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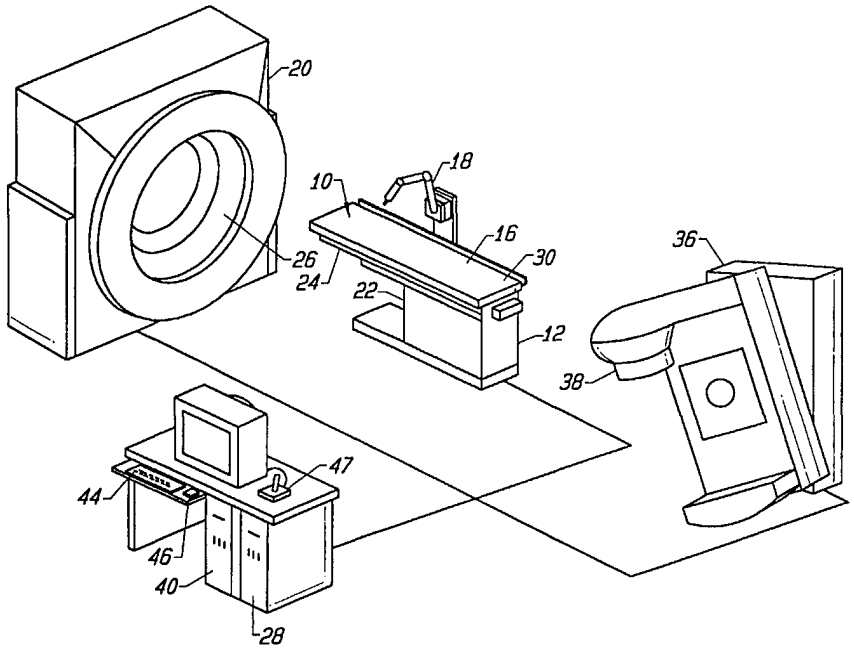

(57) Abstract

This invention is a robotics simulation, planning and marking platform (10) for medical diagnostic and treatment procedures including treatment simulation, planning and patient marking. The platform includes a support structure (12) with a top surface (16) for supporting a patient, and a robotics arm unit (18) mounted to the support structure. The arm unit has an articulable arm (64) with a distal end having a tool holder (62). A computer control system (28) is included for stereotaxic location of the tool holder with a light or ink marking tool (68) in accordance with data relating to the computerized image of the patient and the proposed treatment of the patient.

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ROBOTIC SIMULATION, PLANNING AND MARKING PLATFORM

BACKGROUND OF THE INVENTION

This invention relates to a robotic simulation, planning and marking platform particularly useful for medical diagnostic and treatment procedures that utilize costly scanning and therapy equipment. The robotic simulation, planning and marking platform is devised as a useful, inexpensive simulator where use of the primary scanning and/or treatment equipment is advantageously avoided during the intermediate treatment planning and patient marking procedures. The robotic platform provides an economical alternative to existing simulators without sacrifice of accuracy and with an increase in versatility of the robotic platform in diagnostics and treatment of medical conditions other than those for which the invention was primarily devised.

Modern use of computerized tomographic (CT) scanning or magnetic resonance imaging (MRI) have provided physicians with three-dimensional imaging of a patient or part of the patient containing the potential treatment area. Using appropriate virtual imaging software and a computer workstation, a virtual image of the patient or treatment area can be constructed for diagnostic analysis and treatment planning by the physician. In many instances, the scanning procedure is employed in conjunction with a subsequent radiation treatment procedure utilizing a Cobolt 60 radioactive source or a linear accelerator. Coordinating the scanning process and the treatment process, which use separate pieces of expensive equipment often situated in separate locations is difficult. Similarly, where scanning is utilized for diagnosing and planning stereotaxic surgery, the procedures are often separated by time and location.

Greater correlation of the diagnostic and treatment procedures for radiation therapy has been provided by scanning patients in the proposed or probable treatment position using positioning means such as a bag-

like "alpha cradle" to immobilize the patient and marking means such as radio-opaque markers to point mark the position of the patient. After analysis of the scanned images, the patient is positioned in the identical or an adjusted position and using the guidelines of an expensive two-dimensional travel laser beam system, the patient is marked by a pen on the patient's skin with a pattern or target to visually display the radiation treatment path or any other information required for the subsequent therapy or treatment. In certain instances, the laser marking system is incorporated into the structure of the imaging equipment, resulting in equipment scheduling problems.

This intermediate session with the patient is best accomplished with simulator equipment to avoid use of the expensive primary equipment. However, existing simulator equipment often duplicates the large and expensive original equipment, for example, the structure of the imaging table and portal design of the CT scanner unit. This might insure registration of the laser pattern from the laser tracings of the associated laser equipment. This pattern is used for marking the patient in conformity with the plan derived from the virtual image of the patient collected during the patient scan. Using the laser projected light beams on the skin of the patient, the patient is manually marked with a marking pen for radiation portal design, or, for other surgical or therapeutic treatments.

Alternately, the simulator may simulate the structure of the radiation therapy unit. This simulator is constructed without the high energy beam sources and uses live, low energy x-ray imaging to allow the physician to see the tumor during the simulation process. During planning and marking, the physician can devise the optimum treatment position for the patient by tracing laser beams that simulate the prospective path of the radiation beam in the radiation treatment unit.

By further reduction in simulator cost, the

patient and physician sessions required for planning and/or marking of the patient can be scheduled at the convenience of patient and physician and not primarily at the availability of the required equipment.

The robotic simulation, planning and marking platform of this invention is designed as an inexpensive simulator that is small in size and is readily portable. The robotic simulation platform is constructed in its preferred embodiment as a standardized radiation table top or pallet integrated with a moveable robotic arm having a laser light pen or skin marker stereotaxically coordinated with the defined field of the pallet for accurate tracing and marking.

The robotic simulation, planning and marking platform of this invention is primarily, but not exclusively designed for use in conjunction with a CT or MRI diagnostic and imaging system, and, is particularly adapted for incorporation in such systems that include radiotherapy equipment, either as an auxiliary component, or with the robotic arm removed, as a marked radiotherapy treatment table.

The typical procedures using a conventional simulator or a CT simulator may be summarized and compared with the robotic simulator as follows.

Conventional Simulator - The conventional simulator is similar in construction to the radiation therapy unit, but with low energy x-rays instead of a high energy beam. The CT/MRI scan is (taken in the diagnostic department and) used to find or diagnose the tumor. Using the conventional treatment simulator, the physician decides how to position and treat the patient. Using the accumulated information, the physician plans the best radiation dosage distribution aimed at the tumor in a manner avoiding normal tissue or sensitive organs. This process may alter the physicians initial decision. The simulator process is repeated to insure the plan is effective, and after adjustments the patient is marked by

a cross for portal and center of beam incidence.

It may be preferred that this last step be performed on a treatment table in the treatment room. Finally, the patient is treated in the radiation unit in the treatment room.

CT Simulator - The CT simulator, is often a retired or special designed CT scanning unit equipped with a laser beam tracing mechanism. The CT/MRI scan is taken to find or diagnose a tumor using a dedicated scanning unit in the treatment department. Simulation and planning can be accomplished by the physician or the simulator unit, without holding the patient for additional live x-rays. The patient is manually marked with a cross for portal and center of incidence beam using the laser light on the simulator. For simple procedures, the simulation, planning and marking can be accomplished in a single session. The patient is then moved to the treatment room for treatment according to the plan.

Robotic Simulator - The CT/MRI scan is taken from any CT/MRI diagnostic department to find or diagnose the tumor. Simulation and planning can be done together on the robotic simulator without holding the patient for live x-rays. The robot automatically marks the patient with the portal shape and the center of the incidence beam. The patient is then taken to the treatment room for treatment.

It is to be understood that the procedures vary from one medical center to another, often depending on the type and availability of scanner and radiation equipment. The substantially lower cost of the robotic simulator provides for greater flexibility in locating the simulator at one or more locations.

SUMMARY OF THE INVENTION

The robotic simulation, planning and marking platform of this invention is an inexpensive simulator device that can be advantageously integrated into a diagnostic and treatment regimen, particularly one including a CT or MRI scanner and a radiation therapy unit such as a linear accelerator. The robotic simulator platform combines a radio-translucent or radiolucent pallet and a computer-controlled, robotic arm mountable to the pallet in a position providing access of the tip of the robotic arm to the area of the patient to be marked.

Preferably, for maximized versatility, the radiolucent pallet includes a flat, rigid panel for supporting a patient in a prone or supine position. The support panel in one embodiment has a perimeter mounting rail with predefined mounting positions for the robotic arm. In this manner, the stereotaxic position of the tool tip of the arm relative to the planar reference field of the support panel is directly calculated. Where the robotic arm is used with a pre-existing CT or MRI table or a similarly constructed radiation treatment table having controlled linear transport of the table top, the robot arm can have a fixed mount to the table support. In this manner, the table is moved relative to the fixed position of the arm mount, and the table position is factored into the calculations determining the tip position relative to the patient.

The robotic arm is connected to a supporting mount that is readily detachable from the mounting rail of the pallet or a robot mount on an existing table. The mounting rail as well as any fasteners of the rail to the support panel are similarly radiolucent enabling the pallet to be ideally utilized as the table top or top pad in both the scanning and radiation treatment procedures. Alternately, the panel of the pallet is dimensioned and marked for correlation with the tabletop or pad used in the radiotherapy or other stereotaxic procedure. Direct

correlation for registration purposes can be achieved by use of a panel identical to the pallet panel without the mounting rails. In other situations, the robot arm unit position must be correlated with the scanner table and/or radiation table for proper image registration and robotic control. Finally, where the robotic simulation, planning and marking platform is used as a stand-alone simulation device for planning and marking, reliance on patient markers and the archived correlation data is required to position or reposition a patient during the simulator process. Ultimately, the tip of the robot arm must be correlated with the surface topology of the patient with reference to the internal target.

Because the radiolucent pallet is inexpensive, use of multiple pallets with a single robotic unit is cost effective, allowing multiple patients to be prepared at different locations and moved to a simulation control room for actual planning and marking. Similarly, because the robotic planning and marking platform is relatively inexpensive compared to existing simulator systems, separate apparatus may be located at various computer stations having networked access to the imaging data. For example, an inexpensive robotic planning and marking platform may be located at the site of the scanner unit, optionally on the scanner table allowing instant simulation and possible repositioning of the patient for an immediate follow-up scan. Additionally, a robotic planning and marking platform may be located at the site of the radiation unit, again, optionally on the therapy table, allowing the radiotherapist to make a final check of patient position or portal design before actual radiation treatment. And, customarily, for reasons of economics as well as patient and physician convenience, the simulation platform may be located at the site other than the site of either the scanning or radiation equipment.

It will be apparent from a consideration of the detailed description of the preferred embodiments that the

robotic simulation, planning and marking platform of this invention is a versatile device having many medical uses in addition to the conventional simulation use for imaging and radiotherapy as set forth in the description as a setting for the preferred embodiment procedures under actual or simulated conditions.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a schematic view of the robotic planning and marking platform in a system including an imaging unit and a radiotherapy unit.

Fig. 2 is a perspective view of the robotic planning and marking platform on a portable table support.

Fig. 3 is an end view of the robotic planning and marking platform.

Fig. 4 is an enlarged partial cross section view of the mounting mechanism on the robotic planning and marking platform taken on the lines 4-4 in Fig. 2.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

Referring to the schematic view of Fig. 1, the invented robotic simulation, planning and marking platform, designated generally by the reference numeral 10 is shown supported on an extendible diagnostic and treatment table 12. It is to be understood that a separate table device is customarily used for diagnostics and radiation therapy, and the integrated system shown schematically in Fig. 1 is to provide a general background setting for preferred use of the robotic planning and marking platform 10 as a radiotherapy simulator. The robotic platform 10 can be used on a dedicated imaging table, a dedicated radiotherapy table or a mobile table 12 as shown. As shown in Fig. 2, the robotic simulation planning and marking platform 10 is supported on a simple gurney 14, which is suitable for ordinary simulations for planning the design of an entry portal and marking a patient in preparation of the therapy or treatment regimen.

The robotic simulation planning and marking platform 10 combines a radiolucent pallet 16 with a robotic arm unit 18 that is detachable from the pallet 16. When the simulation platform of this invention is employed with a pre-existing imaging table or therapy table having an extensible table top, repositioning of the robotic arm unit 18, is unnecessary. Also, the existing patient support surface may be used although use of a surface identical to the pallet, with or without rails, facilitates correlation of data. Detachment of the robotic arm unit 18 from the pallet 16, of course, preferred when the mobile table 12 is moved into position for use with a scanning unit 20, which may comprise a computerized tomographic scanner (CT) or magnetic resonance imager (MRI). Typically, the table 12 has a support base 22 with a mechanism for extending a cantilevered table top 24 on which the patient rests, into the gantry 26 of the scanning unit 20. The scanning unit 20 makes a series of x-ray or magnetic resonance images that are processed by a computer processing unit 28 to

provide a 3D virtual simulation of the scanned patient or at least the portion of the patient including the target volume containing the disease or injury.

The computer processing unit 28 processes the patient scan data to provide the physician or radiotherapist with the necessary pilot images, or orthogonal, and lateral projections necessary for defining patient position, and, the image slices of the target volume necessary to analyze the disease or injury and plan for a therapy or treatment.

During the scanning procedure, the patient is preferably positioned in the prospective therapy or treatment position and immobilized with an appropriate immobilization device such as an alpha cradle, aqua-plast, vacuum bag or other device that does not interfere with the scanning or radiation procedures. In order to accurately reproduce this position, the patient is marked with a radio-opaque marking ink at appropriate landmark points that are easily identifiable in the images. Alternately, a radio-opaque wire or other geometric localizing device can be placed on the patient's body or embedded inside pallet 16 as a reference device.

Although in general the patient is repositioned on a simulation table in the identical location using the markings, accuracy affecting shafts inevitably occur. In the pallet 16 of the robotic planning and marking platform of this invention, the top surface has inlaid radio-opaque reference markers 32. The markers 32 shown are point markers and enable the patient position during the imaging process using the pallet 16 to be recorded as landmarks in the imaging data set. In some applications, a pallet having grid lines formed by thin wire inlays may be preferred. On repositioning the patient on the pallet during the planning and marking session in reference to patient markings, corrections can be made mathematically on the processor 28 when the location of the patient on the pallet is not identical to the patient's location during

the scan.

After the data set is captured and processed by the computer processing unit 28, programmed with a 3D CT simulation program, the virtual patient images are analyzed on the image display monitor. The robotic simulation, planning and marking platform 10 is used for further planning of the therapy or treatment session and the marking of the treatment portals. In Fig. 1, the therapy or treatment, for example, utilizes a radiation unit 36 with a rotatable radiation beam source 38 that defines the geometry of the treatment and therapy options. The diagnostic and treatment table 12 is positioned during therapy or treatment in conjunction with the patient's position on the top surface 30 to locate the target volume at the isocenter of the convergent beam paths.

The process of optimizing these variables is accomplished during the planning and marking session with the patient on the robotic simulation platform 10, which optionally is the mobil table 12.

As shown in Fig. 2, the robotic simulation, planning and marking platform 10 is supported on the gurney 14 that allows the platform to be moved to the location of the computer processing unit 28 or to a satellite computer station that is networked, or has access to the data set and simulation program. For purposes of convenience in this description, the computer processing unit 28 is used together with the robotic simulation platform 10 for simulations and includes a controller 40 electronically connected to the robotic arm unit 18 by a cable 42 for powering and controlling the operation of the robotic arm unit 18. The controller 40 is connected to the computer processing unit 28 and the processing unit 28 is programmed with a robot control application program for coordinating input from an input device such as keyboard 44, mouse 45, or joy stick 47, with data extracted from the data set and simulation program.

The robotic arm unit 18 is constructed with a

robot arm module 46 having a base 48 mounted to a vertical support mount 50 that seats in a cradle 52 on a slidable mounting bracket 54 that connects to a side rail 56 mounted along the sides and ends of a flat panel 58 that forms the support surface 30 of the platform 10.

The side rail 56, panel 58 and interconnecting spacer 60 are preferably all fabricated from a radiolucent material which may comprise specialty plastics or graphite compositions, or, where economy is required, wood or wood composites. With the robot arm module 46 and attached support mount 50 removed from the mounting bracket and the mounting bracket removed from the side rail 56, the remaining pallet 16 is radiolucent, except for topology reference markers 32, which show as reference landmarks in the imaging. Where the pallet is not used in scanning or treatment procedures, radiolucence is not required.

The robot arm module 46 comprises an inexpensive industrial robot, for example, the relatively inexpensive SCORBOT-ER 4pc from Eshed Robotec that is programmed and controlled using a graphic user interface program supplied with the device. The exemplar robot arm module 46 has five axis of movement plus the gripping action of the tool gripper 62 at the end of the three-link, articulated arm 64. The tool gripper or tool holder 62 holds a self-contained pen or laser pointer 66 as shown in Fig. 3 or a marking pen 68 as shown in Fig. 2 as required during the planning and marking procedure. For example, during initial planning, the robot arm module can trace a prospective path of the radiation beam while the tool holder 62 is displaced a distance from the patient. The attendant can manually mark the tracing. Or, once the portal design is generally defined, the tool holder 62 is equipped with a marking tool, such as the marking pen 68, and, utilizing the virtual topology of the patient, the patient is marked with the pen 68.

To improve the marking process, a pneumatic liquid color spray marker may be utilized to avoid direct

contact of the tool with the patient. The robot arm module 46 is preferably equipped with feedback sensors. Use of a distance feedback sensor 69 at the tool holder enables the marking pen 68 to safely contact the patient. The sensor may comprise a pressure sensor, or a distance sensor. A conventional capacitor sensor, ultrasound sensor or other such sensor is suitable where a spray marking is performed.

Because the robot arm module 46 is unable to access all locations on the pallet 16, the side rail 56 has a series of mounting stations 70 for positioning the mounting bracket 54. As shown in Fig. 4, the mounting bracket has a spring loaded position pin 72 engageable in position hole 74 to accurately locate the mounting bracket at one of the defined locations.

The position pin 72 has a guide 76 that contains a compression spring 78 that contacts a ring 80 fixed to the pin 72 to bias the pin 72 into the position hole 74. To lock the mounting bracket 54 to the side rail 56, a pair of threaded clamping knobs 84 on each side of the position pin 72 thread into threaded holes 86 in the side rail 56 at each mounting station 70.

It is to be understood that use of a larger robot arm module will enable a greater area and volume to be accessed by the tool holder allowing access from a single side of the pallet 16. In such case, the side rails 56 at the ends of the pallet and one side rail along the length of the pallet can be eliminated. Additionally, where mounted to an imaging table or therapy table having an extensible top as shown in Fig. 1, a fixed mounting position is suitable for accessing all table locations when coordinated with the reference data of the table position.

The robot arm module 46 can be mounted with its base 48 mounted to a vertical mount 50 as shown in Fig. 3 or with its base 48 mounted to a horizontal mounting platform according to the size of the robot arm module and the particular table structure to which the robotic arm unit is adopted.

While, in the foregoing, embodiments of the present invention have been set forth in considerable detail for the purposes of making a complete disclosure of the invention, it may be apparent to those of skill in the art that numerous changes may be made in such detail without departing from the spirit and principles of the invention.

WHAT IS CLAIMED IS

1. A robotic simulation platform for medical diagnostic and treatment procedures including simulation, planning and patient marking, the simulation platform comprising:

a support structure having a patient support surface; and,

a robotic arm unit mounted to the support structure, the robotic arm unit having an articulable arm with a distal end having holder means for holding a tool; and,

control means for controlling the articulation of the robotic arm, the control means including program means for stereotaxic location of the distal end of the arm relative to a patient supported on the support structure.

2. The robotic simulation platform of claim 1 wherein the control means comprises a robot controller electronically connected to the robotic arm unit and a computer processor connected to the robot controller.

3. The robotic simulation platform of claim 2 wherein the program means is a computer software program in the computer processor.

4. The robotic simulation platform of claim 2 wherein the computer processor has input means for user control of the robotic arm unit.

5. The robotic simulation platform of claim 4 wherein the input means comprises a user hand control device.

6. The robotic simulation platform of claim 1 wherein the patient support surface comprises a radiolucent table top.

7. The robotic simulation platform of claim 6 wherein the radiolucent table top has a position correlated with the robotic arm unit wherein the stereotaxic location of a tool in the tool holder means is controlled with reference to the table top.

8. The robotic simulation platform of claim 6 wherein the table top has discrete radio-opaque markers.

9. The robotic simulation platform of claim 1 wherein the control means includes patient image reference data with radio-opaque patient marker means for locating the stereotaxic position of the holder means with reference to the patient marker means.

10. The robotic simulation platform of claim 1 wherein the holder means has a marking tool.

11. The robotic simulation platform of claim 10 wherein the marking tool comprises a light means for tracing a light pattern on a patient on the patient support surface.

12. The robotic simulation platform of claim 10 wherein the marking tool comprises a marking means for marking a patient with a pattern.

13. The robotic simulation platform of claim 12 wherein the marking means comprises a marker pen.

14. The robotic simulation platform of claim 1 wherein the holder means includes distance sensor means for sensing the distance of the holder means from a material object.

15. The robotic simulation platform of claim 6 wherein the radiolucent table top comprises a pallet having mount means to mount the robotic arm unit to the pallet.

16. The robotic simulation platform of claim 15 wherein the mount means comprises a rail.

17. The robotic simulation platform of claim 16 wherein the rail has a plurality of different mounting stations and the robotic arm unit is mountable at each mounting station.

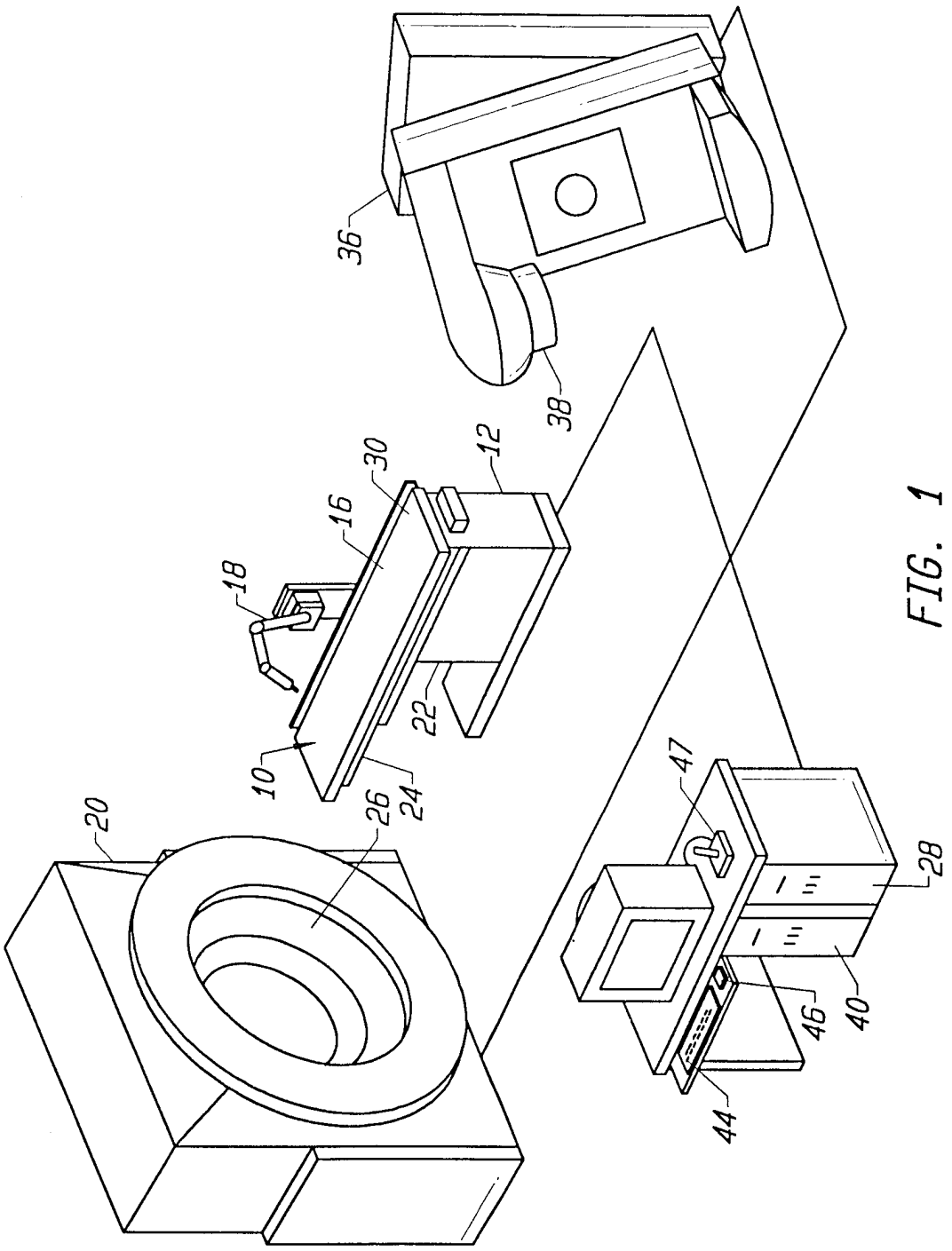

FIG. 1

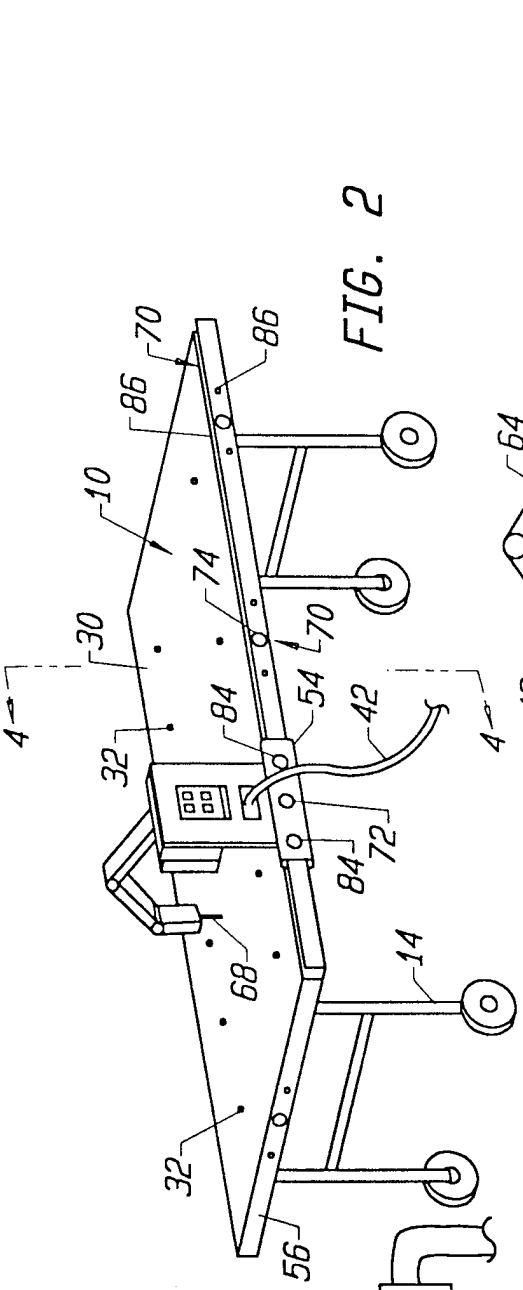

FIG. 2

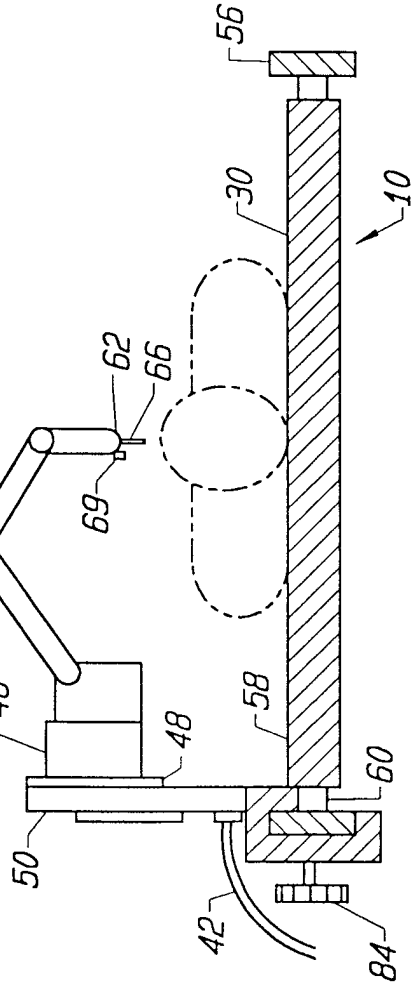

FIG. 3

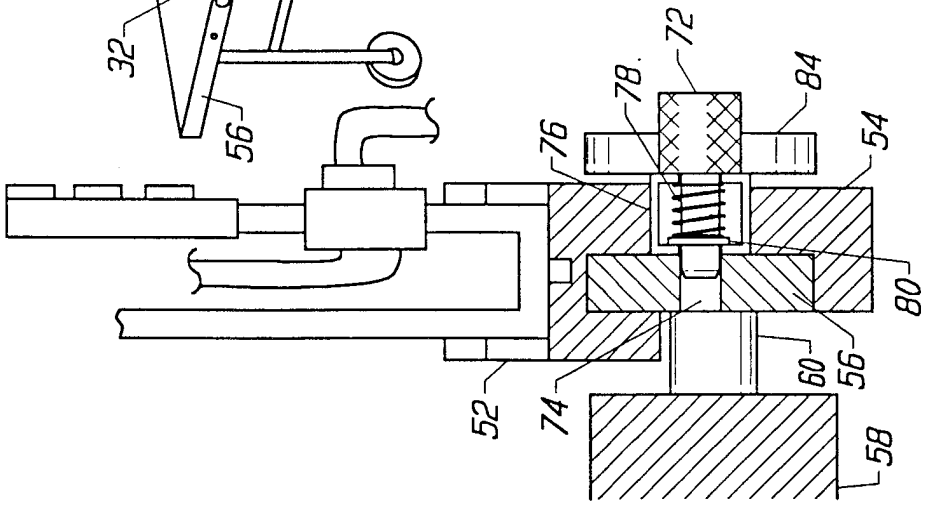

FIG. 4

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US98/03059

A. CLASSIFICATION OF SUBJECT MATTER
IPC(6) :A61B 19/00
US CL :606/130
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

U.S. : 604/116; 606/001, 108, 116, 130

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

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

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 5,305,203 A (RAAB) 19 April 1994, entire document	1-17
X	US 5,078,140 A (KWOH) 07 January 1992, entire document.	1-5, 7, 10, 12
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☐ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

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Date of the actual completion of the international search	Date of mailing of the international search report
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