrasonic probe which is held by a probe holder mechanism for outputting position and direction information and is brought into contact with a body surface of a patient, the ultrasonic probe transmitting/receiving ultrasound with regard to a three dimensional space including a target tissue; an ultrasonic diagnostic apparatus for obtaining, via the ultrasonic probe, echo data for each of voxels forming the three dimensional space; and a host controller which extracts a voxel corresponding to the target tissue based on an echo level of the echo data, computes first relative coordinate information of the target tissue using the ultrasonic probe as an origin, computes second relative coordinate information of the ultrasonic probe using a reference position as an origin based on the position and direction information, and computes combined relative coordinate information of the target tissue using the reference position as an origin based on the first relative coordinate information and the second relative coordinate information and outputs the combined relative coordinate information.

[0020] Preferably, the above ultrasonic medical system further comprises a remedial beam source apparatus for performing irradiation with a remedial beam while controlling an aim in accordance with a movement of the target tissue based on the combined relative coordinate information.

BRIEF DESCRIPTION OF THE DRAWINGS

[0021] These and other advantages of the invention will be explained in the description below, in connection with the accompanying drawings, in which:

[0022] **FIG. 1** is a diagram showing a configuration of an ultrasonic medical system according to the present invention;

[0023] **FIG. 2** is a diagram showing transmission and reception of ultrasound with regard to a three dimensional space;

[0024] **FIG. 3** is a diagram showing a relationship between position vectors in the present invention;

[0025] **FIG. 4** is a diagram showing a relationship between coordinate systems in the present invention;

[0026] **FIG. 5** is a diagram showing a remedial method utilizing an ultrasonic medical system according to the present invention;

[0027] **FIG. 6** is a diagram showing a configuration of an ultrasonic medical system according to another embodiment of the present invention;

[0028] **FIG. 7** is a diagram showing a relationship between positional vectors in the present invention; and

[0029] **FIG. 8** is a diagram showing a remedial method utilizing an ultrasonic medical system according to the present invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0030] Preferred embodiments of the present invention will be described with reference to the drawings.

[0031] [Embodiment 1]

[0032] **FIG. 1** shows the overall configuration of an ultrasonic medical system according to a first embodiment of the present invention. The ultrasonic medical system shown in **FIG. 1** is basically composed of a three dimensional probe (three dimensional echo data capturing probe) **10** which is a wave transceiver, an ultrasonic diagnostic apparatus **12**, a magnetic field generator **14**, a magnetic field detector **16**, an X-ray source apparatus **18** which is a radiation source apparatus, and a host controller **20** including a first relative coordinate operator, a second relative coordinate operator, and a combined relative coordinate operator.

[0033] The three dimensional probe **10** includes an array transducer **22**, a drive motor **24** for driving the array transducer **22**, and a transducer position detector **26** for detecting the position of the array transducer **22**. The three dimensional probe **10** is capable of transmitting and receiving ultrasound **28** with regard to a three dimensional space by causing the array transducer **22**, which transmits and receives ultrasound **28**, to be oscillated by the driver motor **24**. The array transducer **22**, which is moved to a predetermined position by the drive motor **24**, effects electronic scanning to form a scanning plane S and obtains reception wave data within the scanning plane. The reception wave data thus obtained by the array transducer **22** and transducer position data detected by the transducer position detector **26** are output to the ultrasonic diagnostic apparatus **12**. The array transducer **22** performs electronic scanning for transmitting and receiving ultrasound, with the scanning plane S being moved by oscillating the array transducer **22** by the drive motor **24**, so that transmission/reception of ultrasound **28** is performed over the range of a scanning space.

[0034] **FIG. 2** shows transmission/reception of the ultrasound **28** with regard to the three dimensional space. Referring to **FIG. 2**, the array transducer **22** transmits and receives the ultrasound **28** in the depth direction r and in the electronic scanning direction θ to form the scanning plane S. The array transducer **22** is then oscillated in the oscillation direction Φ to form a scanning space V including a tumor **30** which is a target tissue and a central point P of the tumor. It should be noted that the three dimensional echo data obtaining probe according to the present embodiment may include a two dimensional array transducer, namely a transducer which performs electronic scanning over the range of the scanning space V. Further, a probe is not limited to the three dimensional echo data obtaining probe and may also be a two dimensional echo data obtaining probe, namely a probe which transmits the ultrasound **28** only to the scanning plane S in **FIG. 2**.

[0035] Referring again to **FIG. 1, a** transmitting beam former **32** in the ultrasonic diagnostic apparatus **12** controls a transmission drive signal to be supplied to the array transducer **22** for forming the ultrasound **28** via the three dimensional probe **10**. A receiving beam former **34** collects reception wave data supplied from the array transducer **22** for forming echo data. A controller (motor position and transmission/reception control unit) **36** drives the drive motor **24** for the array transducer **22** and also obtains oscillation position data of the array transducer **22** from the transducer position detector **26**, thereby controlling the oscillation position of the array transducer **22**. The controller **36** further controls the transmitting beam former **32** and the receiving beam former **34** to form the ultrasound **28** and collect the reception wave data of the array transducer **22** at each oscillation position. More specifically, the controller **36**, by controlling the transmitting beam former **32**, the receiving beam former **34**, and the array transducer drive motor **24**, transmits the ultrasound **28** to a desired three dimensional space and obtains echo data for each of voxels forming the three dimensional space. The echo data for each voxel is designated with an address corresponding to relative coordinates using the three dimensional probe **10** as a reference. The echo data is then written into a three dimensional memory **40** and is also output to the host controller **20**. The echo data is simultaneously output to an image forming unit **42** within the ultrasonic diagnostic apparatus **12** for forming an ultrasonic image, which is then displayed in an image display unit **44** in the form of a three dimensional ultrasonic image or the like.

[0036] The host controller **20** includes a tissue extraction unit **46** and a tissue coordinate operation unit **48** which constitute the first relative coordinate operator, a magnetic field transmission/reception control unit **50** and a probe coordinate operation unit **52** which constitute the second relative coordinate operator, and a combined tissue coordinate operation unit **54** which is a combined relative coordinate operator. A part or all of these elements forming the host controller **20** may be incorporated in the ultrasonic diagnostic apparatus **12** or the X-ray source apparatus **18**.

[0037] The tissue extraction unit **46** extracts the tumor **30** which is a target tissue, based on the echo data within the three dimensional space which is written in the three dimensional memory **40**. In one example extraction method, echo levels are previously obtained as echo data, and the echo levels are used to discriminate the tumor **30** from normal tissue. More specifically, the echo level for each echo data written in the three dimensional memory **40** is compared with a predetermined level which corresponds to a border between the echo levels of the tumor **30** and the echo levels of normal tissues to determine echo data portions corresponding to the echo levels of the tumor **30** as the tumor **30**. Because each echo data is designated with an address corresponding to relative coordinates using the three dimensional probe **10** as a reference before the data is written in the three dimensional memory **40** as described above, it is possible to determine the relative coordinates of the echo data which corresponds to the tumor **30**. However, methods

other than the above method may be adopted for discriminating the tumor. For example, image analysis such as a texture analysis may be used.

[0038] The tissue coordinate operation unit **48** computes target tissue coordinates using the three dimensional probe **10** as a reference, based on the relative coordinates of the extracted echo data portion corresponding to the tumor **30** using the three dimensional probe **10** as a reference. The target tissue coordinates may be obtained for just the central point of the tumor **30** by computing the position of a gravity center of the tumor **30** from the outer surface coordinates of the extracted tumor **30** portion. Alternatively, all of the relative coordinates which have been determined as the tumor **30** may be output as the target tissue coordinates. Further, a position on the ultrasonic image of the target tissue displayed on the image display unit **44**, which is designated by the examiner who is observing the ultrasonic image may be determined as the target tissue coordinates. In any case, the coordinates of the extracted target tissue use the three dimensional probe **10** as a reference, because the ultrasound **28** is transmitted and received using the three dimensional probe **10** as a reference. In the following description, a case wherein the coordinates for only the central point of the tumor **30** is output as the target tissue coordinates will be explained.

[0039] The magnetic field transmission/reception control unit **50** controls the magnetic field generator **14** mounted on the X-ray source apparatus **18** to generate magnetic field distribution in a room for measuring information regarding the position of the three dimensional probe **10**. The magnetic field transmission/reception control unit **50** also controls the magnetic field detector **16** mounted on the three dimensional probe **10** to detect the magnetic field distribution generated within the room. More specifically, the magnetic field generator **14** has three magnetic field generating coils whose axial directions correspond respectively to three directions which are orthogonal to each other, for generating magnetic field distribution. The magnetic field detector **16** also includes three magnetic field detecting coils whose axial directions correspond respectively to three directions which are orthogonal to each other. The magnetic field generator **14** and the magnetic field detector **16** are configured to allow detection of not only information regarding the position of the magnetic field detector **16** relative to the magnetic field generator **14** but also information regarding the direction of the magnetic field detector **16**. The information regarding the position of the three dimensional probe **10** (coordinate information) is thus measured by means of the magnetic field generator **14** and the magnetic field detector **16**. Information regarding the position and the direction can be detected using any appropriate known method.

[0040] The method of detecting the coordinate information of the three dimensional probe **10** is not limited to the detection method using the magnetic field generator **14** and the magnetic field detector **16** as described above, and any other appropriate methods may be used. For example, not just a magnetic field, but light, acoustic waves, or radio waves may be used for detection. When detection by means of light is performed, a light signal generator and a light detector are used in place of the magnetic field generator **14** and the magnetic field detector **16**, respectively. The light signal generator generates light with a distribution such that the intensity of the generated light is different at different positions in the room, which is then detected by the light detector. At this time, the light detector is fixed on the three dimensional probe **10** at three different points, and, by detecting the positions of the three points, it is possible to use triangulation to compute not only position information but also direction information regarding the three dimensional probe **10**. Further, it is obvious that when the generator is mounted on the three dimensional probe **10** and the detector is mounted at a reference position, it is also possible to compute the position information and the direction information of the three dimensional probe **10** with respect to the reference position according to the same principle.

[0041] The probe coordinate operation unit **52** computes the position and direction information of the magnetic field detector **16** using the magnetic field generator **14** as a reference, based on the detection result output from the magnetic field transmission/reception control unit **50**. The detection result output from the magnetic field transmission/reception control unit **50** is based on position information and direction information of the magnetic field detector **16** relative to the magnetic field generator **14**. Therefore, by mounting the magnetic field generator **14** at a desired position, such as at the origin of the X-ray source apparatus **18** for example, and mounting the magnetic field detector **16** at the origin of the three dimensional probe **10**, it is possible to directly detect information regarding the position and direction of the three dimensional probe **10** relative to the origin of the X-ray source apparatus **18**. Due to the design limitation, however, there are cases wherein the magnetic field generator **14** cannot be mounted at the origin position of the X-ray source apparatus **18** or wherein the magnetic field detector **16** cannot be mounted at the origin position of the three dimensional probe **10**. These cases will be described with reference to **FIG. 3**.

[0042] Referring to **FIG. 3, a** difference vector a **56** indicates a deviation between the origin position **58** of the X-ray source apparatus **18** which functions as a reference position for X-ray irradiation and a magnetic field generator position **60** which corresponds to a measurement origin for measuring the position and direction of the three dimensional probe **10**. Further, a difference vector b **62** indicates a deviation between the origin position **64** of the three dimensional probe **10** and a magnetic field detector position **66**. The detection result output from the magnetic field transmission/reception control unit **50** (see **FIG. 1**) is a measurement vector **70** corresponding to a relative position vector of the magnetic field detector position **66** relative to the magnetic field generator position **60**. Further, the coordinate information output from the tissue coordinate operation section **48** (see **FIG. 1**) is an ultrasound detection vector (the first relative coordinate information) **72** corresponding to a relative position vector of the tumor position **68** relative to the origin position **64** of the three dimensional probe **10**.

[0043] Accordingly, in order to obtain a combined vector (combined relative coordinate information) **69** indicating the tumor position **68** using the origin position **58** of the X-ray source apparatus as a reference, it is necessary to compute a probe position vector (the second relative coordinate information) **71** by adding the difference vector a **56** and the difference vector b **62** to the measurement vector **70** and then add the ultrasound detection vector **72** to the computed probe position vector **71**. Because the magnetic field generator **14** and the magnetic field detector **16** are fixed to the

X-ray source apparatus **18** and to the three dimensional probe **10**, respectively, both the difference vector a **56** and the difference vector b **62** are fixed vectors and can therefore be measured prior to the measurement of the position **68** of the tumor which is a target tissue.

[**0044**] When computing the coordinates of the tumor position **68**, by performing coordinate transformation based on these difference vectors a **56** and b **62** which have been measured in advance, it is possible to process the origin position **58** of the X-ray source apparatus **18** and the magnetic field generator position **60** equivalently and also process the origin position **64** of the three dimensional probe **10** and the magnetic field detector position **66** equivalently. In the following description, it is assumed that such coordinate transformation has been performed so that the coordinate system having an origin corresponding to the origin position **58** of the X-ray source apparatus **18** matches the coordinate system having an origin corresponding to the magnetic field generator position **60**, and such that the coordinate system having an origin corresponding to the origin position **64** of the three dimensional probe **10** matches the coordinate system having an origin corresponding to the magnetic field detector position **66**.

[**0045**] Referring back to **FIG. 1**, the combined tissue coordinate operation unit **54** computes coordinates of the target tissue relative to the origin of the X-ray source apparatus **18** based on the coordinate information of the target tissue with the three dimensional probe **10** being used as its origin, which is output from the tissue coordinate operation unit **48** and the position and direction information of the three dimensional probe **10** relative to the origin of the X-ray source apparatus **18** which is output form the probe coordinate operation unit **52**. At this point, it is assumed that coordinate transformation between the magnetic field generator **14** and the X-ray source apparatus **18** and between the magnetic field detector **16** and the three dimensional probe **10** has been performed in the probe coordinate operation unit **52**, as described above. In other words, the coordinates having an origin corresponding to the magnetic field generator position and the coordinates having an origin corresponding to the X-ray source apparatus position coincide with each other, and the coordinates having an origin corresponding to the magnetic field detector position and the coordinates having an origin corresponding to the three dimensional probe position coincide with each other.

[**0046**] A computation method in the combined tissue coordinate operation unit **54** will be described with reference to **FIG. 4**. Referring to **FIG. 4, a** coordinate system (X, Y, Z) is a coordinate system which is fixed to the magnetic field generator **14** having an origin at the magnetic field generator position **60**, and corresponds to the coordinate system using the X-ray source apparatus **18** as a reference. A coordinate system (x, y, z) is a coordinate system which is fixed to the magnetic field detector **16** having an origin at the magnetic field detector position **66**, and corresponds to the coordinate system using the three dimensional probe **10** as a reference. Here, the origin of the coordinate system (x, y, z) corresponding to the magnetic field detector position **66** when the coordinate system (X, Y, Z) is used as a reference, is represented by So(Xo, Yo, Zo). A point e indicates the position of a tumor which is a target tissue and is represented by e(xe, ye, ze) relative to the coordinate system (x, y, z) which is a reference. Further, axes X', Y', and Z' which are parallel to the X axis, the Y axis and the Z axis respectively, are provided, for which a coordinate system having the point So as its origin is represented by coordinate system (X', Y', Z').

[**0047**] The positional relationship between the coordinate system (x, y, z) and the coordinate system (X', Y', Z') is such that when the coordinate system (X', Y', Z') is rotated in the order of X' axis, Y' axis, and then Z' axis by α degree, β degree, and γ degree, respectively, the X' axis coincides with the x axis, the Y' axis coincides with the y axis, and the Z' axis coincides with the z axis. As described above, the information regarding the position and direction of the magnetic field detector using the magnetic field generator as a reference has been computed in the probe coordinate operation unit **52**. More specifically, the origin position information (Xo, Yo, Zo) of the coordinate system (x, y, z) relative to the coordinate system (X, Y, Z) and the six dimensional information of the direction information (α, β, γ) have been computed in the probe coordinate operation unit **52**. The coordinate transformation from the coordinate system (x, y, z) to the coordinate system (X', Y', Z') can then be expressed by the following expression.

[**0048**] [Expression 1]

$$[X'Y'Z'1] = [x\,y\,z\,1]\begin{bmatrix}1 & 0 & 0 & 0\\ 0 & \cos\alpha & \sin\alpha & 0\\ 0 & -\sin\alpha & \cos\alpha & 0\\ 0 & 0 & 0 & 1\end{bmatrix}\begin{bmatrix}\cos\beta & 0 & -\sin\beta & 0\\ 0 & 1 & 0 & 0\\ \sin\beta & 0 & \cos\beta & 0\\ 0 & 0 & 0 & 1\end{bmatrix}$$

$$\begin{bmatrix}\cos\gamma & \sin\gamma & 0 & 0\\ -\sin\gamma & \cos\gamma & 0 & 0\\ 0 & 0 & 1 & 0\\ 0 & 0 & 0 & 1\end{bmatrix}$$

[**0049**] Further, coordinate transformation from the coordinate system (X', Y', Z') to the coordinate system (X, Y, Z) can be expressed as follows:

[**0050**] [Expression 2]

$$[XYZ1] = [X'Y'Z'1]\begin{bmatrix}1 & 0 & 0 & 0\\ 0 & 1 & 0 & 0\\ 0 & 0 & 1 & 0\\ X_0 & Y_0 & Z_0 & 1\end{bmatrix}$$

[**0051**] According to the above expressions 1 and 2, coordinate transformation from the coordinate system (x, y, z) to the coordinate system (X, Y, Z) can be expressed as follows:

[**0052**] [Expression 3]

$$[X\ Y\ Z\ 1] = [x\,y\,z\,1][T][T] = \begin{bmatrix}1 & 0 & 0 & 0\\ 0 & \cos\alpha & \sin\alpha & 0\\ 0 & -\sin\alpha & \cos\alpha & 0\\ 0 & 0 & 0 & 1\end{bmatrix}\begin{bmatrix}\cos\beta & 0 & -\sin\beta & 0\\ 0 & 1 & 0 & 0\\ \sin\beta & 0 & \cos\beta & 0\\ 0 & 0 & 0 & 1\end{bmatrix}$$

-continued

$$\begin{bmatrix} \cos\gamma & \sin\gamma & 0 & 0 \\ -\sin\gamma & \cos\gamma & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ X_0 & Y_0 & Z_0 & 1 \end{bmatrix}$$

[0053] Accordingly, using the above coordinate transformation matrix [T], the coordinate transformation can be performed from the coordinate system (x, y, z) to the coordinate system (X, Y, Z), in other words from the coordinate system using the magnetic field detector as a reference to the coordinate system using the magnetic field generator as a reference.

[0054] Referring again to **FIG. 1**, the combined tissue coordinate operation unit **54** sets up the transformation matrix [T] based on the information regarding the position and direction of the magnetic field detector **16** (three dimensional probe **10**) using the magnetic field generator **14** (X-ray source apparatus **18**) as a reference, which is output from the probe coordinate operation unit **52**. Then, the transformation matrix is used to transform the coordinate information output from the tissue coordinate operation unit **48** regarding the position **68** of the tumor which is a target tissue with the magnetic field detector **16** (three dimensional probe **10**) being used as its origin into the coordinate information in the coordinate system using the magnetic field generator **14**, namely the X-ray source apparatus **18**, as a reference. The position information for the target tissue using the X-ray source apparatus as a reference **18** which has been thus computed is output from the host controller **20** to the X-ray source apparatus **18**.

[0055] **FIG. 5** shows a remedial method using the ultrasonic medical system shown in **FIG. 1**. The ultrasonic diagnostic apparatus **12**, the three dimensional probe **10**, the magnetic field generator **14**, the magnetic field detector **16**, and the host controller **20** operate as described above, so that the information regarding the position of the tumor **30** with the X-ray source apparatus **18** being used as a reference is output from the host controller **20** to the X-ray source apparatus **18**. The X-ray source apparatus **18** controls an arm unit **76** and an irradiation unit **78** based on the position information of the tumor **30** such that X-ray is intensively applied onto the tumor **30** located within the body of a patient M. Further, by controlling the aim in accordance with the movement of the tumor **30**, it is possible to apply intense X-ray radiation to just the tumor, while minimizing irradiation of normal tissues, even as the position of tumor moves. When the aim is controlled in accordance with the movement of the tumor **30**, it is desirable to continuously detect the tumor **30** by the three dimensional probe **10** during the X-ray irradiation. In this case, the three dimensional probe **10** may be held by a doctor or other person, or may be fixed to a fixing apparatus which is separately provided for the three dimensional probe **10**. When a doctor or other user holds the three dimensional probe **10** for performing X-ray irradiation, certain measures must be taken, such as that the examiner puts on an X-ray protector, for example. Further, although the magnetic field generator **14** is mounted on a base unit **74** of the X-ray source apparatus in **FIG. 5**, the location where the magnetic field generator **14** is provided may be appropriately selected according to the usage situation, and the magnetic field generator **14** may be fixed at another position in the room.

[0056] [Embodiment 2]

[0057] **FIG. 6** shows the overall configuration of an ultrasonic medical system according to a second embodiment of the present invention. In rough terms, the ultrasonic medical system shown in **FIG. 6** includes a three dimensional probe (three dimensional echo data capturing probe) **10** which is a wave transceiver, an articulated robot **80**, an ultrasonic diagnostic apparatus **12**, a proton beam source apparatus **90**, and a host controller **20** having a first relative coordinate operator, a second relative coordinate operator, and a combined relative coordinate operator.

[0058] The three dimensional probe **10** and the ultrasonic diagnostic apparatus **12** are the same as those shown in **FIG. 1** regarding the first embodiment. More specifically, the ultrasonic diagnostic apparatus **12** transmits ultrasound **28** into a three dimensional space within a patient's body via the three dimensional probe **10**, collects reception wave data for obtaining echo data, and displays a three dimensional ultrasonic image formed based on the obtained echo data on the image display. The obtained echo data is also output to the host controller **20**.

[0059] The articulated robot **80** holding the three dimensional probe **10** moves to a diagnostic position on a surface of the patient's body, and also changes the direction of the three dimensional probe **10**. The three dimensional probe **10** is attached to a probe attachment **82** and changes its position and direction when drive units **84***a* to **84***d* are driven. A drive motor (not shown) is provided in each of the drive units **84***a* to **84***d* for driving arms **85***a* to **85***c*. The operation of each drive motor is controlled by a motor control unit **86**. The three dimensional probe **10** held by the articulated robot **80** transmits and receives ultrasound **28** with regard to the three dimensional space within the patient's body containing the tumor.

[0060] The motor control unit **86** controls each drive motor within each of the drive units **84***a* to **84***d* based on a user operation. The motor control unit **86** may control each drive motor such that the arms automatically follow the movement of the tumor. Further, a pressure sensor (not shown) is provided in the probe attachment **82** for detecting the pressure exerted on the surface of the patient's body when the three dimensional probe **10** is brought into contact with the body surface and outputting the detected pressure to the motor control unit **86**. Then, the motor control unit **86** controls each drive motor so as to maintain the pressure exerted onto the surface of the patient's body to a fixed value, for example, thereby preventing an excessive pressure applied to the patient. The articulated robot **80** outputs the motor driving information indicating the drive states of the drive units **84***a* to **84***d* to the host controller **20**.

[0061] The motor driving information output from the articulated robot **80** will be described. Assuming that the disposition location of the articulated robot **80** (the central point on the bottom portion of the articulated robot **80**, for example) is a measurement origin, the drive unit **84***a* is located at a fixed position relative to the measurement origin. The drive unit **84***a* is connected to one end of the arm **85***a* for turning or moving upward and downward the arm

85*a* to thereby set an angle of the arm **85***a*. The other end of the arm **85***a* is connected to the drive unit **84***b*. Therefore, the position of the drive unit **84***b* relative to the measurement origin is determined by the length and angle of the arm **85***a*. Accordingly, based on the motor driving information (the angle data of the arm **85***a*) corresponding to the drive unit **84***a*, the articulated robot **80** outputs a transformation matrix Ta for deriving the position coordinates (Xb, Yb, Zb) of the drive unit **84***b* relative to the measurement origin from the measurement origin coordinates (Xr, Yr, Zr).

[**0062**] The drive unit **84***b* is connected to one end of the arm **85***b* for moving the arm **85***b* upward and downward. The other end of the arm **85***b* is connected to the drive unit **84***c*. Therefore, the position of the drive unit **84***c* relative to the drive unit **84***b* is determined by the length and angle of the arm **85***b*. Accordingly, based on the motor driving information (the angle data of the arm **85***b*) corresponding to the drive unit **84***b*, the articulated robot **80** outputs a transformation matrix Tb for deriving the position coordinates (Xc, Yc, Zc) of the drive unit **84***c* relative to the measurement origin from the position coordinates (Xb, Yb, Zb) of the drive unit **84***b*.

[**0063**] The position of the drive unit **84***d* relative to the drive unit **84***c* is determined by the length and angle of the arm **85***c*. Accordingly, based on the motor driving information (the angle data of the arm **85***c*) corresponding to the drive unit **84***c*, the articulated robot **80** outputs a transformation matrix Tc for deriving the position coordinates (Xd, Yd, Zd) of the drive unit **84***d* relative to the measurement origin from the position coordinates (Xc, Yc, Zc) of the drive unit **84***c*. Further, because the three dimensional probe **10** turns in accordance with the turning of the drive unit **84***d*, the articulated robot **80** outputs, based on the motor driving information corresponding to the drive unit **84***d*, a transformation matrix Td for deriving the coordinates of the origin position (Xs, Ys, Zs) of the three dimensional probe **10** relative to the measurement origin from the position coordinates (Xd, Yd, Zd) of the drive unit **84***d*. Thus, the transformation matrices Ta, Tb, Tc, and Td representing the holding state of the three dimensional probe **10** is output to the probe coordinate operation unit **52** of the host controller **20**.

[**0064**] The probe coordinate operation unit **52** then computes the position and direction of the three dimensional probe **10** relative to the measurement origin (the disposition location of the articulated robot **80**), based on the motor driving information output from the articulated robot **80**. The position coordinates (Xs, Ys, Zs) of the three dimensional probe **10** relative to the measurement origin is computed by the following expression.

$$[Xs, Ys, Zs, 1]=[Xr, Yr, Zr, 1][Ta][Tb][Tc][Td] \quad \text{[Expression 4]}$$

[**0065**] wherein Ta, Tb, Tc, and Td are transformation matrices based on the motor driving information output from the articulated robot **80**, and (Xr, Yr, Zr) indicates coordinates of the measurement origin.

[**0066**] Here, the direction of the three dimensional probe **10** can be computed from the position coordinates (Xd, Yd, Zd) of the drive unit **84***d* and the position coordinates (Xs, Ys, Zs) of the three dimensional probe **10**. More specifically, it is possible to obtain the line connecting these coordinates (Xs, Ys, Zs) and (Xd, Yd, Zd) and obtain the direction of the three dimensional probe **10** along that line. In this manner, the probe coordinate operation unit **52** computes the position and direction of the three dimensional probe **10** relative to the measurement origin.

[**0067**] The tissue extraction unit **46** and the tissue coordinate operation unit **48** in the host controller **20** operate similarly to those in the first embodiment (see **FIG. 1**). More specifically, the tissue extraction unit **46** extracts a tumor based on echo data within the three dimensional space which is output from the ultrasonic diagnostic apparatus **12** for determining relative coordinates of echo data corresponding to the tumor. The tissue coordinate operation unit **48** then computes coordinates of the central point of the tumor using the three dimensional probe **10** as a reference.

[**0068**] The combined tissue coordinate operation unit **54** uses the coordinate information of the central point of the tumor having an origin at the three dimensional probe **10**, which is output from the tissue coordinate operation unit **48**, and the information regarding the position and direction of the three dimensional probe **10** relative to the measurement point which is output from the probe coordinate operation unit **52**, to compute the coordinates of the central point of the tumor relative to the origin of the proton beam source apparatus **90**. The computation performed by the combined tissue coordinate operation unit **54** will be described.

[**0069**] **FIG. 7** is a diagram for explaining the computation performed by the combined tissue coordinate operation unit **54**. It is assumed that the reference position for proton beam irradiation is an origin position **92** of the proton beam source apparatus **90** and that the measurement origin for measuring the position and direction of the three dimensional probe is a bottom central point **94** of the articulated robot **80**. Further, a position vector of the bottom central point (measurement origin) **94** relative to the origin position (reference position) **92** is assumed to be a difference vector a'**96**. The coordinate information output from the probe coordinate operation unit **52** (see **FIG. 6**) is a measurement vector **98** which corresponds to a relative position vector of the origin position **64** relative to the bottom central point **94**, and the coordinate information output from the tissue coordinate operation unit **48** is an ultrasound detection vector (the first relative coordinate information) **72** which corresponds to a relative position vector of the tumor position **68** relative to the origin position **64** of the three dimensional probe **10**.

[**0070**] Accordingly, in order to compute a combined vector (combined relative coordinate information) indicating the coordinates of the tumor position **68** using the origin position **92** of the proton beam source apparatus **90** as a reference, it is necessary to first compute a probe position vector (second relative coordinate information) **71** by adding the measurement vector **98** and the difference vector a'**96**, and to then add the computed probe position vector **71** with the ultrasound detection vector **72**. The difference vector a'**96** is a known vector because the state in which the articulated robot **80** and the proton beam source apparatus **90** are arranged is known. It is therefore possible to measure the difference vector a'**96** in advance, prior to the measurement of the position **68** of the tumor which is the target tissue.

[**0071**] Referring back to **FIG. 6**, the information regarding the coordinates of the tumor relative to the reference position, such as the coordinates of the central point of the

tumor, which is computed by the combined tissue coordinate operation unit **54** is output to the proton beam source apparatus **90**, which then directs proton beams toward the position corresponding to the coordinates of the central point of the tumor.

[**0072**] **FIG. 8** shows a remedial method using the ultrasonic medical system shown in **FIG. 6**. The ultrasonic diagnostic apparatus **12**, the articulate robot **80**, and the host controller **20** operate as described with reference to **FIG. 6**, so that the information regarding the position of the tumor **30** relative to the reference position is output from the host controller **20** to the proton beam source apparatus **90**. Based on the position information of the tumor **30**, the proton beam source apparatus **90** controls an arm unit **104** and an irradiation unit **106** for applying proton beams **10** intensively to a tumor **30** within a patient M. Further, the proton beam source apparatus **90** controls the aim in accordance with the movement of the tumor **30**, so that proton beams can be intensively delivered to just the tumor **30**, while irradiation of normal tissues is minimized, even when the tumor moves. It should be noted that while the reference position is set to the origin position of the proton beam source apparatus **90** in the example shown in **FIGS. 6 and 8**, the reference position may be appropriately selected in accordance with actual usage, such as at a predetermined location in a room in which the treatment is being carried out.

[**0073**] In addition, other radiation source apparatuses including a lithotomic apparatus may be used in place of the X-ray source apparatus **18** and the proton beam source apparatus **90** for the remedial method using the ultrasonic medical system according to the present invention. It is, of course, possible to use remedial beams other than radiation. A medical method utilizing a puncture apparatus which inserts a puncture needle toward the target tissue may also be used. In any case, control of various remedial beam irradiation or puncture needle insertion is performed based on the information regarding the position of the target tissue using a desired reference position as an origin.

[**0074**] As described above, according to the ultrasonic medical system according to the present invention, appropriate information regarding the tissue position can be obtained.

[**0075**] While the preferred embodiments of the present invention have been described using specific terms, such description is for illustrative purposes only, and it is to be understood that changes and variations may be made without departing from the spirit or scope of the appended claims.

What is claimed is:

1. An ultrasonic medical system comprising:

a wave transceiver for transmitting and receiving ultrasound with regard to a space including a target tissue and for outputting a reception wave signal;

first relative coordinate operation means for computing first relative coordinate information of the target tissue using the wave transceiver as an origin, based on an output reception wave signal;

second relative coordinate operation means for computing second relative coordinate information of the wave transceiver using a reference position as an origin; and

combined relative coordinate operation means for computing combined relative coordinate information of the target tissue using the reference position as an origin, based on the first relative coordinate information and the second relative coordinate information, and outputting the combined relative coordinate information.

2. An ultrasonic medical system according to claim 1, wherein

the wave transceiver transmits and receives ultrasound with regard to a three dimensional space including the target tissue, and

each of the first relative coordinate information, the second relative coordinate information, and the combined relative coordinate information is three dimensional relative coordinate information.

3. An ultrasonic medical system according to claim 2, wherein

the second relative coordinate information includes position information and direction information of the wave transceiver using the reference position as an origin.

4. An ultrasonic medical system according to claim 1, further comprising:

a generator which is provided at either one of a measurement origin whose positional relationship with the reference position is known and the wave transceiver, for generating a measurement signal, and

a detector which is provided at the other of the measurement origin and the wave transceiver, for detecting the measurement signal,

wherein the second relative coordinate operation means computes the second relative coordinate information of the wave transceiver using the reference position as an origin, based on the detection result by the detector.

5. An ultrasonic medical system according to claim 4, wherein

the generator is a magnetic field generator for generating a magnetic field, and

the detector is a magnetic field detector for detecting the magnetic field.

6. An ultrasonic medical system according to claim 1, wherein

the first relative coordinate operation means computes the first coordinate information of the target tissue using the wave transceiver as an origin, based on coordinate information specified by an examiner by using an ultrasonic image formed based on the reception wave signal.

7. An ultrasonic medical system according to claim 1, further comprising:

a holder mechanism for holding the wave transceiver; and

a measurement information operation unit for outputting measurement information regarding the wave transceiver which is held by the holder mechanism,

wherein the second relative coordinate operation means computes the second relative coordinate information of the wave transceiver using the reference position as an origin, based on the measurement information.

8. An ultrasonic medical system according to claim 7, wherein

the measurement information is coordinate information of the wave transceiver relative to a measurement origin whose positional relationship with the reference position is known.

9. An ultrasonic medical system according to claim 8, wherein

the holder mechanism is an articulated robot, and

the measurement information is information based on length data and angle data of each movable section of the articulated robot.

10. An ultrasonic medical system according to claim 7, wherein

the wave transceiver is brought into contact with a body surface of a patient, and

the holder mechanism includes a pressure sensor for measuring a contact pressure exerted to the patient by the wave transceiver, for controlling the contact pressure to a predetermined value based on the output from the pressure sensor.

11. An ultrasonic medical system according to claim 1, further comprising a radiation source apparatus for performing irradiation with radiation while controlling an aim based on the combined relative coordinate information.

12. An ultrasonic medical system according to claim 11, wherein

the radiation is a proton beam.

13. An ultrasonic medical system according to claim 11, wherein

the radiation source apparatus controls the aim in accordance with a movement of the target tissue based on the combined relative coordinate information.

14. An ultrasonic medical system according to claim 1, further comprising

a puncture apparatus for controlling a puncture position based on the combined relative coordinate information.

15. A ultrasonic medical system comprising:

an ultrasonic probe which is held by a probe holder mechanism for outputting position and direction information when brought into contact with a body surface of a patient, the ultrasonic probe transmitting/receiving ultrasound with regard to a three dimensional space including a target tissue;

an ultrasonic diagnostic apparatus for obtaining, via the ultrasonic probe, echo data for each of voxels forming the three dimensional space; and

a host controller which extracts a voxel corresponding to the target tissue based on an echo level of the echo data, computes first relative coordinate information of the target tissue using the ultrasonic probe as an origin, computes second relative coordinate information of the ultrasonic probe using a reference position as an origin based on the position and direction information, and computes combined relative coordinate information of the target tissue using the reference position as an origin based on the first relative coordinate information and the second relative coordinate information and outputs the combined relative coordinate information.

16. An ultrasonic medical system according to claim 15, further comprising

a remedial beam source apparatus for performing irradiation with a remedial beam while controlling an aim in accordance with a movement of the target tissue based on the combined relative coordinate information.

* * * * *

专利名称(译)	超声波医疗系统		
公开(公告)号	US20030187345A1	公开(公告)日	2003-10-02
申请号	US10/397788	申请日	2003-03-26
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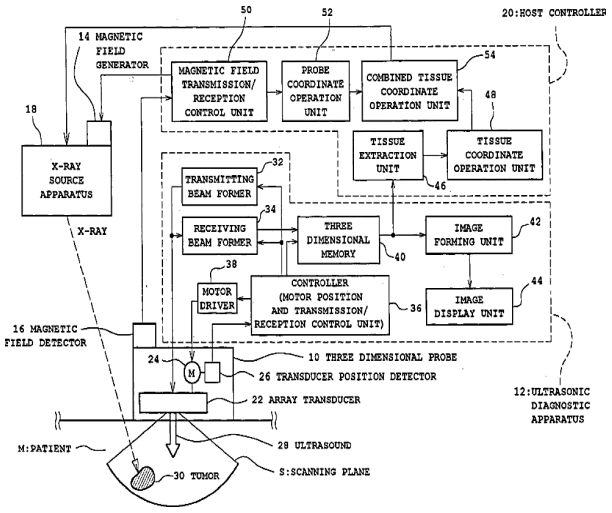
IPC分类号	G01B7/00 A61B8/08 A61N5/10 G01S15/89 A61B5/05 A61B8/00		
CPC分类号	A61B5/6843 A61B8/0833 A61B8/4254 A61N2005/1087 A61N5/1049 A61N2005/1058 A61B8/54 A61B8/4218		
优先权	2002088154 2002-03-27 JP 2003061120 2003-03-07 JP		
其他公开文献	US6796943		
外部链接	Espacenet USPTO		

摘要(译)

超声波诊断装置12将回波数据输出到主控制器20.在主控制器20中，组织坐标操作单元48使用三维探头10作为原点来计算肿瘤30的坐标信息。探头坐标操作单元52使用作为基准位置的X射线源装置18作为其原点，计算三维探头10的坐标信息。组合组织坐标操作单元54使用三维探头10作为其原点使用肿瘤的坐标信息，并使用X射线源装置18作为其原点来计算三维探头10的坐标信息，以计算坐标信息。使用X射线源装置作为其原点的肿瘤30，将计算出的坐标信息输出到X射线源装置18。