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(54) REGISTRATION OF ULTRASOUND TO FLUOROSCOPY FOR REAL TIME OPTIMIZATION OF RADIATION IMPLANT PROCEDURES

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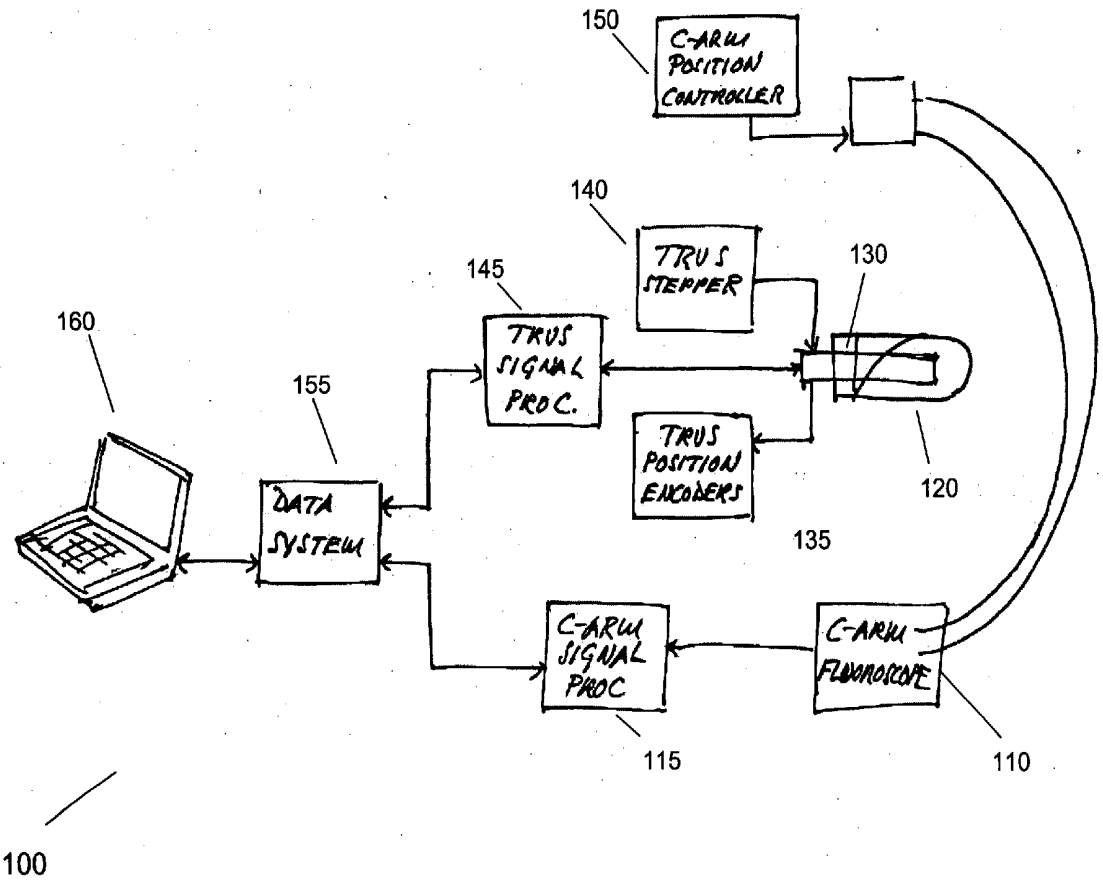
(57) **ABSTRACT**

Transrectal ultrasound guided transperineal low dose-rate brachytherapy has been emerged as one of the definitive treatments of low-risk prostate cancer. Ultrasound has been an excellent tool in guiding the implant needles with respect to prostate anatomy, yet it cannot show reliably the location of radioactive seeds after they are released in the prostate. Intraoperative C-arm fluoroscopy can show the implanted seeds, but it cannot detect prostate anatomy. Intra-operative fusion of these two complementary modalities offers significant clinical benefit by allowing for real-time optimization of the brachytherapy implant as the procedure progresses in the operating room. Disclosed is a system and method for mitigating this problem and providing registration of seeds seen by fluoroscopy with live prostate anatomy visualized by transrectal ultrasound.



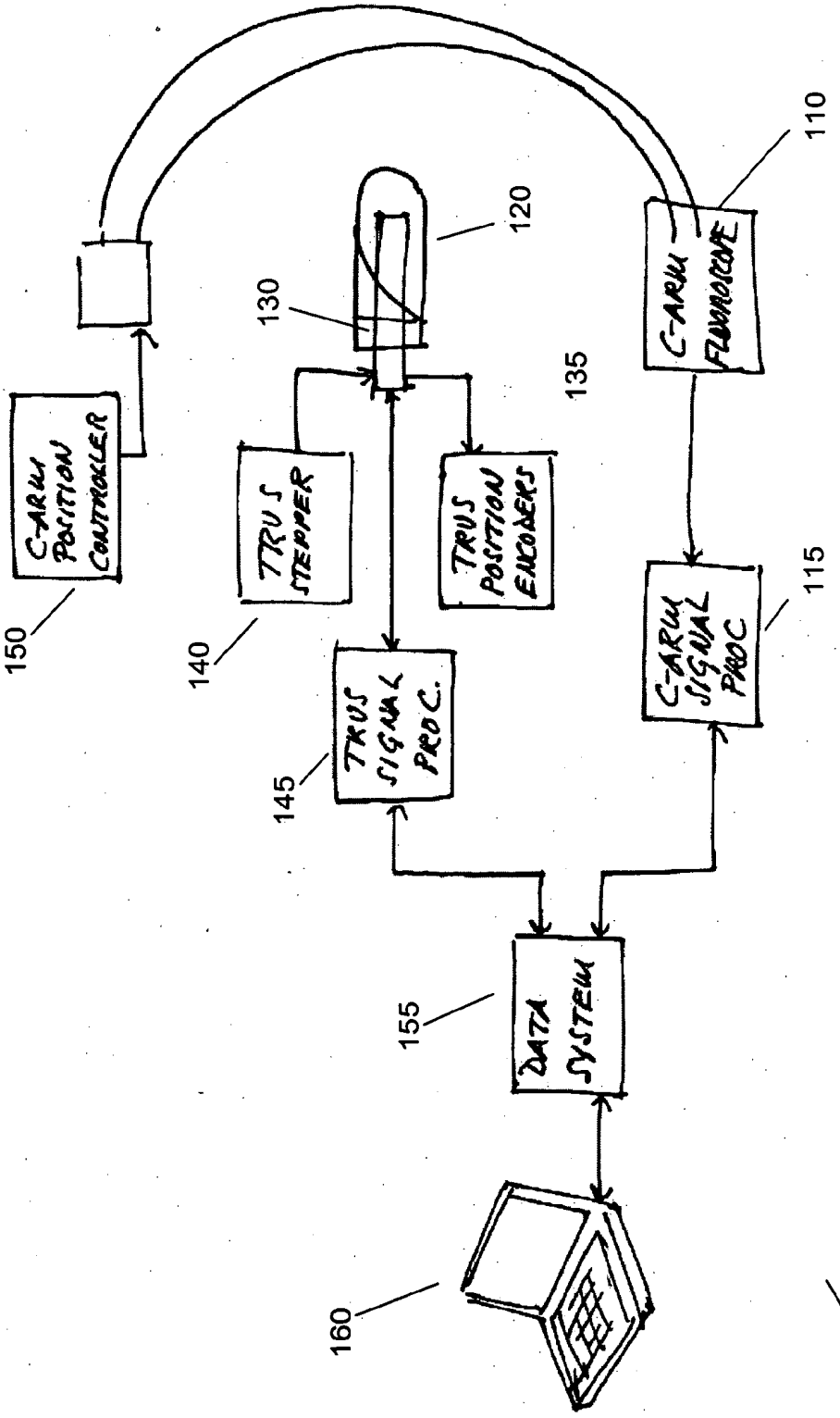

C-ARM POSITION CONTROLLER
150
TRUS STEPPER
140
TRUS POSITION ENCODERS
135
130
120
C-ARM FLUOROSCOPE
110
TRUS SIGNAL PROC.
145
C-ARM SIGNAL PROC
115
DATA SYSTEM
155
160
100

FIG. 1

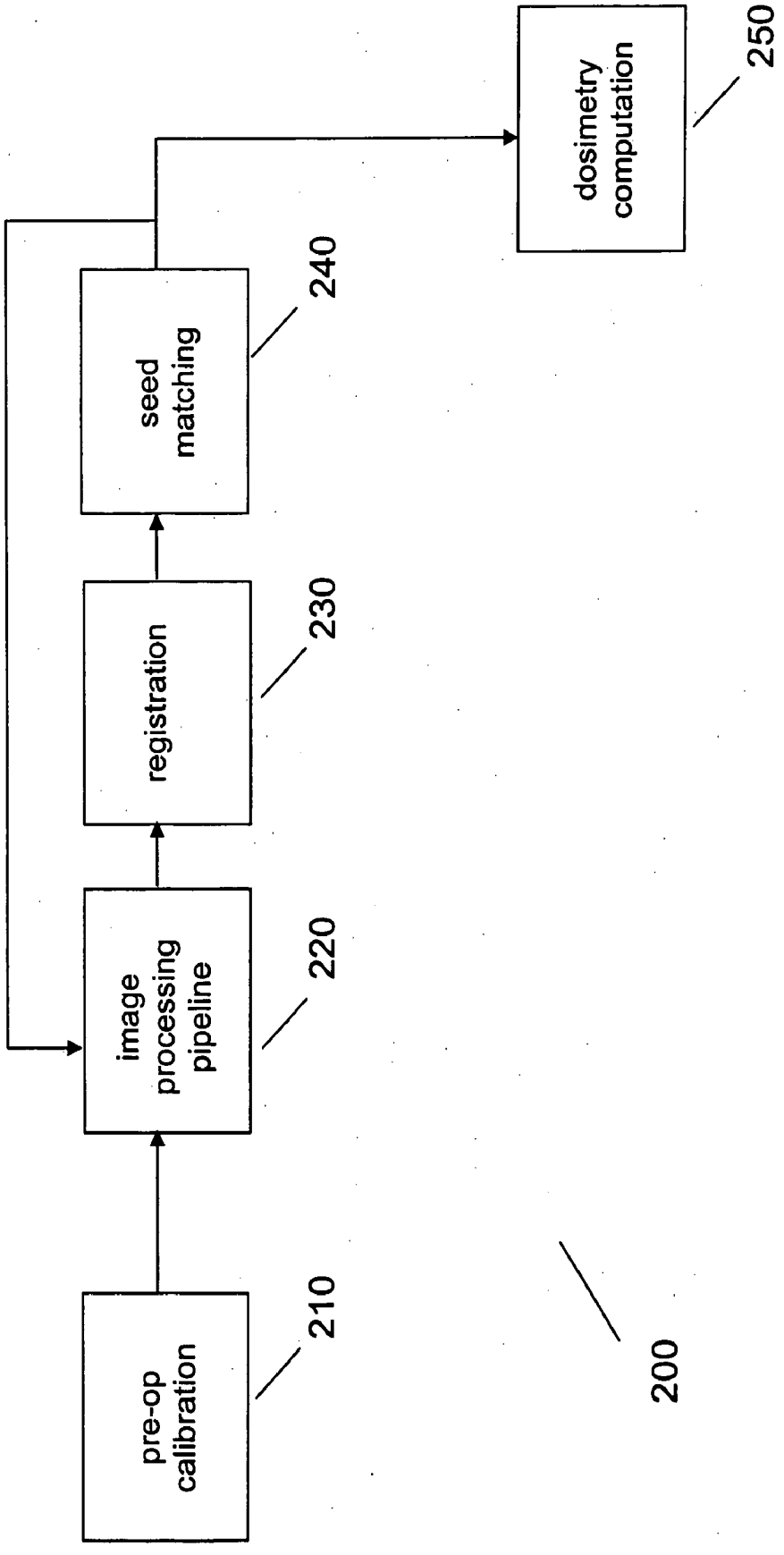

pre-op calibration
210
image processing pipeline
220
registration
230
seed matching
240
dosimetry computation
250
200

FIG. 2

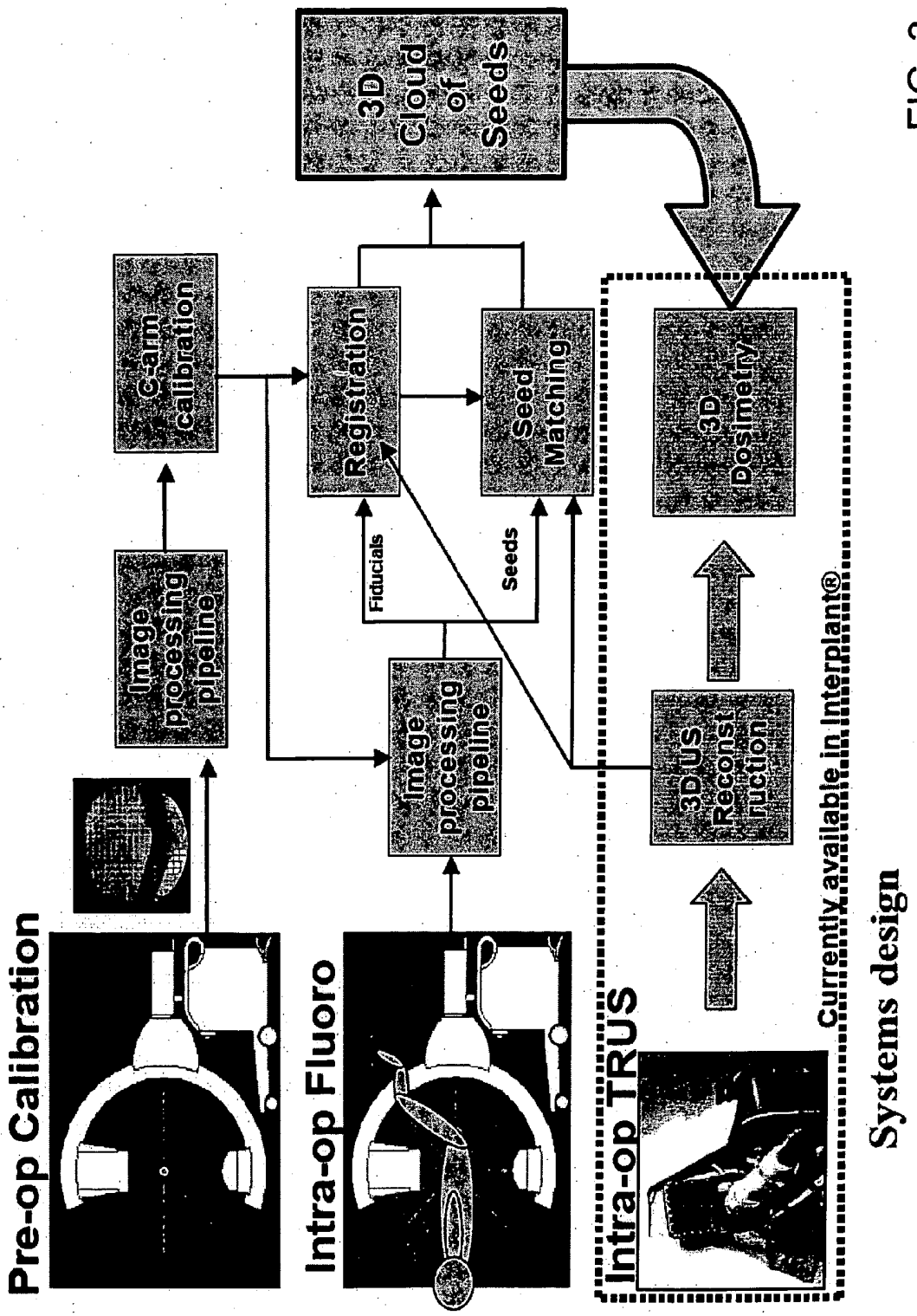

Pre-op Calibration
Intra-op Fluoro
Intra-op TRUS
C-arm calibration
Image processing pipeline
Registration
Seed Matching
3D Cloud of Seeds
3D Dosimetry
Fiducials
Seeds
Image processing pipeline
3DUS Reconstruction
Currently available in Interplant®
Systems design

FIG. 3

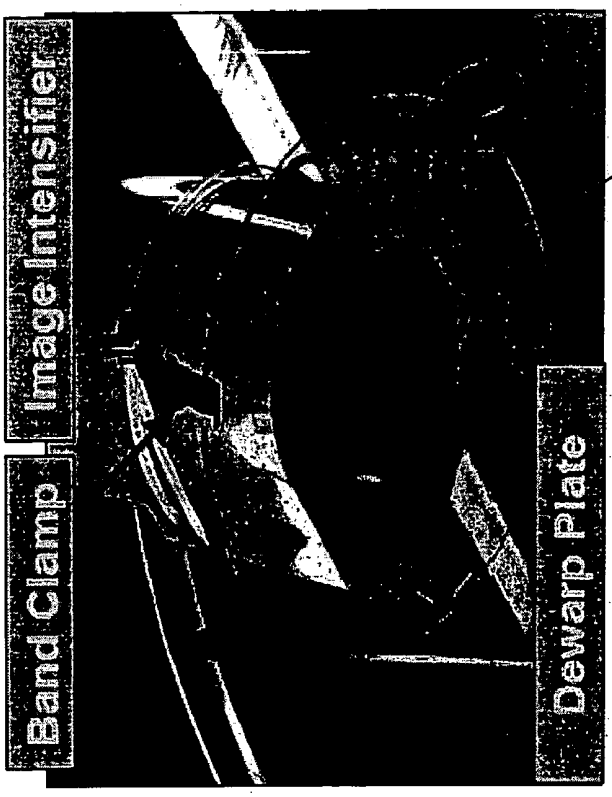

Band Clamp
Image Intensifier
Dewarp Plate
400

FIG. 4b

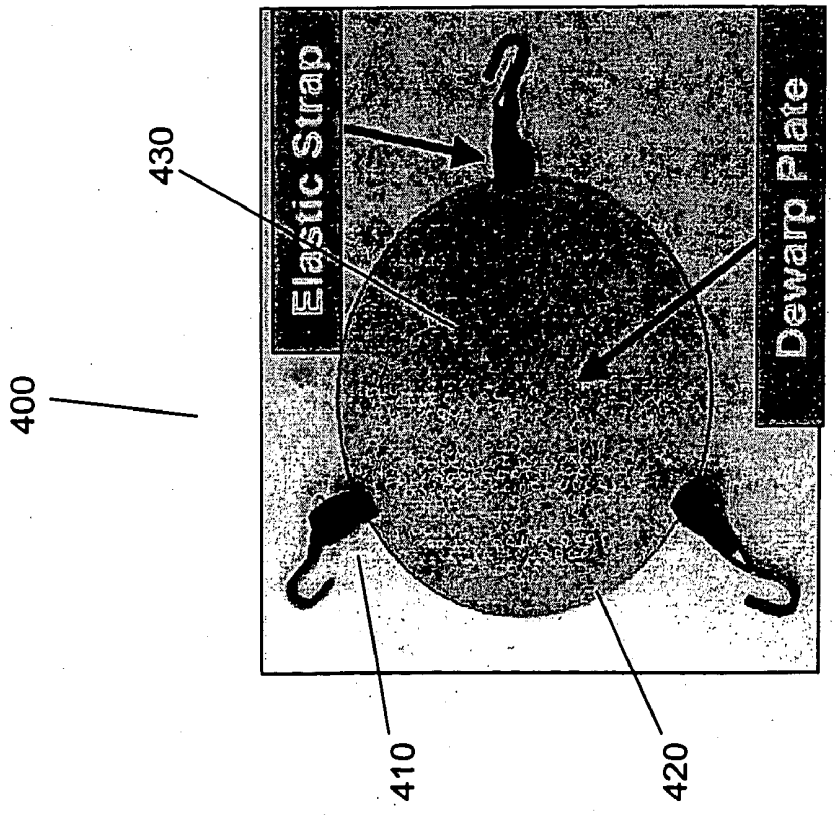

Elastic Strap
Dewarp Plate
400
430
410
420

FIG. 4a

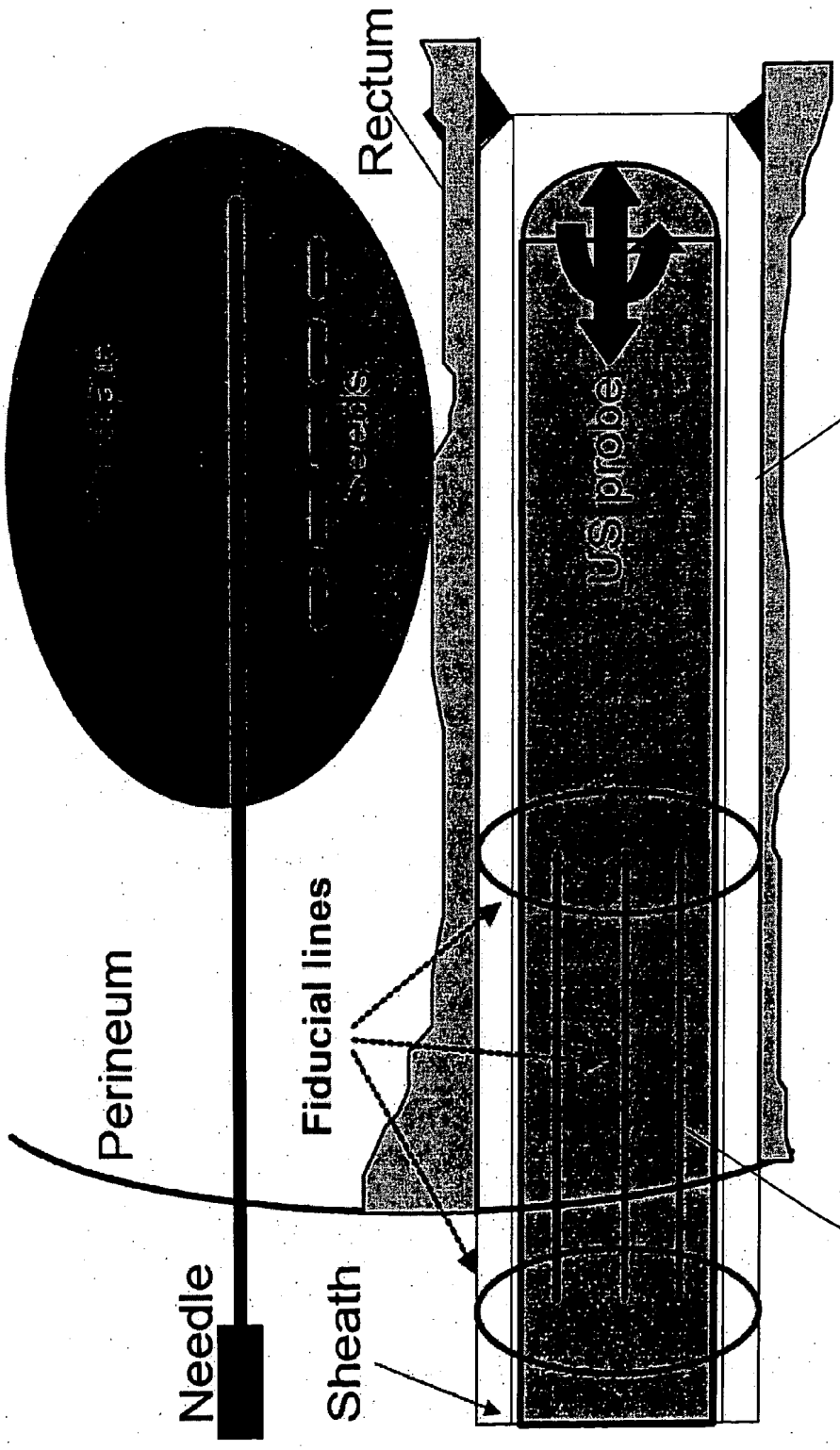

Rectum
US probe
120
Perineum
Fiducial lines
Needle
Sheath
510

FIG. 5

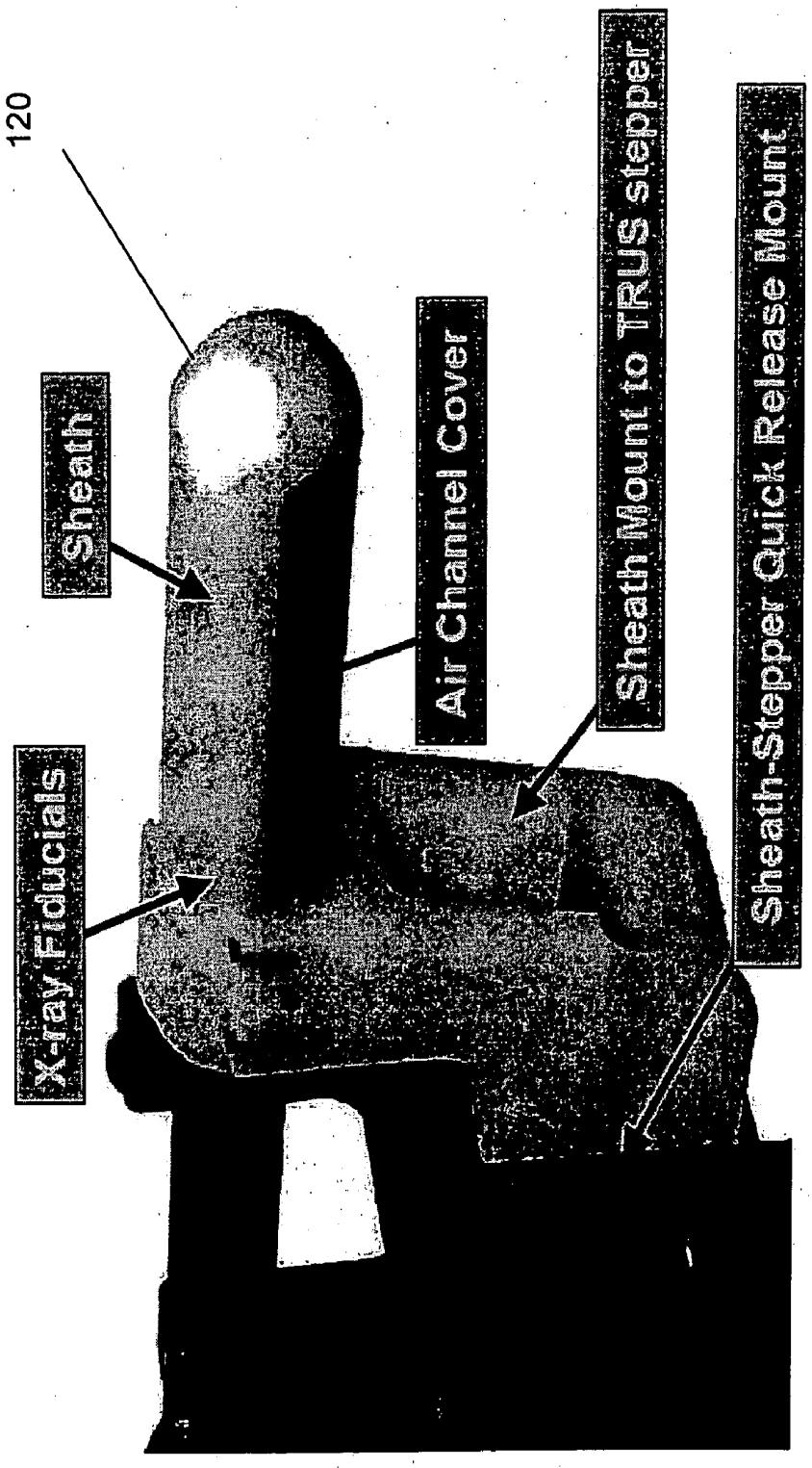

120
Sheath
Air Channel Cover
Sheath Mount to TRUS stepper
Sheath-Stepper Quick Release Mount
X-ray Fiducials

FIG. 6

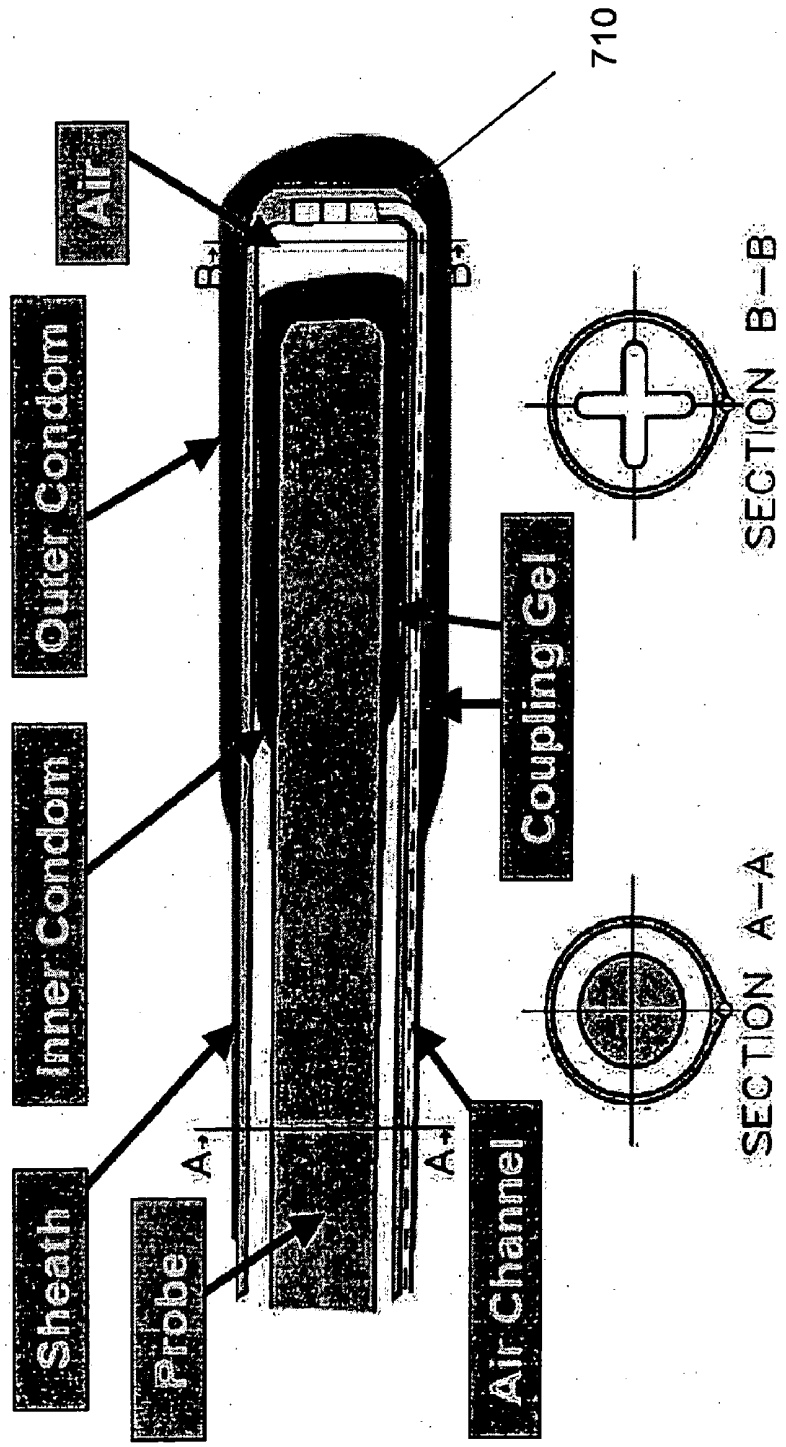

710
Air
Outer Condom
Inner Condom
Sheath
Probe
Coupling Gel
Air Channel
B
B
A
A
SECTION B—B
SECTION A—A

FIG. 7

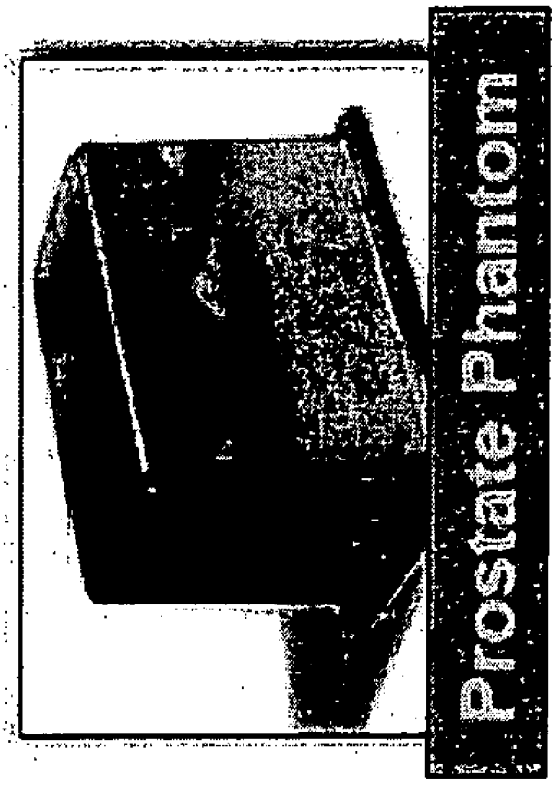


FIG. 8

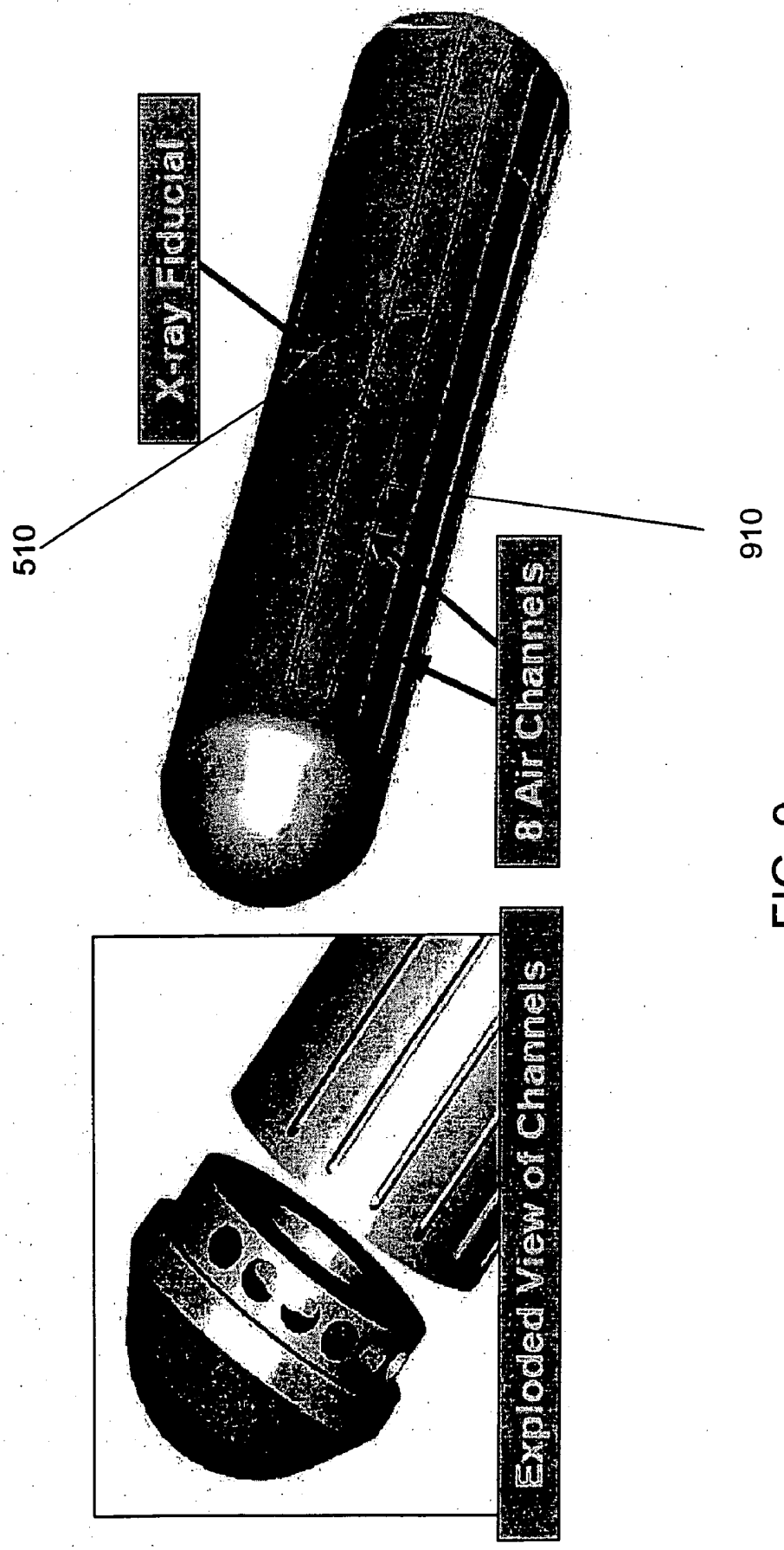

X-ray Fiducial
510
910
8 Air Channels
Exploded View of Channels

FIG. 9

REGISTRATION OF ULTRASOUND TO FLUOROSCOPY FOR REAL TIME OPTIMIZATION OF RADIATION IMPLANT PROCEDURES

[0001] This application claims the benefit of U.S. Provisional Patent Application No. 60/488,965, filed on Jul. 21, 2003, which is hereby incorporated by reference for all purposes as if fully set forth herein.

[0002] Research and development efforts associated with the subject matter of this patent application was supported by the National Science Foundation under Grant No. #ERC 9731478.

BACKGROUND OF THE INVENTION

FIELD OF THE INVENTION

[0003] The present invention relates to the registration of ultrasound and C-arm fluoroscopy imagery for the purposes of providing real-time optimization of medical procedures such as transperineal low-dose rate brachytherapy.

[0004] Adenocarcinoma of the prostate is the most commonly diagnosed cancer in the U.S. male population. During the last half decade, there have been approximately 200,000 new cases of prostate cancer diagnosed each year, which is comparable to breast cancer diagnosis, and there is no evidence that this number would significantly decrease in the foreseeable future. For several decades, the definitive treatment of low-risk prostate cancer was radical prostatectomy or external beam radiation. During the 90's the technique of transrectal ultrasound (TRUS) guided transperineal low dose-rate brachytherapy underwent dynamic improvement. Brachytherapy has become a well-proven treatment modality, comparable to surgery and external beam radiation therapy (EBRT) in any measurable respect. Reports for seven year follow-up to radiation implant therapy have demonstrated excellent local control rates, and most recent data reports excellent long-term (10-12 year) disease-free survival rates equivalent to radical prostatectomy and external beam radiotherapy. Latest results also indicate that good quality transperineal ultrasound prostatic conformal brachytherapy can be accurately reproduced in a community hospital setting and that biochemical no evidence of disease (NED) results and local control rates will be comparable to those of several of the leading authorities, the Seattle Prostate Institute, Memorial Sloan Kettering Cancer Center, NYU, and others with no unexpected urethral or rectal complications or side effects.

[0005] While the technique of brachytherapy for prostate cancer has certainly evolved over the past three decades and modern local control rates have increased, the rate of rectal and urethral complications is still high if radiation implants are to potentially become a new treatment standard. The underlying reason for unsatisfactory clinical results has predominantly been lack of adequate visualization and control of the implant process leading to improperly placed sources of radiation dose. In many respects, the evolution of brachytherapy can be viewed as an evolution of noninvasive visualization and control of the actual implanted source locations. There have been advances in the ability to use different isotopes for better dose distributions; however, even the best isotope is useless without proper visualization, localization, and subsequent control of the implant. The ability to intraoperatively localize seeds in relation to the prostate is key to enabling dynamic dose calculation during the procedure. The solution of this problem would reduce the probability of faulty implants, thus presenting an opportunity for improved outcomes.

[0006] TRUS imaging generally provides satisfactory differentiation of relevant soft issue, but implanted brachytherapy seeds cannot be clearly identified in the TRUS images. Advancements in ultrasound equipment technology are expected to facilitate seed localization in the future, but they will not be available for the majority of prostate brachytherapy practitioners in the foreseeable future. On the other hand, currently sixty percent or more of the practitioners use intra-operative C-arm fluoroscopy as a qualitative check of the implants. While seeds can be accurately localized using X-ray techniques, projected transluminal images do not reveal soft tissue anatomy. Hence, there has been strong demand for coupling relevant information from C-arm with the TRUS-guided delivery system, in a safe, robust, and cost-efficient manner.

DISCUSSION OF THE RELATED ART

[0007] C-arm X-ray fluoroscopy may be the most widely used intra-operative imaging modality in general surgery, and approximately 60+% of the prostate brachytherapy practitioners use it for qualitative implant analysis in the operating room in non-computational qualitative manner. While C-arm fluoroscopy has been used intra-operatively, it has not been utilized in quantitative intra-operative analysis. C-arm has been used a solo guidance modality. However, since TRUS emerged as a primary image guidance modality, C-arm fluoroscopic x-ray imaging has become a secondary tool for gross visual observation. Very few attempts have been made to relate fluoroscopic images to soft tissue anatomy with little success. These attempts have generally used thin metal wire inside a Foley catheter to visualize the prostatic urethra fluoroscopically in anterior-posterior and lateral projections. In other approaches, gold marker seeds have been implanted into the prostate, and the relative positions of the needles and marker seeds have been observed in fluoroscopy.

[0008] X-ray radiography has been used extensively for post-implant brachytherapy evaluation using multi-view X-ray to recover seed locations post implant and determine gross dosimetry. Here the fundamental problem is matching large number of seeds with their projections in multiple X-ray images when some seeds obscure each other and solid objects also can get in the way. Automated methods have been explored, but they also assume conditions that most likely cannot be met on a C-arm, particularly in a realistic intra-operative scenario. Such assumptions include no extrinsic object in the field, optimal beam energy, arbitrary number and orientation of X-ray shots, or unlimited processing time and computational resources—none of which is realistic in real-time image-guided surgery. In conclusion, "off-the-shelf" post-implant seed matching and reconstruction techniques cannot be expected to work in the operating room. Many approaches have met with great difficulty due to the inability to accurately determine the imaging angles relative to the prostate for reconstruction of the multiple projection images. This not only reduces accuracy, but makes the process too lengthy to be used intraoperatively.

[0009] The use of implanted needles as fiducial markers for registration of biplane TRUS data has been explored, but

several key problems have been left unsolved: (1) The use of implanted needles as fiducials may not be practical, because most practitioners implant only one needle at a time and they do not use stabilizing needles. (2) The nearly parallel transperineal needles as fiducials encode weakly in the apex-base direction, with little spatial resolution. (3) As the X-ray and TRUS imaging are not simultaneous, it is imperative that the fiducials do not move relative to the prostate until both imaging sessions are complete. During TRUS scanning, however, the prostate deforms, dislocates, and the needles dislocate relative to the prostate. (4) Previous attempts did not account for the need to pre-operatively calibrate the C-arm fluoroscope, including removing image distortion and some form of intra-operative tracking to know where the multiple X-ray shots are coming with respect to one another.

[0010] Calibration of a C-arm fluoroscope involves intrinsic and extrinsic imaging parameters. Intrinsic parameters correspond to image warping, focal length, pixel scaling, and image center. In most applications, it may be assumed that these parameters do not change during the procedure under different C-arm poses, but it has been reported in the literature that the focal length may vary up to several millimeters at different C-Arm poses, on certain units. For determining the focal length, pixel scaling, and image center comprehensive methods have been reported. Using fluoroscopic imaging for quantitative analysis also requires correction of spatial distortions caused by the image intensifier. Several methods have been explored for distortion correction, such as improved calibration methods involving a fixture attached to the detector. In summary, although C-arm calibration has been well examined, inexpensive, efficient, and robust implementations are still in paucity. Currently known dewarping and calibration kits are custom designed for each C-arm, making them hard to transfer from device to another. If multiple X-ray images are used, determining the relative pose of X-ray projections is also necessary. A related art solution involves external tracking with optical or electromagnetic trackers, recovering the X-ray projection geometry for three-dimensional tomographic reconstruction with an additional optical camera and comparing the results to tracking the C-arm with external navigation system. Other related art approaches involve image-based method for pose estimation without an external tracking device. Such methods rely on identifying features in each X-ray image of precision-machined fiducials and computing the appropriate spatial transformation between the individual X-ray images.

[0011] Accordingly, transrectal ultrasound guided transperineal low dose-rate brachytherapy has been emerged as one of the definitive treatments of low-risk prostate cancer. Ultrasound has been an excellent tool in guiding the implant needles with respect to prostate anatomy, yet it cannot show reliably the location of radioactive seeds after they are released in the prostate. Intraoperative C-arm fluoroscopy can show the implanted seeds, but it cannot detect prostate anatomy. Intra-operative fusion of these two complementary modalities offers significant clinical benefit by allowing for real-time optimization of the brachytherapy implant as the procedure progresses in the operating room.

SUMMARY OF THE INVENTION

[0012] Accordingly, the present invention is directed to the registration of ultrasound to fluoroscopy for real time optimization of radiation implant procedures that substantially obviates one or more of the problems due to limitations and disadvantages of the related art.

[0013] An advantage of the present invention is to provide improved visualization and control during radiation implant processes.

[0014] Another advantage of the present invention is improved localization of radiation doses in cancer treatment.

[0015] Another advantage of the present invention is to enable an advantageous compromise between time, dose, and accuracy during radiation dose implant surgery.

[0016] Another advantage of the present invention is to better enable dynamic dose calculation during radiation implant procedures, including the ability to adjust the planned implant locations to better optimize dose as the implant progresses.

[0017] Additional features and advantages of the invention will be set forth in the description which follows, and in part will be apparent from the description, or may be learned by practice of the invention. The objectives and other advantages of the invention will be realized and attained by the structure particularly pointed out in the written description and claims hereof as well as the appended drawings. To achieve these and other advantages and in accordance with the purpose of the present invention, as embodied and described, a system for registering ultrasound and fluoroscopy data comprises: a fluoroscope; a sheath having fiducial marks disposed on a portion of its outer surface; an ultrasound probe insertable into the sheath; a computer; and a computer readable medium encoded with a program for registering a first set of data acquired by the ultrasound probe with a second set of data acquired by the fluoroscope.

[0018] It is to be understood that both the foregoing general description and the following detailed description are exemplary and explanatory and are intended to provide further explanation of the invention as claimed.

BRIEF DESCRIPTION OF THE DRAWINGS

[0019] The accompanying drawings, which are included to provide a further understanding of the invention and are incorporated in and constitute a part of this specification, illustrate embodiments of the invention and together with the description serve to explain the principles of the invention. In the drawings:

[0020] **FIG. 1** shows an exemplary system for registering ultrasound to fluoroscopy according to the present invention;

[0021] **FIG. 2** shows an exemplary process for registering ultrasound and fluoroscopy according to the present invention

[0022] **FIG. 3** is another depiction of an exemplary process for registering ultrasound and fluoroscopy according to the present invention;

[0023] **FIG. 4*a*** shows an exemplary fluoroscope dewarping kit as may be used in the present invention;

[0024] **FIG. 4*b*** shows an exemplary dewarping kit installed on a C-arm fluoroscope;

[0025] **FIG. 5** shows an exemplary transrectal sheath, along with an ultrasound probe, as may be used in the present invention;

[0026] **FIG. 6** shows an exemplary transrectal sheath mounted to a TRUS stepper base;

[0027] **FIG. 7** is cutaway view of a transrectal sheath, a TRUS probe, acoustically coupled according to the present invention;

[0028] **FIG. 8** shows a prostate phantom that may be used in the pre-op calibration step of the present invention; and

[0029] **FIG. 9** is an exemplary transrectal sheath, which includes air channels and X-ray and acoustic fiducials.

DETAILED DESCRIPTION OF THE ILLUSTRATED EMBODIMENTS

[0030] **FIG. 1** shows an exemplary system **100** for registering ultrasound and C-arm fluoroscopy according to the present invention. The system **100** generally comprises commercially available TRUS and C-arm fluoroscopy hardware. The system **100** includes a C-arm fluoroscope **110**; related C-arm fluoroscope signal processing hardware and software **115**; a C-arm position controller **150**; a transrectal sheath **120**; a TRUS probe **130**; a TRUS stepper; a TRUS probe position encoder **135**; TRUS signal processing hardware and software **145**; a data system software **155**; and a computer **160**, which stores and executes the data system software **155**. The computer **160** may comprise multiple computers, including remote databases and embedded processors. It will be apparent to one skilled in the art that the data system software **155**, and the computer **160**, may be provided in many different configurations.

[0031] **FIG. 2** shows an exemplary process **200** for registering ultrasound and C-arm fluoroscopy according to the present invention. The process **200** includes a pre-operation calibration of the C-arm fluoroscope **210**; an image processing pipeline **220**; a registration process **230**; seed matching **240**; and dosimetry computation **250**. Relevant aspects of the process **200** are consistent with the use of C-arm in current clinical protocols. In process **200** operating room staff may perform an implant with TRUS imaging feedback as customary and use the C-arm **110** for seed reconstruction after a batch of needles, preferably after implanting a row of needles. Such a scenario seems to be a reasonable compromise considering time, dose, and accuracy. During preoperative calibration **210**, we attach calibration fixtures to the C-arm **110**, collect X-ray images, push them through a processing pipeline **220**, and then calculate intrinsic parameters of the C-arm **110**.

[0032] Intra-operatively, we acquire C-arm images of the prostate and process them through an almost identical pipeline, this time using the intrinsic C-arm parameters computed in step **210**. Process **200** involves labelling X-ray fiducials, calculating the pose of the C-arm **110**, and registering the X-ray to TRUS space. Seed clusters are delineated and seed matching performed in step **240** to reconstruct the position of individual seeds. In this process **200**, we make extensive use of prior knowledge from 3D TRUS reconstruction and registration. The end result of this process is a cloud of seeds in TRUS space that we use in dosimetric update in step **250**. The key components of the system are the image processing pipeline, calibration, registration, and seed matching software modules in the data system software **155**.

[0033] The goal of the image processing pipeline **220** is to delineate and identify objects (seeds, needles, fiducials, etc.) in the fluoroscopic images. The image processing pipeline **220** includes a chain of operators acting on the X-ray images: (1) Image Acquisition→(2) Dewarping→(3) Noise Reduction→(4) Image Normalization→(5) Background Removal→(6) Thresholding→(7) Pre-Labeling.

[0034] (1) Image Acquisition from C-arm signal processor **115** is a relatively straightforward technical issue. The C-arm signal processor **115** has either digital output or produces VHS signal that can be captured through frame grabbing card on the central computer. In a preferred embodiment, a Matrox frame grabber may be used.

[0035] (2) Dewarping filter helps remove the spatial distortion introduced by the image intensifier of the C-arm signal processor **115**. The present invention includes a dewarping fixture and corresponding computer instructions in the data system software **155**, which is described later.

[0036] (3) Noise Reduction in the static X-ray images may be achieved most effectively by averaging multiple frames taken in the same position. While this method substantially preserves image features, it also may increase radiation dose. For example, averaging five short-burst fluoro frames may give excellent noise suppression, while exposing the patient to a dose of one radiograph.

[0037] (4) Image Normalization. The intensity of X-ray falls exponentially as the ray passes through the body, and the gray level of objects depends very heavily on the thickness of other objects that the ray had to penetrate on its way. Logarithmic normalization of the image may result in simple sum of the attenuations of the seeds and body. As the implanted seeds, needles, and fiducials tend to have large attenuation compared to bone and soft tissues, they may stand out brightly in logarithmic image.

[0038] (5) Background Removal. Important to the accuracy of our system is its ability to find the centers and centerlines of objects in the X-ray imaging. Calculating simple weighted centroid may not suffice, because non-point like regions skew the determination of the center and centerline along the gray level gradient. A preferred embodiment may use a method developed by Bzostek et al. originally developed for finding spherical beads by applying linear gradient correction followed by Gaussian filtering over the log-corrected image. A preferred embodiment may use the Bzostek-Taylor algorithm for implanted spherical markers and further expand the method for line objects and seeds. Background removal in step **220** may use mathematical morphology, introduced by Haralick et al. in a 1987 paper, later refined and reported by Tubic D, Zaccarin A, Beaulieu L, Pouliot J. Automated seed detection and three-dimensional reconstruction. II. Reconstruction of permanent prostate implants using simulated annealing. Med Phys. November 2001; 28(11): 2272-9 (hereinafter "Tubic"), which is incorporated by reference as if fully disclosed herein, for fluoroscopic imaging of prostate implants by defining a chain of four basic morphological operations: erosion, dilatation, opening, and closing.

[0039] (6) Thresholding may not be done statically, because the intensity of seeds and objects also depends on

the thickness of bone structures. However, the optimal threshold may be found automatically by applying entropy maximization over a two-dimensional histogram that reflects both the gray levels and spatial relationship of pixels. The result of the image processing pipeline **220** includes a distortion-free binary image, in which only artificial implanted objects are present, while all details of the natural body (bone, ligaments, etc.) are removed from the picture. Subsequent labeling can be further assisted by optimizing material density of the custom-made objects (de-warp grid, calibration phantom, rectal sheath, fiducials, etc.) so that the processing pipeline can be fine-tuned to suppress or enhance these objects selectively.

[**0040**] (7) Pre-Labeling is performed to delineate and identify all objects other than seeds, then digitally remove those from the images. In a preferred embodiment, the data software **155** uses prior shape information about the objects in the field of view. Two sorts of dense objects may be expected in the field of view: implanted markers (needles, wire markers, spherical markers) and brachytherapy seeds. Needles and wire markers typically appear as thin lines that are typically well segmentable by Hough transform. At any given time, only a very limited number of marker objects are generally present in an X-ray field. Knowing the shape, orientation, and estimated relative positions of these objects; the data system software **155** may label them automatically, or with minimal input from the operator, in the worst case. If they are labeled once, the data system software **155** may remember where they are supposed to show up the next time and how they actually look like in the images. After a marker object is positively identified, the data system software **155** calculate its 3D locations for registration purposes and then digitally remove its silhouettes from the X-ray images. This process may be repeated until only seeds are left in the images that then undergo a sophisticated pattern recognition process described below under "Seed Matching". It should be noted that some seeds may have been obscured by marker objects and thus inadvertently removed from the images. That is why it is so important to place needles and line markers where they are the least likely to obscure seeds.

[**0041**] Calibration of the C-arm **110** in step **210** should be performed pre-operatively, before the patient is brought into the room. Commercially available C-arms **110** generally apply electronic image intensifier, in which "parameter shift" may occur unexpectedly. Therefore it is recommend that calibration step **210** be performed before each procedure, even if the same C-arm **110** is being used. Exemplary process **210** repeats a limited set of C-arm poses under the assumption that in a given pose the intrinsic parameters do not change during the procedure, so the dewarping grid may be removed during the implant procedure. During calibration step **210**, a dewarping grid is placed on the detector and the C-arm signal processor **115** process the images in these poses, in a transverse and sagittal sweep planes at approximately +30°, 0°, −30° poses. Next, the calibration step **210** uses an image processing pipeline substantially similar to that described for step **220**, only without using the dewarping filter that is computed during calibration step **210**. In step **210**, the system software **155** assigns labels to the beads of the dewarping grid automatically and determines the dewarping filter. Next, a calibration object may be placed in the field and the C-arm **110** is driven through the same poses as before. This time, however, the system software **155** processes the images through the complete pipeline **220**, now including dewarping. The data system software **155** labels the calibration fixture automatically and then calculates the intrinsic C-arm **110** parameters using techniques like those described in Yao J, Taylor R H, Goldberg R P, Kumar R, Bzostek A, Van Vorhis R, Kazanzides P, Gueziec A. A C-arm fluoroscopy-guided progressive cut refinement strategy using a surgical robot. Comput Aided Surg. 2000; 5(6): 373-90, which is incorporated by reference as if fully disclosed herein.

[**0042**] **FIG. 4 a** dewarping grid structure **400** that may universally fit C-arms **110** of different detector size. An adjustable band clamp **410** goes around the C-arm **110**, so that the plate **420** hooks into blocks positioned around the C-arm **110**, as shown in **FIG. 4***b*. The plate **420** is firmly attached to image intensifier and substantially does not move during the calibration process **210**. This plate **420** may be easy to install and simple to use, partly because our dewarping process does not require that the centers of the dewarping plate **420** and the intensifier be aligned. The radio-opaque beads **430** may be arranged in triangular pattern. The dewarping algorithm implemented by data system software **155** includes three basic steps: (1) Establish a correlation between points in the image and points in the known bead pattern **430** by using a fast crawling method that can circumvent problems caused by missing beads **430** in the image. (2) Determine the rigid body transformation and scale factor that will align the images, by using a conventional singular value decomposition method. (3) Align the images and perform least-squares polynomial fit between the point sets. The data system software **155** may use nth-order Berstein polynomials to describe the patterns in the dewarping grid and then achieve deformable matching between warped and warp-free features.

[**0043**] A preferred result of registration step **230** is a 6 degree of freedom (DOF) transformation between TRUS and X-ray space. In step **230**, a set of fiducial objects are generally needed that can be seen both in TRUS and X-ray and are substantially stationary with respect to the prostate during the matching process.

[**0044**] A preferred embodiment of the transrectal sheath **120** includes a 6-DOF external fiducial system **510** mounted on the outside of the sheath **120**, as shown in **FIG. 5**, that is mounted on the base of the TRUS stepper of the implant system. Inside the sheath **120** the TRUS probe **130** can move freely without mechanical interaction with the rectum, thus the location and shape of the prostate does not change due to scanning motion of the TRUS probe **130**. The sheath **120** may be made of thin plastic, mylar, polypropylene, polyethylene or similar material and fits tightly round the TRUS probe **130**. As shown in **FIG. 7**, gel material **710** substantially provides ultrasonic coupling between the sheath **120** and the rectum wall. The presence of sheath **120** causes some degradation of the acoustic signal, yet minimizing the thickness of the sheath and maintaining even distribution of the coupling gel mitigates this effect. As shown in **FIG. 9**, multiple air channels **910** substantially provide equalized air pressure in the sheath **120** during scanning motion of the TRUS probe **130**.

[**0045**] The fiducial pattern **510** on the outer surface of the sheath **120** may contains a suitable combination of straight lines, helices, and ellipses formed by 1 mm thick Tantalum wire, as shown in **FIG. 9**. Other materials with good

visibility under X-ray illumination, such that it makes a good X-ray contrast material, may be used in place of Tantalum. In order to determine the location of fiducials **510** in C-arm **110** space, the relative pose of the X-ray images must be known. The mechanical encoders supplied on the C-arm **110** are not always reliable. The fiducial system **510**, which is preferably precision-machined, that is rigidly fixed in the field of X-ray enables the determination of the relative pose of the multiple X-ray images.

[**0046**] In summary, the fiducials on the sheath provide common coordinate system for the individual X-ray shots. At the same time, the sheath is rigidly mounted on the base of the stepper and the motion of the TRUS probe is encoded relative to the stepper base, so there is a known spatial relationship between the TRUS probe and the fiducials at any time. Therefore, the fiducials on the sheath provide a common reference coordinate system for both X-ray and the TRUS images. This frame of reference is considered to be sufficiently stationary with respect to the prostate during a registration session typically involving the acquisition of multiple X-ray shots and a TRUS volume. The fiducial lines can be auto-segmented, as shown in **FIG. 9**. Altogether, using rigidly mounted fiducials for pose encoding appears to be inherently reliable, robust, simple, and inexpensive.

[**0047**] In seed matching step **240**, reconstructing implanted seeds is complicated by a large number of seeds (sometimes as many as 150) are confined in a small volume (as small as a walnut), overlapping one another in an apparent disorder. The X-ray images may also be very noisy, especially in the lateral direction where the pelvic and femur bones create a strong heterogeneous shadow over the seeds. Preferably, no more than three X-ray images are taken in one sweep plane.

[**0048**] The data system software **155** issues instructions to implement a technique that draws heavily on prior information from the TRUS-based implant plan and from earlier seed matching and reconstruction sessions. Having established 3D registration between X-ray and TRUS, the data system software **155** transfers spatially registered information from the TRUS space to X-ray space to assist seed segmentation and matching, by recognizing previously reconstructed seeds.

[**0049**] Method 1: Certain commercially available TRUS-based treatment planning systems, such as Interplant® made by CMS Burdette Medical Systems of Urbana-Champaign, Ill., have the capability of spatially locating an inserted needle. Although there is some tissue deformation, a good estimation is provided regarding where the seeds will end up in the prostate. By projecting the location of the needle forward onto the 2D X-ray pictures, a reasonably confined area is defined where these new seeds are supposed to show up in X-ray. Consequently, the data system software **155** can label clusters of previously implanted old seeds that could not have come from the newly implanted needles the data system software **155** updates their 3D locations and then excludes those from the seed matching process. When a needle is retracted from the prostate, it leaves the seeds behind along a slightly bent trajectory. Based on observations of actual implants, the bending and perturbation of seeds from the ideal curvilinear trajectory may be statistically modeled by the the data system software **155**. Using this estimate in confining the newly implanted seeds can improve the efficacy of elimination of false candidates.

[**0050**] Method 2: It may be assumed that seeds implanted by the last fluoroscopy session have not migrated substantially within the prostate since then. By projecting the location of these previously located seeds forward onto the 2D X-ray pictures, the data system software **155** can obtain a reasonably confined area, where they are supposed to show up in the new X-ray images, then update their 3D locations and then exclude those from the seed matching process, as described above in Method 1.

[**0051**] Method 3: If the prostate did not move between imaging sessions, then subtracting the previous image from the new image taken in the same C-arm **110** pose would show the newly derived seed locations and nothing else. In reality, the prostate moves somewhat between imaging sessions and the C-arm **110** pose is generally not precisely repeatable, but still a large portion of previously implanted seeds can be excluded from the matching problem on this basis. The data system software **155** can apply the images to the processing pipeline **220** and perform deformable mapping using information that is mutual between the images.

[**0052**] After seed matching **240** is complete, the data system software **155** may transform the location of seeds to TRUS space, their three-dimensional dose cloud may be computed and analyzed by the Interplant® system. The number of seeds found is likely to be different from the actual number of implanted seeds, so the activity of seeds will be adjusted so that the analysis shows the distribution of truly implanted dose. Finally, the remainder of the treatment plan is updated, in order to maintain to maintain optimal dose coverage of the prostate. For visual evaluation of the registration, fiducial objects and other reconstructed structures may be projected back to ultrasound space and superimposed in the 3D view provided by the Interplant® system. Although our present goal is to achieve intra-operative seed matching and registration, this method could be extended to post-operative care. In this approach, the last available implant plan would be projected onto post-operative images and the individual seeds would be matched. The data system software **155** may repeat imaging sessions regularly, over an expanded period of time. As a result, it is possible to track the path of each individual seed, which could provide an insight to how the prostate changes shape, volume, and pose over time. Having collected data from a sufficiently large number of patients, the data system software **155** may predict statistical motion of seeds with respect to the relevant anatomy. This may prove to be helpful in understanding the process of post-operative edema, a crucially important issue in prostate brachytherapy. The efficacy of projecting prior information to new X-ray images can be greatly facilitated by synchronizing the insertion sequence with the X-ray poses, so that the newly inserted seeds are the least likely obscure each other. This condition can be easily met if the implant is executed by rows of needles and we perform C-arm imaging after every row.

[**0053**] It will be apparent to those skilled in the art that various modifications and variation can be made in the present invention without departing from the spirit or scope of the invention. Thus, it is intended that the present invention cover the modifications and variations of this invention provided they come within the scope of the appended claims and their equivalents.

What is claimed is:

1. A system for registering ultrasound and fluoroscopy data comprising:

a fluoroscope;

a sheath having fiducial marks disposed on a portion of its outer surface;

an ultrasound probe insertable into the sheath;

a computer; and

a computer readable medium encoded with a program for registering a first set of data acquired by the ultrasound probe with a second set of data acquired by the fluoroscope.

2. The system of claim 1, wherein the ultrasonic probe includes a stepper.

3. The system of claim 1, wherein the fiducial marks comprise Tantalum.

4. The system of claim 1, wherein the fiducial marks comprise a wire including a thickness of substantially 1 mm.

5. The system of claim 1, wherein the fluoroscope is a C-arm fluoroscope comprising an image intensifier.

6. The system of claim 1, wherein the sheath comprises a thin plastic.

7. The system of claim 1, further comprising a gel material disposed between the sheath and the ultrasound probe.

8. A method for registering ultrasound to fluoroscopy comprising the steps of:

calibrating a fluoroscope;

acquiring ultrasound data using an ultrasound probe;

acquiring fluoroscopy data from the fluoroscope;

registering the ultrasound data to the fluoroscopy data to create a set of registered data;

identifying at least one radiation seed in the registered data; and

computing a radiation dose corresponding to the at least one radiation seed.

9. The method of claim 8, wherein the step of calibrating the fluoroscope comprises the steps of:

attaching a dewarping plate having a bead pattern to the fluoroscope;

acquiring calibration data from the fluoroscope;

correlating the calibration data to the bead pattern;

determining a transformation corresponding to the correlating; and

aligning the calibration data to the bead pattern.

10. The method of claim 8, wherein the step of acquiring fluoroscopy data comprises the steps of:

acquiring an image from the fluoroscope;

dewarping the image;

reducing noise in the image;

normalizing the image;

removing background from the image;

thresholding the image; and

pre-labeling the image.

* * * * *

专利名称(译)	将超声波注册到荧光检查以实时辐射植入程序的优化		
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[标]申请(专利权)人(译)	FICHTINGER GABOR MUSTUFA TABISH WYROBEK KEENAN BURDETTE权证		
申请(专利权)人(译)	FICHTINGER GABOR MUSTUFA TABISH WYROBEK KEENAN BURDETTE E. C.		
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摘要(译)

经直肠超声引导经会阴低剂量率近距离放射治疗已成为低风险前列腺癌的最终治疗方法之一。超声波一直是引导植入针针对前列腺解剖结构的极好工具，但是它们在前列腺释放后不能可靠地显示放射性种子的位置。术中C臂透视可以显示植入的种子，但它不能检测前列腺解剖。这两种互补模式的术中融合通过允许随着手术过程中的过程进行实时优化近距离放射治疗植入物而提供显着的临床益处。公开了一种用于减轻该问题的系统和方法，并且提供通过透视所见的种子的登记，其具有通过经直肠超声可视化的活体前列腺解剖结构。