



US012387395B2

(12) **United States Patent**
Helm et al.

(10) **Patent No.:** **US 12,387,395 B2**

(45) **Date of Patent:** **Aug. 12, 2025**

(54) **SYSTEM AND METHOD FOR ARTIFACT
REDUCTION IN AN IMAGE**

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(*) Notice: Subject to any disclaimer, the term of this
patent is extended or adjusted under 35
U.S.C. 154(b) by 0 days.

(21) Appl. No.: **18/464,537**

(22) Filed: **Sep. 11, 2023**

(65) **Prior Publication Data**

US 2023/0419565 A1 Dec. 28, 2023

Related U.S. Application Data

(63) Continuation of application No. 17/493,208, filed on
Oct. 4, 2021, now Pat. No. 11,756,242, which is a
(Continued)

(51) **Int. Cl.**
G06T 11/00 (2006.01)
A61B 6/00 (2006.01)
(Continued)

(52) **U.S. Cl.**

CPC **G06T 11/006** (2013.01); **A61B 6/5282**
(2013.01); **A61B 34/10** (2016.02);
(Continued)

(58) **Field of Classification Search**

CPC A61B 34/10; A61B 90/37; A61B 6/5282;
A61B 2090/376; A61B 2090/3764;
(Continued)

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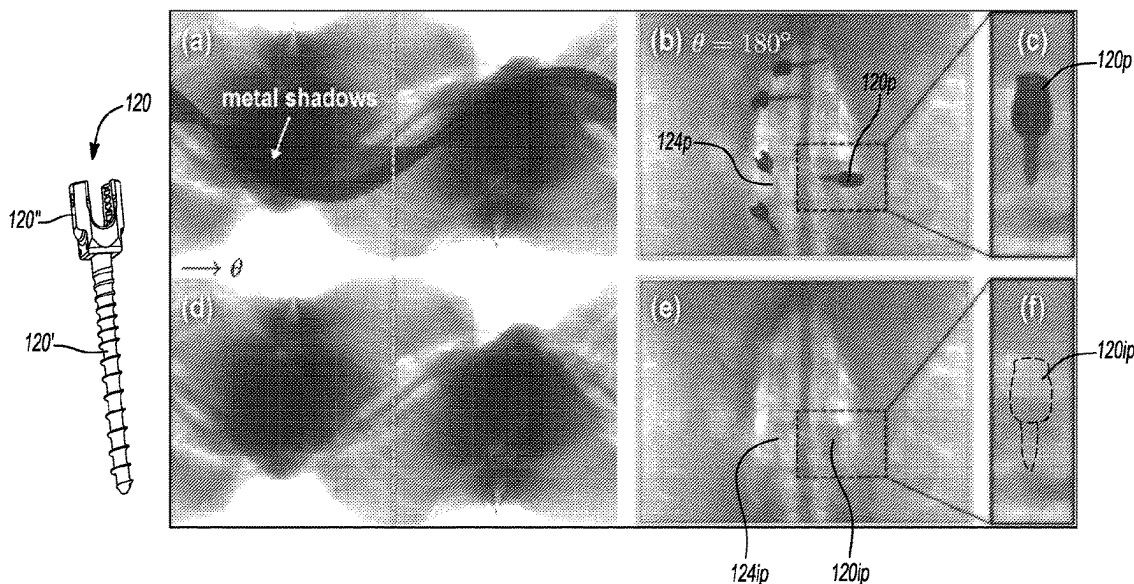
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(57) **ABSTRACT**

Selected artifacts, which may be based on distortions or
selected attenuation features, may be reduced or removed
from a reconstructed image. Various artifacts may occur due
to the presence of a metal object in a field of view. The metal
object may be identified and removed from a data that is
used to generate a reconstruction.

17 Claims, 6 Drawing Sheets



Related U.S. Application Data

continuation of application No. 16/375,292, filed on Apr. 4, 2019, now Pat. No. 11,138,768.

- (60) Provisional application No. 62/654,038, filed on Apr. 6, 2018.

(51) **Int. Cl.**

A61B 34/10 (2016.01)

A61B 90/00 (2016.01)

G06T 5/70 (2024.01)

G06T 5/77 (2024.01)

G06T 7/60 (2017.01)

(52) **U.S. Cl.**

CPC *A61B 90/37* (2016.02); *G06T 5/70* (2024.01); *G06T 5/77* (2024.01); *G06T 7/60* (2013.01); *A61B 2034/102* (2016.02); *A61B 2090/376* (2016.02); *A61B 2090/3764* (2016.02); *G06T 2207/10124* (2013.01); *G06T 2207/20081* (2013.01); *G06T 2207/20182* (2013.01); *G06T 2207/20221* (2013.01); *G06T 2207/30052* (2013.01)

(58) **Field of Classification Search**

CPC ... *A61B 2034/102*; *G06T 5/002*; *G06T 5/005*; *G06T 5/70*; *G06T 5/77*; *G06T 11/006*; *G06T 7/60*; *G06T 2207/10024*; *G06T 2207/10124*; *G06T 2207/20221*; *G06T 2207/20081*; *G06T 2207/20182*; *G06T 2207/30052*

See application file for complete search history.

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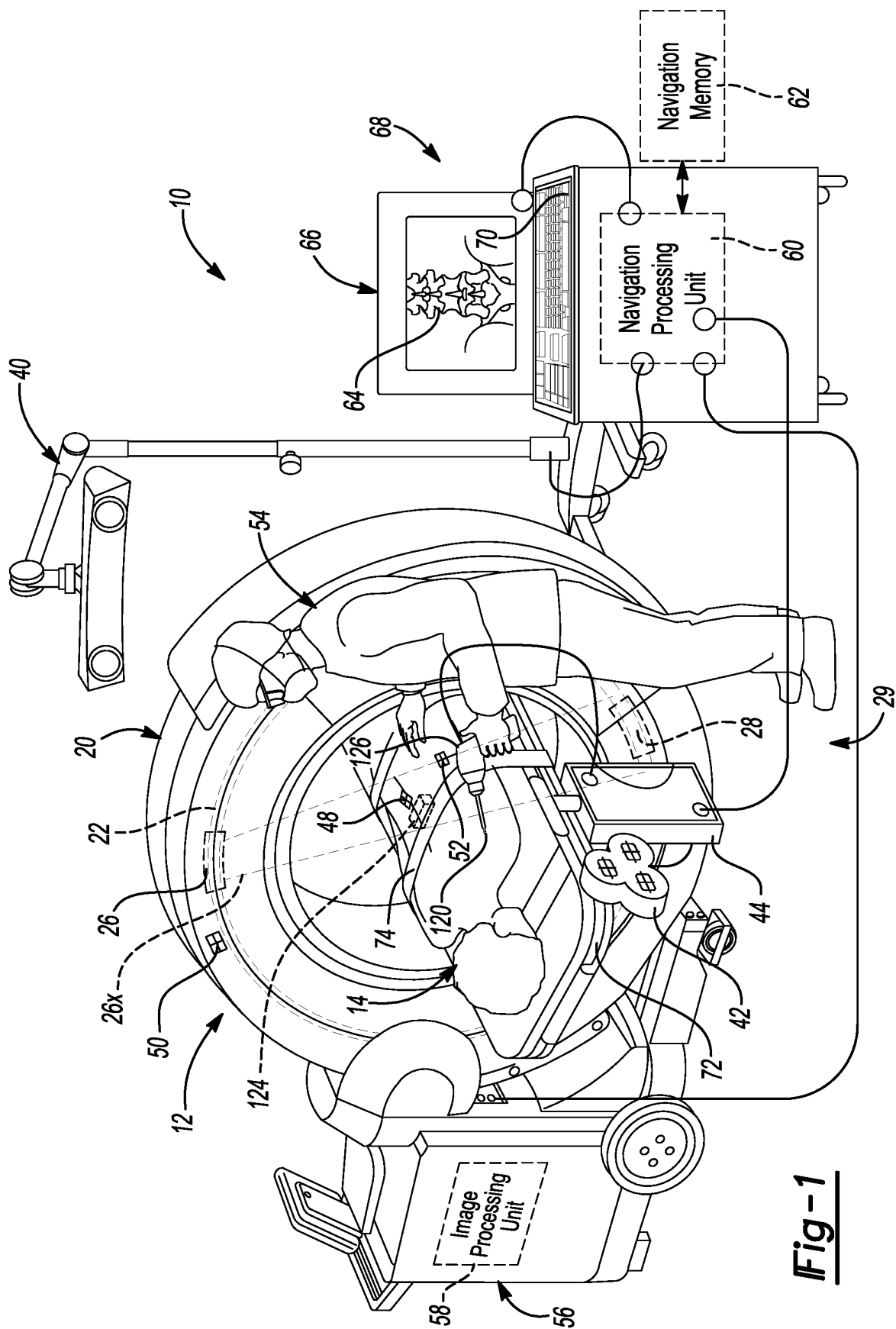
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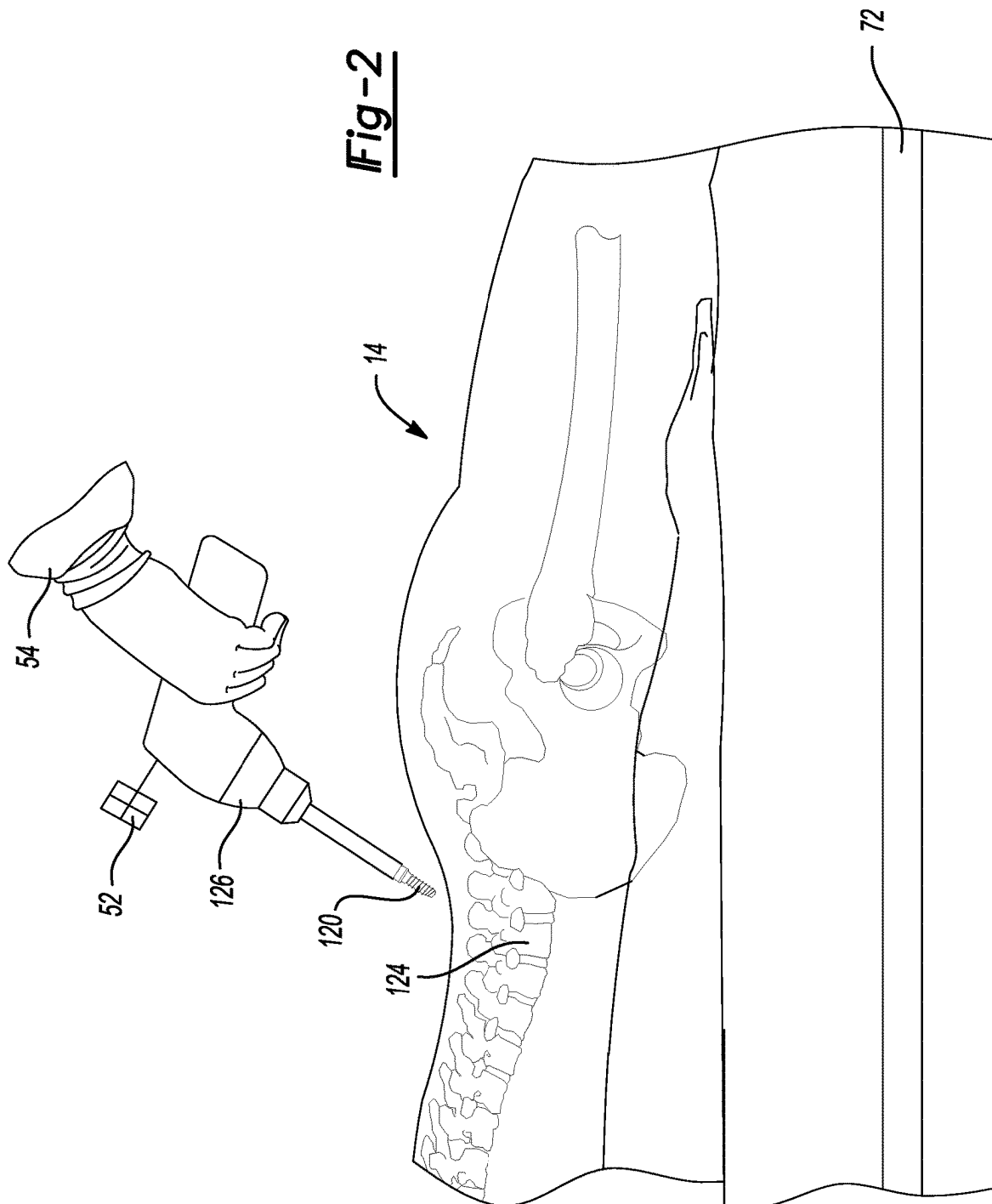
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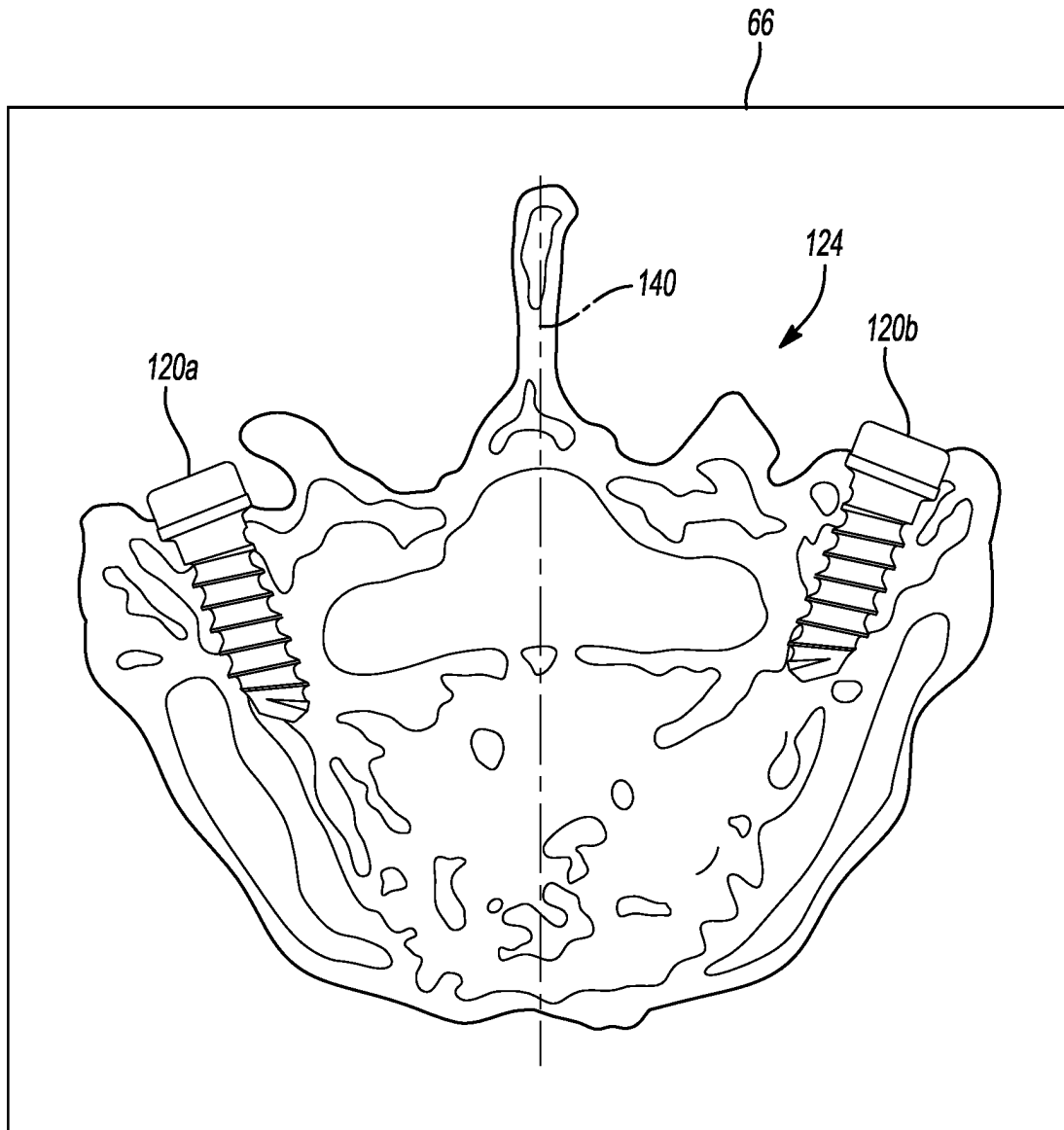
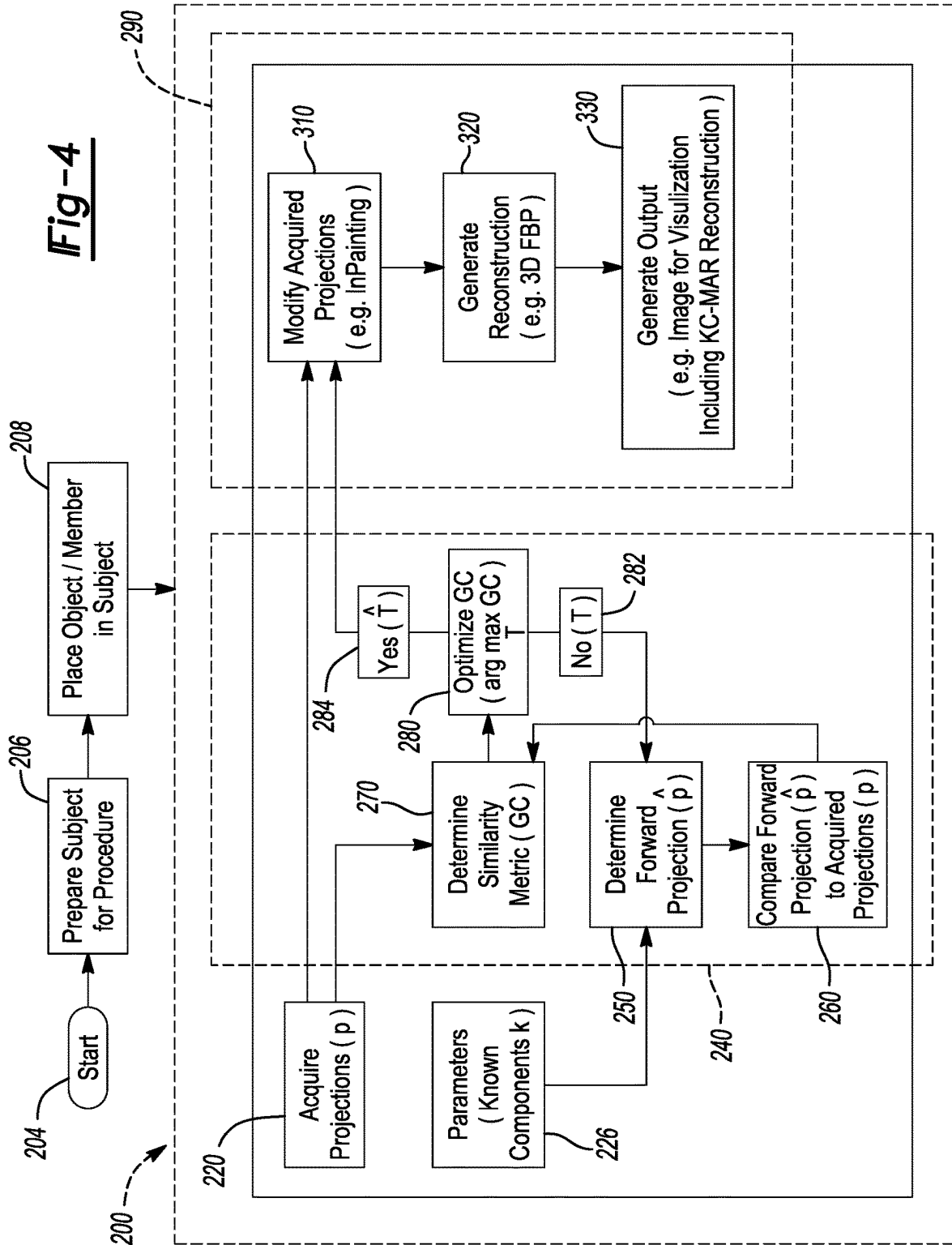


Fig-3

Fig-4



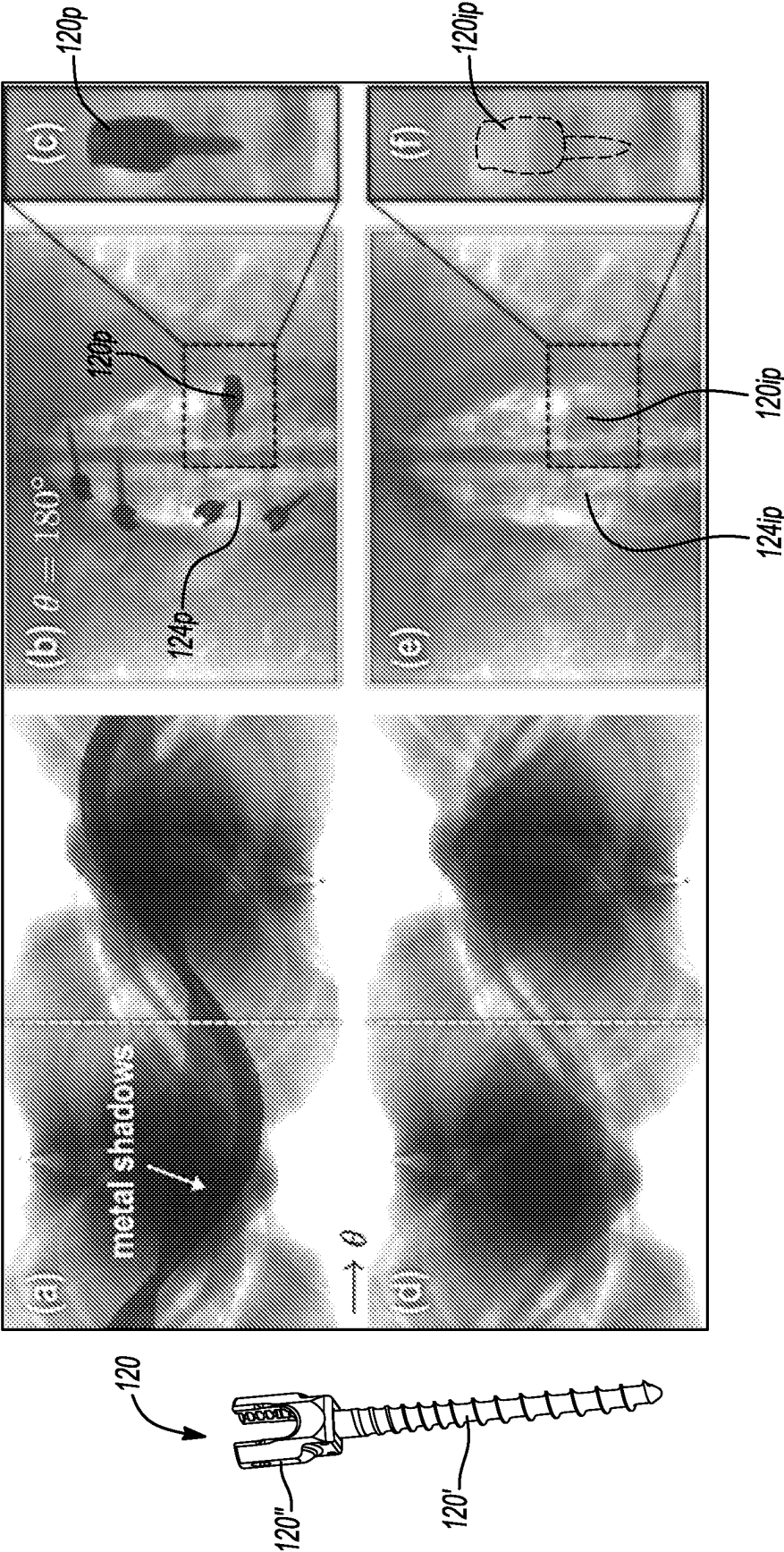
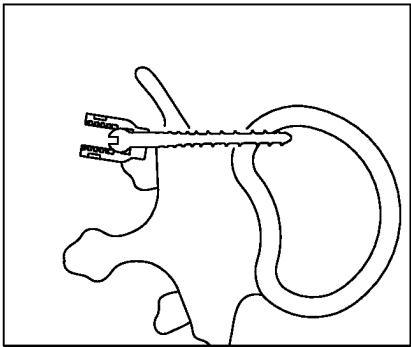
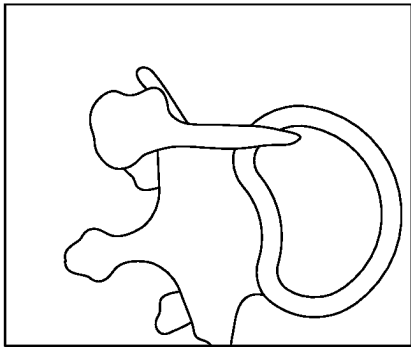
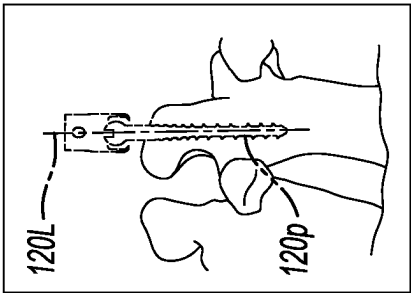
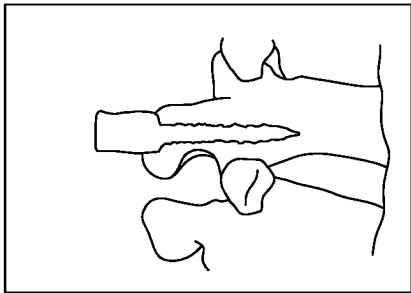
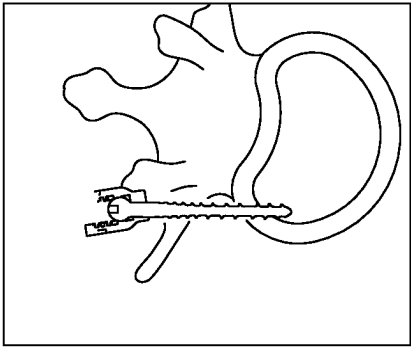
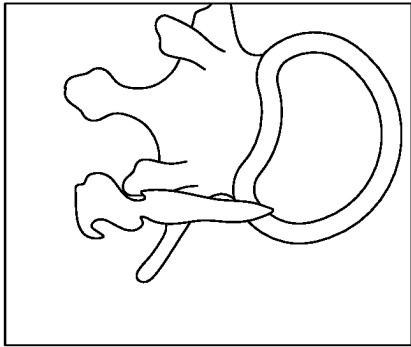
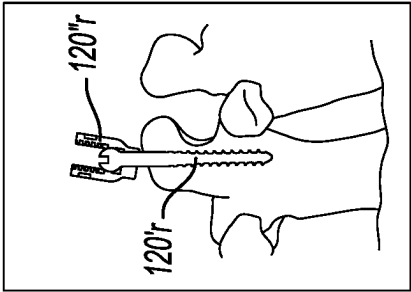
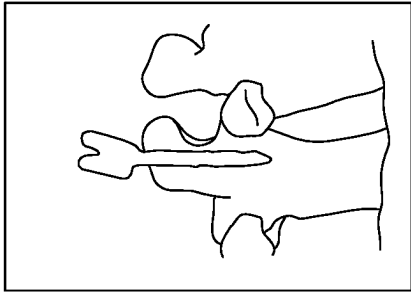


Fig-5

L4 Right



L4 Left



FBP with KC-MAR

A

B

Fig-6

SYSTEM AND METHOD FOR ARTIFACT REDUCTION IN AN IMAGE

CROSS-REFERENCE TO RELATED APPLICATIONS

This application is a continuation of U.S. patent application Ser. No. 17/493,208, filed Oct. 4, 2021, which claims the benefit of U.S. patent application Ser. No. 16/375,292, filed on Apr. 4, 2019, which claims the benefit of U.S. Provisional Application No. 62/654,038, filed on Apr. 6, 2018. The entire disclosure of the above applications are incorporated herein by reference.

GOVERNMENT LICENSE RIGHTS

This invention was made with government support under R01-EB-017226 awarded by National Institutes of Health. The government has certain rights in the invention.

FIELD

The subject disclosure relates to displaying an image, and particularly to correction or reduction of artifacts or distortion.

BACKGROUND

This section provides background information related to the present disclosure which is not necessarily prior art.

When acquiring image data or images of a selected object, such as a human patient, various artifacts or distortions may occur. For example, when acquiring X-ray based images of a subject, certain materials may interfere with X-rays in a manner disproportionate or different than other materials, such as tissue of a subject. For example, metal or polymer objects may attenuate and/or scatter X-rays in a manner different from the surrounding tissue of the subject. These effects of the non-tissue material may cause distortion or artifacts in the images generated with the acquired image data. The distortions may be amplified or easily viewed after a reconstruction, such as a three-dimensional reconstruction, based upon the two-dimensional projections of the subject. Correction of the distortions, therefore, may be selected in an attempt to generate images for viewing that are minimally distorted or without distortion.

SUMMARY

This section provides a general summary of the disclosure, and is not a comprehensive disclosure of its full scope or all of its features.

A subject may be imaged with a selected imaging system. In various embodiments, an X-ray imaging system may be used to acquire image data of the subject. The X-ray image data may be acquired according to various techniques, such as with an X-ray system that creates or acquires one or more two-dimensional projections. The two-dimensional projections may be used to generate a three-dimensional reconstruction. Accordingly, one or more two-dimensional projections may be acquired, such as in a sequence, to generate the three-dimensional reconstruction.

In acquiring the image data of the subject, the X-rays are attenuated by the material through which the X-rays pass from an X-ray source to a detector. The X-rays emitted from a source may be in a spectrum around an average or within a selected boundary. Accordingly, an X-ray source emitting

X-rays at a selected energy, such as 120 kilo-electronvolts (keV), may actually be X-rays that are emitted at a range or in a spectrum around this amount. Accordingly, the attenuation may be different for each of the particular X-ray energies.

Further, similar materials may attenuate X-rays in a similar manner, such as soft tissue or hard tissue of a subject. Various non-tissue materials, such as metal objects (e.g. implants, instruments, etc.) may attenuate X-rays in a substantially different manner. For example, non-tissue materials may attenuate and/or reflect or scatter X-rays away from the item in the field of view (FOV) of the X-ray source or detector. It is understood that non-tissue materials may include items or materials other than metal, such as polymers, composite materials, or the like.

An image, such as a 2D projection, may include a plurality of effects (e.g. distortions) due to various non-tissue items within the FOV. The distortion may generate artifacts that are accumulated or magnified when generating a reconstruction based on a plurality of projections. Accordingly, removal of the distortions and the projections and inclusion of known effects of the selected components or items in the field of view may be inpainted to the rejections which are then used for the reconstruction. A reconstruction may include information based upon the facts of known components within an X-ray system to reduce or eliminate distortion and artifacts and a reconstruction.

Further areas of applicability will become apparent from the description provided herein. The description and specific examples in this summary are intended for purposes of illustration only and are not intended to limit the scope of the present disclosure.

DRAWINGS

The drawings described herein are for illustrative purposes only of selected embodiments and not all possible implementations, and are not intended to limit the scope of the present disclosure.

FIG. 1 is an environmental view of an operating theatre including an optional imaging system and a navigation system;

FIG. 2 is a schematic illustration of an instrument for inserting an implant into a patient;

FIG. 3 is a schematic illustration of an implant in a subject;

FIG. 4 is a flowchart of a process for reducing artifacts or distortion in an image;

FIG. 5 is an illustration of a projection without and with inpainting; and

FIG. 6 is an illustration of a reconstruction without and with inpainting.

Corresponding reference numerals indicate corresponding parts throughout the several views of the drawings.

DETAILED DESCRIPTION

Example embodiments will now be described more fully with reference to the accompanying drawings.

With reference to FIG. 1 and FIG. 2, a diagram illustrating a procedure area is shown. The procedure area may include a surgical suite. Placed for use in the surgical suite may be a navigation system 10 that can be used for various procedures. The navigation system 10 can be used to track the location of an item, such as an implant or an instrument (as discussed herein), relative to a subject, such as a patient 14. It should further be noted that the navigation system 10 may

be used to navigate any type of instrument, implant, or delivery system, including: guide wires, arthroscopic systems, orthopedic implants, spinal implants, deep brain stimulation (DBS) leads, cardiac pacing leads, ablation instruments, etc. Moreover, the instruments may be used to navigate or map any region of the body. The navigation system 10 and the various tracked items may be used in any appropriate procedure, such as one that is generally minimally invasive or an open procedure.

The procedure room may further include an imaging system 12. The imaging system 12 may, in various embodiments, interface with the navigation system 10. The imaging system 12 may be used to acquire pre-operative, intra-operative, post-operative, or real-time image data of the patient 14. In various embodiments, the imaging system 12 may be used to acquire images at a selected time for confirmation and/or determining progress of a selected portion of a procedure. It will be understood by one skilled in the art, any appropriate subject can be imaged and any appropriate procedure may be performed relative to the subject. The subject 14 may be a human patient and the procedure may be a surgical procedure, such as an implantation of a device (e.g. a screw, lead, etc.).

Exemplarily illustrated in FIG. 1, the imaging system 12 comprises an O-Arm® imaging device sold by Medtronic Navigation, Inc. having a place of business in Louisville, Colorado, USA. The imaging device 12 may have a generally annular gantry housing 20 that encloses an image capturing portion 22. The image capturing portion 22 may include an x-ray source or emission portion 26 and an x-ray receiving or image receiving portion 28 (also referred to as a detector to detect the x-rays having past the subject 14) located generally or as practically possible 180 degrees from each other within the gantry housing 20. The x-ray emitting portion 26 may emit or generate a cone beam 26x of x-rays. The x-rays in the cone beam 26x will generally encompass a field-of-view, which may include at least a portion of the subject 14, such as a vertebra 124. The detector 28 may detect the x-rays that have passed through the subject 14. The x-rays may, however, be attenuated and/or scattered due to the subject or items in the cone beam 26x. Further, the detector may detect and/or generate two-dimensional (2D) image data or projections.

In various embodiments, the x-ray source or emission portion 26 and the x-ray receiving or image receiving portion 28 may be mounted on a rotor (not illustrated) relative to a track (not illustrated) within the generally annular gantry housing 20. The image capturing portion 22 can be operable to rotate 360 degrees during image acquisition. The image capturing portion 22 may rotate around a central point or axis, allowing image data of the patient 14 to be acquired from multiple directions or in multiple planes. The imaging system 12 can include those disclosed in U.S. Pat. Nos. 7,188,998; 7,108,421; 7,106,825; 7,001,045; and 6,940,941; all of which are incorporated herein by reference. The imaging system 12, however, may also include or be replaced with other imaging systems including C-arm fluoroscopic imaging systems, computer tomography (CT) imaging systems, etc. which can also generate three-dimensional views of the patient 14.

The position of the image capturing portion 22 can be precisely known relative to any other portion of the imaging device 12. In addition, as discussed herein, the precise knowledge of the position of the image capturing portion 22 can be used in conjunction with a tracking system 29 to determine the position of the image capturing portion 22 and the image data relative to the subject, such as the patient 14,

which is tracked. For example a patient tracking device 48 may be placed on the patient 14 to track the patient 14.

The tracking system 29 can include various portions that are associated or included with the navigation system 10. The tracking system 29 can also include a plurality of types of tracking systems including an optical tracking system that includes an optical localizer 40 and/or an electromagnetic (EM) tracking system that can include an EM localizer 42. The optical localizer 40 may “view” or optically track trackable portions (tracking devices) with cameras. The EM localizer 42 may generate a field and a trackable portion (e.g. EM tracking device) may sense the field to determine a location relative to another tracking device in the field. Various tracking devices, including those discussed further herein, can be tracked with the tracking system 29 and the information can be used by the navigation system 10 to allow for a display of a position of an item. Briefly, tracking devices, such as a patient tracking device 48, an imaging device tracking device 50, and an instrument tracking device 52, allow selected portions of an operating theater to be tracked relative to one another with the appropriate tracking system 29, including the optical localizer 40 and/or the EM localizer 42.

It will be understood that any of the tracking devices 48, 50, 52 can be optical or EM tracking devices, or both, depending upon the tracking localizer used to track the respective tracking devices. It will be further understood that any appropriate tracking system can be used with the navigation system 10. Alternative tracking systems can include radar tracking systems, acoustic tracking systems, ultrasound tracking systems, and the like.

An exemplarily EM tracking system can include the STEALTHSTATION® AXIEM™ Navigation System, sold by Medtronic Navigation, Inc. having a place of business in Louisville, Colorado. Exemplary tracking systems are also disclosed in U.S. Pat. No. 8,644,907, issued Feb. 4, 23012, titled “Method And Apparatus For Surgical Navigation”; U.S. Pat. No. 7,751,865, titled “Method And Apparatus For Surgical Navigation”, issued Jul. 6, 2010; U.S. Pat. No. 5,913,820, titled “Position Location System,” issued Jun. 22, 1999 and U.S. Pat. No. 5,592,939, titled “Method and System for Navigating a Catheter Probe,” issued Jan. 14, 1997, all incorporated by reference herein.

Further, for EM tracking systems it may be necessary to provide shielding or distortion compensation systems to shield or compensate for distortions in the EM field generated by the EM localizer 42. Exemplary shielding systems include those in U.S. Pat. No. 7,797,032, titled “Method and system for navigating a catheter probe in the presence of field-influencing objects”, issued on Sep. 14, 2010 and U.S. Pat. No. 6,747,539, titled “Patient-shielding and coil system”, issued on Jun. 8, 2004, all of which are incorporated herein by reference. Distortion compensation systems can include those disclosed in U.S. Pat. No. 6,636,757, titled “Method and apparatus for electromagnetic navigation of a surgical probe near a metal object”, issued on Oct. 21, 2003, all of which are incorporated herein by reference.

With an EM tracking system, the EM localizer 42 and the various tracking devices can communicate through an EM controller 44. The EM controller can include various amplifiers, filters, electrical isolation, and other systems. The EM controller 44 can also control the coils of the localizer 42 to either emit or receive an EM field for tracking. A wireless communications channel, however, such as that disclosed in U.S. Pat. No. 6,474,341, entitled “Surgical Communication

Power System,” issued Nov. 5, 2002, herein incorporated by reference, can be used as opposed to being coupled directly to the EM controller 44.

It will be understood that the tracking system may also be or include any appropriate tracking system, including a STEALTHSTATION® TRIA®, TREON®, and/or S7™ Navigation System having an optical localizer, similar to the optical localizer 40, sold by Medtronic Navigation, Inc. having a place of business in Louisville, Colorado. Optical tracking systems may also include those disclosed in U.S. Pat. No. 8,010,177, Aug. 30, 2011, Intraoperative Image Registration”; U.S. Pat. No. 6,235,038, issued on May 22, 2001, titled “System For Translation Of Electromagnetic And Optical Localization Systems”, all incorporated herein by reference. Further alternative tracking systems are disclosed in U.S. Pat. No. 5,983,126, to Wittkamp et al. titled “Catheter Location System and Method,” issued Nov. 9, 1999, which is hereby incorporated by reference. Other tracking systems include an acoustic, radiation, radar, etc. tracking or navigation systems.

The imaging system 12 can include a support housing or cart 56. The imaging system 12 can further include a separate image processing unit 58 that can be housed in the cart 56. The navigation system 10 can include the navigation processing unit 60 that can communicate or include a navigation memory 62. The navigation member 62 may include any appropriate non-transitory memory including a random access memory, magnetic media drive, etc. Further, the navigation memory 62 may be integrated with the navigation processing unit 60 or remote from the navigation processing unit 60. The navigation processing unit 60 can receive information, including image data, from the imaging system 12 and tracking information from the tracking systems 29, including the respective tracking devices 48-52 and the localizers 40-42. Image data can be displayed as an image 64 on a display device 66 of a workstation or other computer system 68.

The workstation 68 can include appropriate input devices, such as a keyboard 70. It will be understood that other appropriate input devices can be included, such as a mouse, a foot pedal or the like. Further, the various processing units, as discussed above, may be incorporated into the workstation or computer system 68. Thus, the various inputs may be used by the user 54 to include commands to the system. Further, the navigation member 62 or other appropriate and/or similar memory may be used to transfer or for recall of information, such as image data and/or instructions for execution by the selected processing units. The various processing units, computers, and/or workstations may include internal or local memory and processing units. The processing units may include central processing units that are general computers that execute instructions to perform tasks on a chip. The processing units may also be specific circuits, such as application specific integrated circuits (ASIC). Accordingly, the processing units may be devices that receive information and execute instructions that are stored or received based on the information. Further, the memories may include transient and non-transient memory systems, such as random-access memory, volatile or non-volatile memory, etc.

The image processing unit 58 may process image data from the imaging system 12 and may transmit the image data, before or after selected processing, to the navigation processing unit 60. It will be further understood, however, that the imaging system 12 need not perform any image processing and it can transmit the image data directly to the navigation processing unit 60. Accordingly, the navigation

system 10 may include or operate with a single or multiple processing centers or units that can access single or multiple memory systems based upon system design. Moreover, the processed image data, as discussed herein, may be displayed on the display device 66 or any appropriate display device. Thus, the displayed images need not be displayed with a navigation system 10.

The patient 14 can be fixed onto a support 72, such as an operating table, but is not required to be fixed to the table 72. The table 72 can include a plurality of straps 74. The straps 74 can be secured around the patient 14 to fix the patient 14 relative to the table 72. Various apparatuses may be used to position the patient 14 in a static position on the operating table 72. Examples of such patient positioning devices are set forth in commonly assigned U.S. patent application Ser. No. 10/405,068, published as U.S. Pat. App. Pub. No. 2004/0199072, entitled “An Integrated Electromagnetic Navigation And Patient Positioning Device”, filed Apr. 1, 2003, which is hereby incorporated by reference. Other known apparatuses may include a Mayfield® clamp.

Also, the position (including three-dimensional location and orientation) of the patient 14 relative to the imaging system 12 can be determined by the navigation system 10 with the patient tracking device 48 and the imaging system tracking device 50. As discussed herein, the position (including three-dimensional location and orientation) relative to the patient 14 may be determined, at least in part, with images acquired of the patient 14. Accordingly, the position (including three-dimensional location and orientation) of the patient 14 relative to the imaging system 12 can be determined. The imaging system 12, such as the O-Arm® can know its position and be repositioned to the same position within about 10 microns. This allows for a substantially precise placement of the imaging system 12 and precise determination of the position of the imaging device 12. Precise positioning of the imaging portion 22 is further described in U.S. Pat. Nos. 7,188,998; 7,108,421; 7,106,825; 7,001,045; and 6,940,941; all of which are incorporated herein by reference. Generally, it may be selected to determine the position of the image data relative to the patient 14. For example, the position, including the orientation relative to the patient, of the image data may be used to determine a location of a portion of the patient 14.

Subject or patient space and image space can be registered by identifying matching points or fiducial points in the patient space and related or identical points in the image space. The imaging device 12, such as the O-Arm® imaging device sold by Medtronic Navigation, Inc., can be used to generate image data at a precise and known position. This can allow image data that is automatically or “inherently registered” to the patient 14 upon acquisition of the image data. Essentially, the position of the patient 14 is known precisely relative to the imaging system 12 due to the accurate positioning of the imaging system 12 relative to the patient 14. This allows points in the image data to be known relative to points of the patient 14 because of the known precise location of the imaging system 12.

Alternatively, manual or automatic registration can occur by matching fiducial points in image data with fiducial points on the patient 14. Registration of image space to patient space allows for the generation of a translation map between the patient space and the image space. According to various embodiments, registration can occur by determining points that are substantially identical in the image space and the patient space. The identical points can include anatomical fiducial points or implanted fiducial points. Exemplary

registration techniques are disclosed in U.S. Pat. No. 9,737, 235, issued Aug. 22, 2017, incorporated herein by reference.

In various embodiments, the navigation system 10 may be used to assist in performing a procedure. It is understood, however, that the navigation system 10 is not required. In various embodiments, a procedure may proceed without the navigation system. The procedure, however, may also use, alone or in combination with the navigation system 10, the imaging system 12, can be used to perform selected procedures. Selected procedures can use the image data generated or acquired with the imaging system 12. Further, the imaging system 12 can be used to acquire image data at different times relative to, such as during, the procedure. As discussed herein, image data can be acquired of the patient 14 subsequent to a selected portion of a procedure for various purposes, including confirmation of the portion of the procedure.

With continuing reference to FIG. 1, the imaging system 12 can acquire image data, such as projections of the subject 14. The projections may include 2D projections that are able to be displayed as 2D images. The imaging system 12 may also be used to generate or reconstruct three dimensional (3D) images of the patient 14. The patient 14 can be placed relative to the imaging system 12 to allow the imaging system 12 to obtain image data of the patient 14. To generate 3D image data, the image data can be acquired from a plurality of views or positions relative to the patient 14. The positions may be positions around the patient 14, such as separated by angles by movement of the detector 28 relative to the subject 14. Each position may be defined or referred to as an angle or theta (δ) position relative to the patient 14. The 3D image or image data of the patient 14 can be used alone or with other information to assist in performing a procedure on the patient 14 or an appropriate subject. It will be understood, however, that any appropriate imaging system can be used, including magnetic resonance imaging, computed tomography, fluoroscopy, etc. to acquire image data (including 3D image data) of the patient 14.

As discussed above, the imaging system 12 may include any appropriate imaging system, such as the O-Arm® Imaging System sold by Medtronic Navigation, Inc. The O-Arm® Imaging System can acquire images of the subject 14 by acquiring image data of the subject 14 that may include two-dimensional projections. The projections are acquired by emitting X-rays from the source 26 and detected at the detector 28. The projections may be displayed as two-dimensional images on the display device 66 and/or may be reconstructed into a three-dimensional image, such as the image 64, for display on the display device 66. The image, for example the reconstructed image 64, may include artifacts or distortion if various items are positioned within the field of view of the imaging system, such as within the cone of X-rays 26x emitted from the X-ray source 26 and detected at the detector 28. This distortion refers not only to the spatial distortion in the reconstructed image, but also includes distortion of the signal recorded by the detector—e.g., polyenergetic effects (beam hardening) associated with energy-dependent detector response, and “zero” data or electronic noise contribution (photon starvation effects). Distortions may be generated when various non-tissue elements or materials, such as a pedicle screw 120 that may be driven or moved with an instrument, such as a surgical motor 126, are within the X-ray cone 26x when the subject 14 imaged. For example, according to various embodiments, the pedicle screw 120 may be implanted into a vertebra 124 in the patient 14. It is understood that discussion herein to a single or plural vertebrae is merely exemplary and generally

a procedure maybe performed on any selected number of appropriate vertebrae. The pedicle screw 120 may be positioned in the vertebra 124 during a surgical procedure, as is generally understood in the art. The imaging system 12 may then be used to acquire images after placing the pedicle screw 120 in the subject 14, but prior to completing a procedure, such as placing a connection rod, or other selected portion of a procedure. Imaging the subject 14 while the pedicle screw 120 is in place, distortion may occur in the image projection that causes further distortion and/or artifacts in the image reconstruction 64 for display on the display device 66. According to various embodiments, therefore, a process may be performed, such as by instructions executed by the navigation processing unit 60 and/or the imaging processing unit 58 or other appropriate processor, to assist in removing the artifacts and/or accounting for the artifacts for displaying a non-distorted image.

The process of removing or accounting for the distortion in the images may be initiated by accounting for or determining artifacts or distortion in a projection due to a selected item, such as an object including an implant or instrument. The selected item may then be replaced in projections prior to a reconstruction, where the replacement can be performed according to a variety of inpainting methods. The process may be developed into an algorithm and instructions based thereon that are stored in a memory, such as the navigation memory 62 or other appropriate memory, and executed by one or more processors or processing units, including those discussed above. A reconstruction with the correction or artifact reduction may then be displayed on the display device 66 as the image 64.

As discussed above, images may be generated and viewed on the display device 66. The acquired images are acquired with the imaging system 12, which may include the O-Arm® Imaging System, at a selected time. For example, the images may be acquired during a selected procedure, such as an operative procedure on the subject 14. In various embodiments, the operative procedure may include positioning an implant into the patient 14. The implant may include the pedicle screw 120, or more than one pedicle screw 120, positioned in one or more vertebrae 124. As illustrated, exemplary, in FIG. 3, first and second pedicle screws 120a and 120b are schematically illustrated positioned in the vertebra 124 relative to a midline 140. The midline 140 may be displayed on the display device 66 relative to an image, such as the image 64, or may be exemplary of a midline extending from a posterior to an anterior portion of the patient 14. After positioning the pedicle screw 120 in the patient 14, such as in the vertebra 124, the imaging system 12 may be used to acquire image data of the patient 14, including the vertebra 124 having the pedicle screws 120a and 120b positioned therein. As illustrated in FIG. 3, the pedicle screw 120 may be positioned in the vertebra 124 in any appropriate manner, such as with the drill motor or tool 126 by the user 54.

Acquiring image data of the subject 14 after positioning the pedicle screw 120 in the patient may be performed for any appropriate purpose, such as confirmation of positioning the pedicle screw 120 in a selected or predetermined position. During image data acquisition, particularly after the pedicle screws 120a, 120b are placed, distortion or artifacts in the image 64 may hinder or slow confirmation of the correct or accurate position of the pedicle screw 120 in the vertebrae 124. Accordingly, as discussed further herein, a selected process may be used to reduce and/or correct for distortion or errors in the acquired image data before or prior to generating the image 64, which may include a reconstruction

tion such as a three-dimensional reconstruction, based upon one or more projections acquired of the subject **14** with the imaging system **12**.

Turning reference to FIG. **4**, a process or flowchart **200** illustrates an efficient process for removing or accounting for artifacts in projections and later reconstructions, such as the image **64**, of the subject **14** for viewing by the user **54**. The process **200** allows for an efficient, including lower computational time and/or necessary resources, to generate the image **64** for viewing by the user **54** without artifacts and/or showing a clear or high contrast edge of a selected item. In various embodiments, the selected item may include the pedicle screw **120** positioned in the vertebra **124**. In various embodiments, computational time may be lowered to less than about three minutes, including less than about two minutes for generating a reconstruction with inpainted objects, as discussed herein, with the process **200**. The removal of the artifacts may allow for a more precise and clear image and/or distinction between the selected item, such as the pedicle screw **120** and in surrounding areas, such as the vertebra **124**. It will be understood that the positioning of the pedicle screw **120** in the vertebrae **124** is exemplary and contrast and/or distortions may occur between any differing materials. Accordingly, discussion of the pedicle screw **120** relative to the vertebrae **124**, herein, is exemplary unless specifically identified otherwise.

Also, it is understood that the pedicle screw **120** may be formed of one or more selected material (e.g. metal or metal alloy) that affects X-rays when generating X-ray image data in a manner to cause distortion or artifacts relative to the X-rays that generate the image data of the vertebrae **124**. Therefore the process **200** may be used to remove or account for the artifacts in the image data when generating the image **64** for display with the display device **66**. It is further understood that the pedicle screw **120**, or other selected item, may be formed of or include a plurality of materials.

With continued reference to FIG. **4** the process **200** is understood to be an image analysis and/or reconstruction process **200** that may be performed alone and/or in part of a selected procedure, such as a surgical procedure including positioning the pedicle screw **120** in the vertebrae **124**. The process **200**, therefore, may also be an algorithm, or include algorithmic portions, that may be executed by a selected processor or processor system, such as the imaging processing unit **58** discussed above. It is understood, however, that any appropriate processing system may be used to execute the process **200** to generate an image for display on the display device **66**.

The process **200** may be incorporated into other procedures, such as a surgical procedure including placing a selected item, such as the pedicle screw **120**. The selected procedures, therefore, may include starting a procedure in block **204** and then preparing a subject for procedure in block **206**. Preparing the subject for procedure in block **126** may include predetermining or selecting a location for the pedicle screw **120**, or other appropriate implant, within the subject **14**. Such preplanning or predetermination may include acquiring preoperative image data of the subject **14** and planning a position for the pedicle screw **120** in the vertebra **124**. Further, preparing the subject may include moving the subject **14** into the operating theatre on the support **72**, forming an incision of the subject **14**, positioning instruments relative to the subject **14**, or other appropriate procedure steps.

After preparing a subject for a procedure in block **206**, placing a selected item in the subject in block **208** may be performed. As discussed above, exemplary embodiments

may include positioning the pedicle screw **120** in the vertebra **124**, as illustrated in FIG. **2**. The pedicle screw **120** may be any appropriate pedicle screw such as a CD Horizon® Solara® or Legacy® spinal or pedicle screws, sold by Medtronic, Inc. having a place of business in Minnesota, USA.

With additional reference to FIG. **5**, the pedicle screw **120** may include selected portions, such as a first shank portion **120'** that is positioned within the vertebrae and/or a second portion **120''**, such as a head or gimbal head portion that is movable relative to the shank. It is understood, however, that the pedicle screw **120** may be any appropriate type of pedicle screw positioned in the patient. It is further understood that the selected item positioned in block **208** need not be a pedicle screw, but may be any appropriate type of item positioned relative to the subject **14**, or any other appropriate portion. Generally the selected item, such as the pedicle screw **120**, is formed of a different material (e.g. metal) than the portion in which it is placed, such as the vertebrae **124** (e.g. bone tissue).

After positioning the selected item in block **208**, the process **200** may be used to assist in generating a selected or appropriate reconstruction for viewing by the user **54**. The process **200** may include or start with the acquisition of projections including the selected items in block **220**. The acquisition of projections in block **220** may include the acquisition of two-dimensional projections of the subject **14**. The acquisition may be a real time image data acquisition, recalling of image data, or a combination of both. With continuing reference to FIG. **5**, projections that are acquired may include those shown in parts (a), (b), and (c). The projections may include the vertebra **124** and the pedicle screw **120**.

As illustrated in FIG. **5**, the pedicle screw **120** is schematically or exemplary illustrated. The pedicle screw **120** may include various features such as the shank **120'** the head **120''** and other portions. The shank **120'** may include a thread or other feature to allow for purchase or connection with the vertebra **124**. The head **120''** may include additional features, such as a U-shape and be moveable relative to the shank **120'**. The head **120''** may then be fixed to the shank **120'** in a selected manner, such as with a set screw or a nut. It is understood that the shank **120'** and the head **120''** may be formed of the same material or a different material, such as two different metal alloys or one metal and one polymer.

Nevertheless, the pedicle screw **120** may be positioned in the vertebra **124** and images may be acquired of the vertebrae **124** and the screw **120** positioned therein. For example, as illustrated in FIG. **5**, part (b) one or more of the pedicle screws **120** may be positioned may be positioned in the patient, such as the vertebra **124**. As illustrated in FIG. **5** the image of the vertebra **124p** is shown and the image of the pedicle screw **120p** is shown. The projection may include a two-dimensional projection generated with the imaging system **12** in the field of view. It is understood, however, a plurality of projections, for example including about 360 projections, may be generated of the subject **14** in the field of view including the vertebrae **124** and the pedicle screw **120**. Any appropriate selected number of projections, however, may be acquired and included in the process **200**. For example, the projection in (b) is denoted as theta (θ)=180 degrees ($^{\circ}$), and, therefore, may be a projection acquired at 180° from an origin or start point.

As discussed further herein, the projections, as illustrated in FIG. **5**, may include a plurality of projections that are acquired in any appropriate manner. For example, as discussed above, the process **200** may be executed with the

image processing unit 58. Accordingly, the imaging system 12 may generate or collect the image data including the projections and they may be immediately processed with the imaging processing unit 58. Alternatively thereto, or in addition thereto, the image data may be acquired with the imaging system 12 and then may be forwarded or transferred to selected processing units or processors. For example, the image data may be transferred with a coupling, such as a wired or wireless protocol, saved to a selected memory medium (e.g. CD-ROM, volatile or nonvolatile memory, etc.). Accordingly, it is understood by one skilled in the art, that the acquiring projections in block 220 may include operating the imaging system 12 to acquire image data, receiving image data from a selected memory, or transferring the image data from a selected memory or source to a sourcing unit.

Regardless of the particular method of acquiring the projections in block 220 that may be further processed, as discussed herein. Each of the projections from block 220 may be distorted, in the sense that the signal levels recorded by the detector 28 are inaccurate. The distortion leads to artifacts in the 3D images reconstructed from those projections, such as streaking or shadows, due to the material of the pedicle screw 120 in the field of view, including the cone 26x of X-rays. In FIG. 5 the part (c) illustrates a close up or detail view of an area of interest (AOI) or field of interest.

The acquisition of the projections in block 220 may include a first input for the process 200. Additional inputs may include known component parameters or known components (KC) in block 226. The known component parameters may be predetermined parameters of the selected item, such as the pedicle screw 120. In various embodiments, for example, the KC may include the pedicle screw 120 having the shank 120' and the head 120". The known component parameters may further include the type of material of the selected portions of the pedicle screw 120, such as the shank 120' formed of a stainless steel alloy and the head 120" being formed of the same stainless steel alloy. It is understood, however, that the pedicle screw, such as the shank 120', may be formed of other materials such as titanium or titanium alloys, polymers, or the like. Nevertheless, the known parameters in block 226 may include the specifics of the selected item, such as the pedicle screw 120.

The known parameters in block 226 may also include selected dimensions such as length, width, height, and the like. The known parameters in block 226 may further include the number of components or portions of the pedicle screw 120 and the relative geometry of the various components or portions of the pedicle screw. For example, the known parameters in block 226 may include a fixed geometry of the pedicle screw 120 and/or various possible geometries of the pedicle screw 120. As illustrated in FIG. 5, the pedicle screw 120 includes the shank 120' and the head 120" movable relative to one another. Accordingly, the known parameters in block 226 may include a range of motion and/or degree of freedom of motion (e.g. possible geometries) of the shank 120' relative to the head 120".

The known parameters in block 226 may further include known interactions of X-rays relative to the selected item, including the pedicle screw 120. The known parameters in block 226 may include the known interactions of X-rays with the stainless steel forming the shank 120' and the stainless steel forming the head 120". The known parameters in block 226 may further include interactions of X-rays with titanium or titanium alloys, polymers, or other materials that may form the pedicle screw 120. The known interactions of the KC may include the amount of attenuation, the amount

of scattering, the amount of absorption, or other selected parameters of X-rays relative to materials of the pedicle screw 120. The known component parameters may be determined via testing prior to the process 200 and saved for further access. Further, the KC may relate to a specific item, such as the pedicle screw 120, that is input or used to select a specific, including singular, KC in block 226.

The known component parameters, also referred to as parameters of the component or object (e.g. the pedicle screw 120), may be defined in various manners, such as those discussed above, including exact values and/or defined or determined during a selected process. Exact values or parameters may be based upon specifications of the object (e.g. predetermined and/or known technical specifications of the object). The specifications of the object may include the features, such as those identified above, including a length, diameter, interaction with a polyenergetic x-ray beam, or other features. These values may be exact or nearly exact, such as knowing the exact width or range length, diameter, or the like, such as within selected tolerances. In various embodiments, however, the parameters may also be determined or defined during a selected process. As discussed herein, the object may be determined or registered in the projections based upon a selected process, as discussed further herein. During the registration process the object may be parametrically defined and/or determined in the acquired projections. By defining the parameters during a registration process, a determination may be made during the selected procedure of the parameters including a length, diameter, or the like. These may be based upon analysis of the image or require projections based upon selected known or assumed interactions with an x-ray beam, or other features. Accordingly, the parameters may be predetermined, as discussed above and noted herein, and/or determined during a registration process by analyzing the image data acquired in the projections.

In various embodiments, therefore, the known component parameters in block 226 may be representations, such as a lookup table, of the selected item including the pedicle screw 120. Further, the known parameters in block 226 may include selected specific models, such as a computer aided design (CAD) model of the pedicle screw 120 including known materials thereof and known interactions of X-rays relative thereto. In various embodiments, the pedicle screw 120 is the CD Horizon® Solara® implantable pedicle screw and the known component parameters in block 226 may include a CAD model of the specific pedicle screw (including a specific model number and/or geometry and dimensions thereof) or a deformable spline model (such as a spline model of a cylindrical wire, needle, or rod) along with known materials, known interaction of materials, and the like. The known parameters in block 226 may then be accessed, such as recalled with the processing unit 58, for further portions of the process 200.

With continued reference to FIG. 4, once the projections are acquired in block 220 and the known parameters are acquired or accessed in block 226, a registration, also referred to as a known component (KC) registration may occur in a sub-block or sub-process 240. The KC registration in block 240 may include various steps or processes including a forward projection in block 250. The forward projection in block 250, as discussed further herein, may then be compared to the projections in block 260. Based upon the comparison in block 260 a similarity metric (GC) may be determined in block 270. The comparison in block 260, yielding the similarity metric in block 270, may then be optimized in block 280. In particular, the optimizer block

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280 may generate a transformation that is again applied to a forward projection in block 250 to determine a similarity metric in block 270 based upon a comparison in block 260. Accordingly, the KC registration in block 240 is an iterative process until the optimizer in block 280 determines an optimized transformation.

An optimized transformation may be a convergence where the differences between the forward projection in block 250 and the projections in block 260 are substantially small or have a selected similarity metric in block 270. At the selected transformation of similarity metric, the transformation is determined to have converged or been optimized as an optimized transform (i) and may be used for a reconstruction process 290. The reconstruction process 290 is understood to be a sub-process of the artifact or noise reduction process 200. The reconstruction process 290 will be discussed further herein and, briefly, generally combines the acquired projections from block 220 with the optimized or converged transform from block 280.

Returning to the KC registration process 240, the KC registration process 240 includes a registration of the known components from block 226 with a selected number of projections, including less than or all of the acquired projections from block 220, that may be used for a later reconstruction in the reconstruction sub-process 290. In particular, the KC registration attempts to determine the portion in the acquired projections from block 220 that match to the known component in block 226. For example, one or more pixels in one or more of the projections are generated by the selected item (e.g. pedicle screw 120) positioned within the subject in block 208 and therefore should match a forward projection of the known component from block 226. For example, as discussed above, the pedicle screw 120 may have precise parameters known that define the known component parameters in block 226. Accordingly, the known parameters may be input as represented by κ . A digital radiograph reconstruction or digitally reconstructed radiograph (DRR) forms the forward projection in block 250 and may be defined by Equation 1 (Eq. 1):

$$\hat{p}(\kappa, T) = \int_{\vec{r}} \kappa(T) d\vec{r} \quad \text{Eq. 1}$$

In Eq. 1, the forward projection \hat{p} is a projection of the known component. In particular, Eq. 1 includes a DRR formed from the input known parameters κ from block 226, which may include a mesh model of the selected item that is a line integral along a ray \vec{r} incident on the transformed KC κ . Accordingly, the forward projection \hat{p} is a digitally reconstructed radiograph (also referred to as a mask herein) based upon the known component parameters κ from block 226 that may be compared to the acquired projection (also referred to herein as p). One or more selected transformation models (T) may be employed, such as a rigid homogeneous transform or a deformable b-spline function. Generally, only one transformation model may be selected in any specific application, but various appropriate models may be selected or the transformation (T). Furthermore, select parameters of κ may be included within the optimization process, for example to model the unknown diameter of a tool with a cylindrical profile.

The forward projection as defined in block 250 may be compared in block 260 to the acquired projections p from block 220. The comparison in block 260 may allow for the output of the similarity metric which, in various embodiments, is defined as a gradient correlation (GC). While GC, according to Equation 2 (Eq. 2), is an appropriate similarity

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metric, it is understood that other similarity metrics may also be used. Regarding GC, however, Eq. 2 includes:

$$GC(p, \hat{p}) = \frac{1}{2} \{NCC(\nabla_x p, \nabla_x \hat{p}) + NCC(\nabla_y p, \nabla_y \hat{p})\} \quad \text{Eq. 2}$$

and Equation 3 (Eq. 3):

$$NCC(a, b) = \frac{\sum_i (a_i - \bar{a})(b_i - \bar{b})}{\sqrt{\sum_i (a_i - \bar{a})^2} \sqrt{\sum_i (b_i - \bar{b})^2}} \quad \text{Eq. 3}$$

The GC generally looks for gradients (also referred to as high contrast regions or edges) between the forward projection \hat{p} in block 250 and the acquired projections in block 220. According to Eq. 2 and Eq. 3, the GC is defined as a sum of normalized cross-correlation (NCC) of orthogonal image gradients. For example, the NCC defines the correlation of the normalized intensities of image gradients a and b for images p and \hat{p} , respectively. Therefore, the GC, as illustrated in Eq. 2, is a sum of the gradients between the forward projection from block 250 and the acquired projections from block 220.

The optimizer in block 280 is then used to determine whether the converged transform \hat{T} has been found or achieved. In particular, the convergence is defined by Equation 4 (Eq. 4):

$$\hat{T} = \underset{T}{\operatorname{argmax}} \sum_{\theta} GC(p_{\theta}, \hat{p}_{\theta}(\kappa, T)) \quad \text{Eq. 4}$$

which may be iteratively solved between the forward projection in block 250 and the acquired projections from block 220. Eq. 4 is used to determine the greatest similarity between the forward projection in block 250 and the acquired projections in block 220. The iteration occurs by determining the GC in block 270 based upon the comparison in block 260 and then transforming the forward projection from the optimizer in block 280 to a different forward projection in block 250. Accordingly, the optimizer block may determine whether the similarity metric in block 270 is the same or has been optimized and/or within a selected threshold of change, for example when the mean change in T is smaller than about 0.01 millimeters (mm) to about 0.2 mm, including about 0.1 mm and about 0.01 degrees to about 0.2 degrees, including about 0.1 degrees. The threshold may also or alternatively include or when changes in the similarity metric GC approach the machine precision (such as an image processing unit 58) for representing floating-point numbers.

If the optimizer in block 280 determines that a threshold has not been reached then a NO path 282 may be followed to the forward projection block 250. The forward projection may then be altered, such as determining a forward projection at a different perspective relative to the known component in block 226 to form a new forward projection for comparison to the acquired projections from block 220. If the optimizer block 280 determines at a convergence has been achieved (e.g. a difference from a present GC is within a threshold relative to a prior GC) then the converged or optimized transform T may be output with the YES path 284.

Appropriate optimization techniques may be used in the optimizer block 280, such as those that may be executed by

the processing unit **58**, or other appropriate processing unit. In various embodiments, a covariance matrix adaptation evolution strategy may be used to achieve the optimization. The selected strategy may include a stochastic derivative free optimization method. It is understood, however, that other appropriate optimization methods or techniques may be used in the optimizer block **280**.

Once the Yes path **284** is followed to output the optimized transformation, the optimized transformation (T) may be used for modifying the projections acquired in block **220**. Modification to the projections acquired in block **220** may be made according to any appropriate process, including those discussed further herein. In various embodiments, inpainting in a selected manner may be performed in a modification block **310**, as discussed further herein. Inpainting may include generally known digital inpainting such as an interpolation based inpainting of the acquired projections. During interpolation based inpainting, the pixels or voxels identified as a part of the component or object (e.g. the pedicle screw **120**) may be replaced with pixels or voxels of a selected type or manner. For example, the identified pixels, based upon the above described process **200**, may be replaced with a selected model or graphical representation of the object (e.g. the pedicle screw **120**). In addition or alternatively, the identified pixels or voxels may be replaced with a selected color or feature in the acquired projections that have been identified as the object. In addition to the direct inpainting from a selected model, interpolation may be made determined or identified or replace pixels that are at edges or between identified object pixels or voxels or non-identified pixels or voxels. Moreover, a selected amount of noise, such as an optional random noise component, may be added to the inpainted voxels or pixels to selectively characterize the representation of the object in the projections.

In addition to a direct and/or interpolation based inpainting, various other processes may be used to assist in or preform inpainting. For example, a machine learning process or system may be used to perform the inpainting into the projections. For example, the pixels or voxels identified in the process **200** may be inpainted based upon prior training of a machine learning system. For example, a neural network (e.g. a deep learning system) may be used to determine pixels or voxels to be inpainted based upon training of previously determined object projections and the identification of the object on the projection and the inpainting therein. In various embodiments, therefore, inpainting may replace voxels or pixels in a projection according to an appropriate system such as an interpolation or machine learning base system.

The modification of the projections in block **310** may also include determining or estimated pixel values, such as calculating or computing pixel or voxel values using a selected modeling of an imaging system, such as of the x-ray beam. As discussed above the x-ray beam may include x-rays that are emitted by the emitter **26**. The x-rays in an emitted beam may be polyenergetic, such as including a spectrum. Accordingly, the x-rays emitted may not be of only a single frequency or power. The polyenergetic x-ray beam may interact with material in a known manner based upon the polyenergetic identity of the x-ray beam. The interactions may be known based upon the known components, as discussed above, of the various x-ray components (defined by the x-ray spectrum) with the object in the projections. Accordingly, the determined pixel values based upon the known polyenergetic model of the x-ray beam may

be used to generate pixel or voxel values in the projections and therefore may be used to replace the determined pixels in the projections.

As discussed above, the projections may be modified in various manners and in appropriate processes. Discussion herein to inpainting is merely exemplary, and not intended to limit the scope of the subject disclosure of the following claims. Accordingly, modifying may include inpainting in the projections acquired in block **220** at modifying (e.g. inpainting) block **310**. The inpainting block **310** is the first process or step of the reconstruction process **290**. The reconstruction process **290** may also be referred to as a metal artifact reduction or removal (MAR) process. Accordingly, the MAR reconstruction may be used to reduce or remove artifacts due to the selected item, such as the pedicle screw **120**. By reducing the metal artifacts, or other selected artifacts, in the inpainting block **310**, the artifacts are removed for the later reconstruction. Reconstruction may include or be based on a back projection reconstruction including a filtered back projection (FBP). In various embodiments, the back projection may be a three-dimensional (3D) projection in block **320**. A reconstruction occurs in block **330** which may form the reconstruction of the image **64** for viewing on the display device **66**.

With continuing reference to FIG. 4 and FIG. 5, inpainting block **310** uses the optimized transformation to inpaint the acquired projections from block **220**. As illustrated in process **200**, the projections (p) are input with the optimized transformation or converged transformation T into inpainting block **310**. In the inpainting block **310**, the surrounding pixels of projections (p) may be used to interpolate the region identified by the forward projection of the KC. Alternatively, the DRR of the forward projection (p) that accounts for the various effects of x-ray and metal interaction may be painted into the acquired projection **220** at the registered position based on the optimized transform T from the optimizer block **280**. In other words, selected polyenergetic signal models informed by the KC model of the component shape and material content, based on known material interactions with X-rays included in the forward projection, may be used to paint into the acquired projection **220** at the registered position. Accordingly, the pixels in the acquired projections **220** that match or have the greatest similarity metric to the forward projection from block **250** are replaced with the forward projection from block **250** in the inpainting block **310**.

As noted above, with reference to FIG. 5, the projection from block **220**, or one of the projections, includes the vertebrae **124p** and the imaged screw **120p**. Once the transformation is optimized in block **280** the forward projection that is optimized or best matches the screw **120p** in FIG. 5 part (b) may be replaced or inpainted with the forward projection from block **250**. As illustrated in FIG. 5 part (e), an inpainted screw **120ip** (schematically illustrated by a dotted line in part (f)) may be inpainted or used to replace the screw **120p** in the projection and replace it in the image, including the vertebrae **124p**. As discussed above the acquired projections in block **220** may include one or more of the projections acquired of the subject **14**. In various embodiments the number of projections may include three projections, six projections, all of the projections, or any appropriate number. In various embodiments, the acquired projections in block **220** may include six projections that are offset or displaced from one another by 30 degrees (or any appropriate selected angle theta (δ) around the subject **14**. The similarity metric in block **270** and the optimized transformation in block **280** may be for only a portion or selected

number of the projections of the subject **14**. However, it is understood, that the use of the known component parameters in block **226** may minimize or allow for a fast and efficient registration based upon a forward projection in block **250** that similarly or most closely matches the actual projections in block **220** due to the known component parameters in block **226**. THE KC parameters, again, may include size, shape, material, and interaction with X-rays. Nevertheless the inpainting in block **310** may replace the identified screw **120** with the inpainted forward projection that has been registered thereto as discussed above. The projection may then become an inpainted projection, such that the inpainted projection in FIG. **5** part (e), in block **310** including the inpainted selected portion or item.

The inpainting in block **310** may also include various optimization or robustness features. For example, the forward projection from block **250**, which may also be referred to as a mask, may be dilated or expanded relative to the exact, known component parameters from block **226** relative to the projections from block **220**. In various embodiments, the forward projection mask from block **250** may have a dilation or be dilated one or more pixels when inpainting on the projection in block **310**. The dilation may assist in overcoming errors such as manufacturing variation, geometric calibration of the imaging system, floating precision errors, or other possible errors. The selected amount of dilation or expansion of the mask assists in ensuring appropriate positioning or accounting for errors, as noted above. The final reconstruction, as discussed herein, which may be the image **64** would include the dimensions of the KC parameters from block **220** to illustrate the extent or placed (implanted) final position of the pedicle screw **120** in the vertebrae **124**.

Further, the optimized transformation from block **280** identifies the selected item in the projection to be inpainted in block **310**. The inpainting process or method may be selected from appropriate methods. For example, inpainting may include a linear interpolation in the selected projection. In various embodiments, the linear interpolation is achieved by producing a Delaunay triangulation over a convex hull of the regions (e.g. Quickhull algorithm disclosed in Barber, C. B., Dobkin, D. P., and Huhdanpaa, H. T., "The Quickhull algorithm for convex hulls," ACM Trans. on Mathematical Software, 22(4):469-483, 1996) masked (such as with the DRR of the forward projection **260**) by the identified transformation from block **280** followed by a barycentric interpolation on each produced triangle. The inpainting process (including in various embodiments, at least one of the interpolation-based or the model-based that exercises the KC model) is then repeated for all of the projections (such as all of the projections acquired in block **220**) and measurements in each of the projections input in block **220**.

Once the modification in block **310**, such as including inpainting in the projections from block **220**, is completed, a reconstruction may be performed in block **320** with the modified projections. The reconstruction may be any appropriate reconstruction, as discussed herein. The reconstruction may be used for various purposes as discussed herein.

In various embodiments, the reconstruction in block **320** may include a three-dimensional filtered back projection (3D FBP). In exemplary embodiments, the 3D FBP may include the Feldkamp-Davis-Kress algorithm reconstruction method generally known in the art. It is understood, however, that other appropriate reconstruction (e.g. alternative back projection) methods may be used.

In addition to and/or alternative to the filtered back projection, an iterative reconstruction may also be per-

formed. The iterative reconstruction may include a model based iterative reconstruction (MBIR) algorithm. The iterative reconstruction may include iteratively altering parameters of a model to achieve or minimize a difference between the model and the modified projections from block **310**. For example, a model of the object, such as the pedicle screw **120**, may be identified and a projection through the model may be iteratively altered to match the modified projections from block **310**. When a match is achieved, the model may be used to assist in the reconstruction of the model projections.

Based upon the back projections from block **320**, the reconstruction process **290** may output the reconstructed image in block **330**. The reconstructed image may be a visualization of the reconstruction. The visualization may be displayed as an image for viewing, such as displayed as an image with the display device **66**.

The outputted reconstruction in block **330** may be referred to as a KC-MAR reconstruction and/or a visualization (e.g. a KC-MAR reconstruction visualization). The output, including the visualization, may include or be represented as the image **64** for display on the display device **66** for viewing by the user **54**. The reconstruction may include a three-dimensional reconstruction and/or may illustrate the back projections as images for viewing by the user. With reference to FIG. **6** a back projection of uncorrected acquired projections in block **220** is illustrated in row A. A reconstruction using the process **200**, including the KC registration **240** and the reconstruction process **290**, is illustrated in row B. As clearly illustrated in FIG. **6**, row B, having the inpainted registered known components, reduces metal artifacts or selected distortion. The distortion reduction allows for viewing or reconstruction visualization that includes sharper or higher contrast edges with reduced or minimal streaking and other artifacts in the reconstruction.

As illustrated in FIG. **6** row B, the reconstruction visualization may also include selected information based upon the known components from block **226**. As discussed above, the inpainting in block **310** may be inpainted with the mask from the forward projection in block **250**. The forward projection in block **250** includes the known components parameters from block **226**. Accordingly, the inpainting may include various geometric configurations, such as size, shape, and configuration, and the mask of the forward projection from block **250** may also include differentiation of materials due to different attenuation due to different materials of the known components. For example, as discussed above, the head **120'** of the pedicle screw **120** may be a different material or formed of a different material than the shank **120'**. Accordingly, the reconstruction in FIG. **6** row B may differentiate, such as due to grayscale, the reconstructed portions of different materials. In various embodiments, therefore, the reconstructed projection of the head **120'** may have a different or altered grayscale or visual effect from the shank **120'**. This is due, at least in part, to the forward projection from block **250** being based upon the known component parameter. The KC parameters in block **226** may be exhaustive regarding the known component, such as the pedicle screw **120**.

As the known component parameters may include size and geometry and also include materials, the effects of each may be known and applied for forming the forward projection and the inpainting in block **310**. Again, as discussed above, the known components and their effects on the X-ray projections may be predetermined and known and saved and recalled for the forward projection in block **250** and the inpainting in block **310**. The back projection reconstruction

in block 320 and a reconstruction visualization or output in block 330, respectively, may therefore also be based upon the known component parameters from block 226.

The reconstruction visualization, or the visualization in block 330, may be generated in various formats and/or selected by a user from one or more options. The visualization may include a direct reconstruction of the modified projection from block 310. For example, the reconstruction from block 320 may be displayed for viewing by the user 54. The reconstruction, as discussed above, may include incorporating the modified projections directly into a reconstruction projection. The plurality of projections or a selected plurality of projections may be used to generate a three-dimensional (3D) model or visualization for viewing by the user 54. Accordingly, the visualization in block 330 may be a direct visualization or visualization of the direct reconstruction from block 320.

In various embodiments, the visualization may also include and/or alternatively include picture or image elements (e.g. voxels or pixels) that coincide with a registered object in the modified projections from block 310. For example, once the object is registered, as discussed above, the projection may have the pixels or voxels that coincide or are registered as the object is replaced with a selected other pixels or voxels. For example, selected color, gradient, or type of pixel or voxel may be used to replace the registered voxel in the visualization in block 330. Accordingly, an additional or alternative visualization may not be required or generated, just that the pixel or voxels related to the registered object may be replaced.

As a further alternative and/or additional visualization, selected slices or 2D portions may be displayed relative to a selected feature or parameter of the object. For example, once the object has been identified or registered in the projections (e.g. the pedicle screw 120) slices that include the object and/or coincide with the object may be oriented or re-oriented and illustrated in a selected manner, such as along a long axis of the object. For example, as illustrated in FIG. 6, the illustration or visualization for display may be oriented such that a long axis 102L of the screw 120 is used to orient the visualization. Therefore, the long axis 102L may be used to orient the images vertically and if a plurality of slices or 2D images are displayed they may all be displayed substantially in parallel.

As a further alternative and/or addition, a graphical representation may be superimposed or overlaid on the selected image. For example, as discussed above, the object may include the pedicle screw 120. Further, the object may be determined and/or identified based upon known components, which may include a model of the object. Accordingly, a selected portion or version of the object (such as a representation or outline thereof) may be displayed relative to the image. In various embodiments, for example, the graphical representation may be overlaid or superimposed on the image at the registered location of the object.

Accordingly, the visualization in block 330 may include any appropriate visualization. The visualization may be based upon the registered or known position of the object, such as the pedicle screw 120, in the acquired projections. The visualization may then be displayed on the display device 66, such as the image 54, for viewing by the user 54 for various purposes. In various embodiments, therefore, the little artifacts may be reduced in the visualization block 330 such that the user 54 may view the visualization 64 on the display device 66 with substantially reduced and/or eliminated distortions or artifacts due to metal or other component in the image.

In light of the above, the final reconstruction and/or reconstruction visualization in block 330, which may be displayed as the image 64 on the display device 66, may have substantially reduced or eliminated artifacts due to altered attenuation or distorted attenuation of the X-rays from the imaging system 12 for imaging of the subject 14. Moreover, the known component parameters 226 may assist in enhancing a registration in block 280, such as making it faster by efficiently and more definitely defining the component for forming the forward projection in 250. Moreover, the known component parameters from block 226 may further assist in reducing artifacts and distortion due to a predetermined and known effects of the component for the inpainting in block 310. Thus, the final reconstructed image in block 330 is efficiently and quickly produced based upon the process 200 that may be executed with the processing system, such as the image processing unit 58 as discussed above.

Example embodiments are provided so that this disclosure will be thorough, and will fully convey the scope to those who are skilled in the art. Numerous specific details are set forth such as examples of specific components, devices, and methods, to provide a thorough understanding of embodiments of the present disclosure. It will be apparent to those skilled in the art that specific details need not be employed, that example embodiments may be embodied in many different forms and that neither should be construed to limit the scope of the disclosure. In some example embodiments, well-known processes, well-known device structures, and well-known technologies are not described in detail.

The foregoing description of the embodiments has been provided for purposes of illustration and description. It is not intended to be exhaustive or to limit the disclosure. Individual elements or features of a particular embodiment are generally not limited to that particular embodiment, but, where applicable, are interchangeable and can be used in a selected embodiment, even if not specifically shown or described. The same may also be varied in many ways. Such variations are not to be regarded as a departure from the disclosure, and all such modifications are intended to be included within the scope of the disclosure.

In one or more examples, the described techniques may be implemented in hardware, software, firmware, or any combination thereof. If implemented in software, the functions may be stored as one or more instructions or code on a computer-readable medium and executed by a hardware-based processing unit. Computer-readable media may include non-transitory computer-readable media, which corresponds to a tangible medium such as data storage media (e.g., RAM, ROM, EEPROM, flash memory, or any other medium that can be used to store desired program code in the form of instructions or data structures and that can be accessed by a computer).

Instructions may be executed by one or more processors, such as one or more digital signal processors (DSPs), general purpose microprocessors, application specific integrated circuits (ASICs), field programmable logic arrays (FPGAs), or other equivalent integrated or discrete logic circuitry. Accordingly, the term "processor" as used herein may refer to any of the foregoing structure or any other physical structure suitable for implementation of the described techniques. Also, the techniques could be fully implemented in one or more circuits or logic elements.

What is claimed is:

1. A method of reducing artifacts in an image due to an object, comprising:

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accessing at least one known component parameter of the object selected from a geometry, a dimension, or a material;

acquire at least one projection having the object therein; create at least one forward projection of the object based upon the accessed known component parameter; and registering the object in the forward projection to the at least one acquired projection having the object therein; wherein creating the at least one forward projection of the object based upon the accessed known component parameter includes creating a digitally reconstructed radiograph of the object.

2. The method of claim 1, further comprising modifying the at least one projection to a representation of the registered object.

3. The method of claim 2, wherein modifying the at least one projection includes inpainting the representation of the object in the at least one projection.

4. The method of claim 2, further comprising generating a reconstruction based on the modified at least one projection.

5. The method of claim 4, wherein generating the reconstruction, includes generating a three-dimensional image.

6. The method of claim 1, further comprising: placing the object in a subject; and acquiring the at least one projection of the subject and the placed object.

7. A method of reducing artifacts in an image due to an object, comprising:

accessing least one parameter of the object selected from a geometry, a dimension, or a material;

acquire at least one projection having the object therein; create at least one forward projection of the object based upon the accessed parameter;

registering the object in the forward projection to the at least one acquired projection having object therein; and modifying the at least one projection to a representation of the registered object;

wherein modifying the at least one projection includes inpainting the representation of the object in the at least one projection;

wherein inpainting the representation of the object in the at least one projection includes identifying pixels or voxels and replacing the identified pixels or voxels with a selected model or graphical representation of the object.

8. A method of reducing artifacts in an image due to an object, comprising:

accessing least one parameter of the object selected from a geometry, a dimension, or a material;

acquire at least one projection having the object therein; create at least one forward projection of the object based upon the accessed parameter;

registering the object in the forward projection to the at least one acquired projection having object therein; and modifying the at least one projection to a representation of the registered object;

wherein modifying the at least one projection includes inpainting the representation of the object in the at least one projection;

wherein the inpainting the representation of the object in the at least one projection includes identifying pixels or voxels and replacing the identified pixels or voxels with a selected color in the at least one projection that have been identified as the object.

9. A system for reducing artifacts in an image due to an object, comprising:

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an imager configured to generate at least one projection having the object therein; and

a processor system configured to execute instructions for: accessing at least one known component parameter of the object selected from a geometry, a dimension, or a material;

acquiring the at least one projection from the imager; create at least one forward projection of the object based upon the accessed known component parameter; and registering the object in the at least one forward projection to the at least one projection having the object therein; wherein creating the at least one forward projection of the object based upon the accessed known component parameter includes creating a digitally reconstructed radiograph of the object.

10. The system of claim 9, wherein the processor system is further configured to modify the at least one projection to a representation of the registered object.

11. The system of claim 10, wherein the processor system is further configured to generate a reconstruction based on the modified at least one projection.

12. The system of claim 11, further comprising a display device to display a visualization based on the generated reconstruction.

13. The system of claim 11, wherein the processor system is further configured for:

accessing a plurality of the projections; and modifying at least a first sub-plurality of acquired projections of the acquired plurality of projections to the representation of the registered object; wherein generating the reconstruction includes generating the reconstruction based on all of at least the first sub-plurality of acquired projections of the acquired plurality of projections.

14. The system of claim 13, wherein generating the reconstruction based on at least all of the modified first sub-plurality of acquired projections of the acquired plurality of projections includes generating a three-dimensional image.

15. The system of claim 10, wherein the processor system is further configured to inpaint the representation of the object in the at least one projection.

16. The system of claim 9, wherein the object is a pedicle screw.

17. A system for reducing artifacts in an image due to an object, comprising:

an imager configured to generate at least one projection having the object therein; and

a processor system configured to execute instructions for: accessing least one parameter of the object selected from a geometry, a dimension, or a material;

acquire at least one projection from the imager; create at least one forward projection of the object based upon the accessed parameter; and

registering the object in the at least one forward projection to the at least one projection having object therein;

wherein the processor system is further configured to modify the at least one projection to a representation of the registered object;

wherein the processor system is further configured to inpaint the representation of the object in the at least one projection;

wherein inpainting the representation of the object in the at least one projection includes identifying pixels and

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replacing the identified pixels with a selected model or
graphical representation of the object.

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