(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
06 October 2022 (06.10.2022)

WIPO | PCT

(10) International Publication Number
WO 2022/212009 A1

(51) International Patent Classification:
G21K 1/04 (2006.01) *A61B 6/02* (2006.01)
G21K 1/02 (2006.01)

(21) International Application Number:
PCT/US2022/020128

(22) International Filing Date:
14 March 2022 (14.03.2022)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:

63/170,288	02 April 2021 (02.04.2021)	US
63/175,952	16 April 2021 (16.04.2021)	US
63/182,426	30 April 2021 (30.04.2021)	US
63/188,919	14 May 2021 (14.05.2021)	US
63/194,071	27 May 2021 (27.05.2021)	US
63/209,498	11 June 2021 (11.06.2021)	US
63/214,913	25 June 2021 (25.06.2021)	US
63/220,924	12 July 2021 (12.07.2021)	US
63/222,847	16 July 2021 (16.07.2021)	US
63/224,521	22 July 2021 (22.07.2021)	US
63/225,194	23 July 2021 (23.07.2021)	US
63/226,508	28 July 2021 (28.07.2021)	US
17/592,332	03 February 2022 (03.02.2022)	US

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(81) Designated States *(unless otherwise indicated, for every kind of national protection available)*: AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DJ, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IR, IS, IT, JM, JO, JP, KE, KG, KH, KN, KP, KR, KW, KZ, LA, LC, LK, LR, LS, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PA, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SA, SC, SD, SE, SG, SK, SL, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, WS, ZA, ZM, ZW.

(84) Designated States *(unless otherwise indicated, for every kind of regional protection available)*: ARIPO (BW, GH,

(54) Title: X-RAY MULTI-LEAF DYNAMIC COLLIMATION FOR MULTIPLE SOURCE-IN-MOTION TOMOSYNTHESIS IMAGING SYSTEM

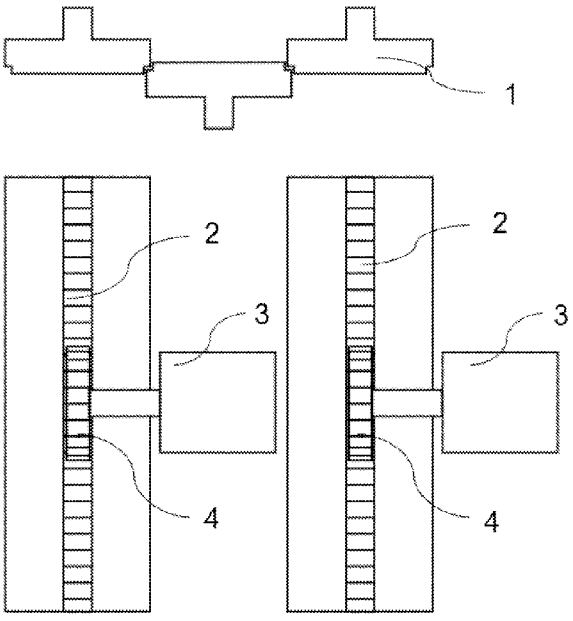

FIG. 1

(57) Abstract: A dynamic multi-leaf collimator system for X-ray exposure on region of interest in conjunction with multiple source-in-motion tomosynthesis imaging system is disclosed. The system comprises two opposite banks of thin heavy metal leaves arranged in parallel and stagger formation. The leaves are individually driven by electrical motors, can move in straight line in X, Y directions and create multiple X-ray exposure holes with desired shapes. The leaves are made of thin heavy metal capable of blocking kV level X-rays. After a preliminary X-ray imaging scan, artificial intelligence or system operator can determine location of region of interest and then determine location of collimation holes. Therefore, subsequent X-ray imaging scan will be performed with automatic collimation dynamically, X-ray dose on an object or patient is then greatly reduced.

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GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, ST, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, KM, ML, MR, NE, SN, TD, TG).

Published:

— *with international search report (Art. 21(3))*
— *before the expiration of the time limit for amending the claims and to be republished in the event of receipt of amendments (Rule 48.2(h))*

X-ray Multi-leaf Dynamic Collimation for Multiple Source-in-motion Tomosynthesis Imaging System

Background

Digital tomosynthesis (DTS) is a limited-angle tomography that eliminates overlapping anatomy or composite artefact. DTS facilitates improved lesion detection, depth localization and contrast resolution compared with regular radiography. Compared with CT, the cost and radiation dose of DTS are much lower. Therefore, DTS has been recommended as an alternative to both chest radiography and CT follow up. In particular, DTS has shown greater diagnostic performance for detecting pulmonary nodules. Because of multiple projections used in DTS, the patient dose is higher compared to regular radiography. This invention describes a method for significant dose reduction using dynamic multi-leaf collimator. The state of art radiographic and DTS systems use rectangular collimators to restrict the X-ray beam. These collimator openings typically are fixed to a certain field of view (FOV) size with rectangular shape, therefor they cannot performance dynamic region of interest exposures. In many diagnostic task, only certain region of interests (ROIs) is important and the rest of the area are less or not important. Therefor exposure to the outside of ROI region can be reduced or totally blocked. Effective dose to patient can be measured by dose-area product (DAP). By reducing the exposure area with dynamic collimator, the effective dose can be dramatically reduced. For example, reducing a 40cm X 40cm field of view to that of 10cm by 10cm can result in 16 times less of DAP. There are prior arts of various collimation mechanism. However, there are disadvantages in the prior arts. The first disadvantage is that although

collimation systems in prior arts are motorized, but they are system of fixed collimation, not dynamic collimation. So, X-ray dose at prior arts is not reduced dynamically. The second disadvantage is that there is no artificial intelligence involved in prior art. Collimation system in prior arts cannot decide precise location of regions of interest during X-ray scan. The third disadvantage is that most collimators in prior art only are using single X-ray source not multi-sources. Multiple sources require collimation in front of every single X-ray tube.

Summary

In one aspect, a system uses multiple X-ray sources-in-motion digital tomosynthesis, in front of each X-ray source tube, a dynamic collimation is used to address the dose problem on patient.

In another aspect, a dynamic multi-leaf collimator system for X-ray exposure on region of interest in conjunction with multi-source tomosynthesis imaging system is disclosed. The system comprises two opposite banks of thin heavy metal leaves arranged in parallel and stagger formation. The leaves are individually driven by electrical motors, can move in straight line in X, Y directions and create multiple X-ray exposure holes with desired shapes. The leaves are made of thin heavy metal capable of blocking kV level X-rays. After a preliminary X-ray imaging scan, self-learning of artificial intelligence or system operator can determine location of region of interest and then determine location of collimation holes dynamically. Therefore, subsequent X-ray imaging scan will be performed with automatic collimation dynamically, X-ray dose on patient is then greatly reduced.

In another aspect, a multi-leaf dynamic collimator system for a multiple source-in-motion tomosynthesis imaging system is disclosed. The system comprises two opposite banks of thin, heavy metal leaves arranged in parallel and stagger formation. Electrical motors individually drive the leaves, move in a straight line in X and Y directions, and create multiple X-ray exposure holes with desired shapes. The leaves are made of thin, heavy metal capable of blocking kV level X-rays. After a preliminary X-ray imaging scan, artificial intelligence or system operator self-learning can determine the location of the

region of interest and then dynamically determine the location of collimation holes. Therefore, subsequent X-ray imaging scans will be performed with automatic collimation dynamically; the X-ray dose on the patient is significantly reduced. Current invention several significant advantages over the prior art. A digital tomosynthesis system with dynamic multi-leaf collimator is described. The collimator comprises two opposite banks of thin, heavy metal leaves arranged in parallel and stagger formation. Electrical motor arrays individually drive the leaves, move in a straight line in X and Y directions, and create multiple X-ray exposure holes with desired shapes. The leaves are made of thin, heavy metal capable of blocking kV level X-rays. After a preliminary X-ray imaging scan, artificial intelligence or system operator with self-learning can determine the location of the region of interest and then dynamically determine collimation holes.

In another aspect, a frame leaf is connected to X-direction linear motor that moves the frame leaf in the X-direction. The above arrangement is suitable for a fixed detector used with the digital tomosynthesis imaging system, such as a fixed detector multi-source tomosynthesis imaging system. In other words, this arrangement will be called a fixed detector X-ray exposure system from now on. A region of interest (ROI) will be used throughout this disclosure in a fixed detector X-ray exposure system. The ROI can be a lesion, a suspicious region, or a particular region required for special treatment. It should be noted that the size of ROI is dynamic and may vary during different medical examinations. A detection plane can be defined to detect different object planes from an original plane.

Another aspect of the present invention is to provide a motor control circuit and an electronic-dynamic multi-leaf collimator system. The collimator system comprises two opposite banks of thin, heavy metal leaves arranged parallel and stagger formation. Each leaf driven by electrical motors can move straight in X and Y directions and create multiple X-ray exposure holes with desired shapes. X-ray beam that passes through the multiple exposure holes generates images of object on the X-ray detector. Another aspect of the present invention is to provide a dynamic multi-leaf collimator system. The system comprises: two opposite banks of thin, heavy metal leaves arranged in parallel and stagger formation, each leaf individually driven by electrical motors and can move in a straight line in X and Y directions and create multiple X-ray exposure holes with desired shapes; the exposure holes that control pass-through X-ray beam would also control the amount of scattered radiation. An object to be imaged by pass-through the X-ray exposure forms images on a tomosynthesis imaging detector.

In another aspect, the artificial intelligence software is to pre-program the location of the region of interest. When tomosynthesis imaging is initiated, the system will auto-locate the ROI by the following steps: using image segmentation method or performing manual segmentation; then drawing a bounding box around the ROI; applying a special filter to isolate border of ROI from surrounding tissues/fluids; then running an algorithm to calculate the optimum number of exposure holes for different sizes; obtaining mean DAP value using histogram; increasing exposure level to achieve specified dose area product value. User-defined or auto size exposure hole will be displayed on the images preferably before exposure. Software algorithm would make dynamic exposure hole arrangement. The physical movement of the leaf can be performed in following modes: mode 1:

exposure hole location moves automatically based on specific rule determined by artificial intelligence (AI). For example, exposure holes could be generated at intersection locations between reference lines and midlines between scan slices. As scan slices progress, exposure hole location moves closer to the next scanning plane according to programmed rules, making the exposure area exactly overlapping subject location during tomosynthesis scan. Alternatively, mode 2: exposure holes could be generated at random locations calculated intersections between reference lines, and exposure holes could be generated based on exposure calculation rules which need exposure calculation.

In another aspect, the use of a multiple X-ray source-in-motion tomosynthesis imaging system is detailed. The scan system may comprise of X-ray source and collimator. A preferred embodiment of this invention uses multiple X-ray sources for exposure of the object. An x-ray tube is placed above an object to be scanned. A scanning system can scan the object by moving the x-ray tube over the object, or the object can be moved to the path of the x-ray beam. The object can be moved by rotating on a turntable mounted on rollers that ride in rails. The object can also be moved using linear motor drives along with one or more linear guides. The scan system may comprise of X-ray source and collimator. A preferred embodiment of this invention uses multiple X-ray sources for exposure of the object. Multiple sources are more effective in obtaining different exposure doses at different exposure regions. Exposing objects to X-rays through multiple X-ray sources with dynamic collimation makes it possible to achieve limited angle exposure on certain desired exposure regions only. With exposure on only limited exposure regions, exposure on unnecessary exposure regions can be avoided. The exposure regions could be decided by X-ray view projection acquired during the

preliminary scan. As seen from the cross-sectional view of exposure, the exposure region may not be circular or elliptical. Still, it is a dynamic exposure hole shape based on the exposure mechanism of the current invention.

The system first performs a preliminary scan to create the DICOM images, then automatically locating the interest region. These steps can be implemented by software running on CPU or FPGA on each source or integrated into a control module or imaging device. Once located, the appropriate collimation area is set up, and the KV-level X-ray beam is restricted dynamically. After dynamic collimation is completed, data acquisition for the final scan is performed to save the required images. For example, if a chest X-ray is taken and the lungs are of more interest than the heart, the heart wall will become part of the region of interest (ROI). A precise ROI image of the lung can be obtained with a collimator dynamically blocking kV level X-rays. Any part of the heart not important to radiologists can be blocked out effectively and significantly reduce patient dose. If a precise bone image is required, after a full-body image is created, a dynamic collimator may be created in front of a single X-ray tube exposed to a specific region only. The rest of the area will be blocked. Breast becomes a critical ROI if mammography is taken, otherwise, the breast tissue can be blocked out effectively and significantly reduce patient dose. In summary, different medical procedures have a different need for imaging.

The method involves the following steps for each X-ray source: Collimation for dynamic multi-leaf collimator (DMLC) can be controlled by a computer to adjust its leaf positions. Due to the limitation of fabrication, there is always a gap between two adjacent leaves in DMLC. Therefore, collimation holes cannot perfectly align with each other

between different X-ray source tubes. By analyzing spatial relation between the gap between leaves and voxel positions on image data acquired during scanning, some self-learning algorithms can determine where leaf should be to block unwanted X-rays. Then, the computer sends control signals to DMLC using the calculated leaf positions to move each leaf to the appropriate position in the time domain. The leaf movement will form one or more holes on the area under scan, the so-called "collimation hole."

Using artificial intelligence or image processing to achieve the location of ROI on patients based on anatomy information determined by imaging scan. There is following considerations: The design must have multiple leaves parallel to each other. Also, collimation is used as a masking plate. The most effective way to block X-rays is to use lead, so it is most likely that the leaves are made of lead. Each leaf will have its own motor to move independently in both X and Y directions. The number of X-ray exposures is significantly increased using two opposite banks of leaves arranged in parallel formation compared to only one leaf. Therefore, the patient's dose can be reduced even more interest after each imaging scan. Another round of X-ray imaging scans is performed w. Therefore, a high degree of automation in control and management is required. X-ray system will perform dynamic mapping with the region of ith a dynamic multi-leaf collimator system based on the region of interest. Because different patients have different anatomies, different collimation is required for different patients. To determine the accurate position of the region of interest, an electronic form will be created for each patient to store region of interest information. Once all relevant information is inputted into the computer, this data will be uploaded to an artificial intelligence software program trained with different shapes of regions of interest on the computer.

In another aspect, a dynamic multi-leaf collimator system provides two opposite banks of thin, heavy metal leaves arranged in parallel and stagger formation. Electrical motors individually drive the leaves, move straight lines in X and Y directions, and create multiple X-ray exposure holes with desired shapes. The leaves are made of thin, heavy metal capable of blocking kV level X-rays. The X-ray generator sends a high-energy X-ray beam to each leaf independently. A predetermined area can be defined as region of interest (ROI) by a user or artificial intelligence (AI). The first step of the scan will create the first radiograph digital image. Then, ROI is identified and set automatically by AI or humans. ROI data and the first radiograph digital image are used to train the AI model. The second scan step will then collect radiographs without radiation dose to the ROI region but will create radiation dose in the rest area. After the two steps above, the multi-leaf moving process would start based on AI model's training. A simulated training image would show up to help training.

Brief Description of the Drawings

This application will become more fully understood from the following detailed description, taken in conjunction with the accompanying figures, wherein like reference numerals refer to like elements in which:

Fig. 1 illustrates individual metal leaf of a dynamic multi-leaf collimator that is controlled by motor.

Fig. 2 illustrates that dynamic multi-leaf collimator metal pieces can move in +X, -X directions as a group and move in +Y, -Y directions individually.

Fig. 3 illustrates that in X-ray multiple source-in-motion digital tomosynthesis system, two regions of interest are produced and need to be re-scanned using the dynamic multi-leaf collimator in order to shield other nearby regions and achieve better images.

Detailed Description

A detailed description of preferred embodiments of the present invention will be given below with reference to the accompanying drawings. However, in the following description of the present invention, when it is determined that a detailed description of a related well-known function or element may make the gist of the present invention unnecessarily vague, the detailed description will be omitted.

The present invention will be described in detail by example regarding the attached drawings in the following paragraphs. Throughout this description, the preferred embodiment and examples shown should be considered exemplars rather than limitations on the present invention. As used herein, the "present invention" refers to any one of the embodiments of the invention described herein and any equivalents. Furthermore, reference to various feature(s) of the "present invention" throughout this document does not mean that all claimed embodiments or methods must include the referenced feature(s).

This invention will now be described more fully hereinafter with reference to the accompanying drawings, which show exemplary embodiments. Various embodiments are now described with reference to the drawings, wherein reference numerals are used to refer to such elements throughout. In the following description, for purposes of explanation, numerous specific details are outlined to provide a thorough understanding of one or more embodiments. However, it may be evident that such embodiment(s) may be practiced without these specific details. In other instances, well-known structures and

devices are shown in block diagram form to facilitate describing one or more embodiments.

However, this invention may be embodied in many different forms and should not be construed as limited to the embodiments set forth herein. These embodiments are provided so that this disclosure will be thorough and complete and fully convey the invention's scope to those of ordinary skill in the art. Moreover, all statements herein reciting embodiments of the invention and specific examples thereof are intended to encompass both structural and functional equivalents thereof. Additionally, it is intended that such equivalents include both currently known equivalents and equivalents developed in the future (i.e., any elements developed that perform the same function, regardless of structure).

Thus, for example, it will be appreciated by those of ordinary skill in the art that the diagrams, schematics, illustrations, and such as represent conceptual views or processes illustrating systems and methods embodying this invention. The functions of the various elements shown in the figures may be provided through the use of dedicated hardware and hardware capable of executing associated software. Similarly, any switches shown in the figures are conceptual only. Their function may be carried out through the operation of program logic, through dedicated logic, through the interaction of program control and dedicated logic, or even manually, the particular technique being selectable by the entity implementing this invention. Those of ordinary skill in the art further understand that the exemplary hardware, software, processes, methods, and operating systems described

herein are for illustrative purposes and, thus, are not intended to be limited to any particular named manufacturer.

Fig. 1 illustrates a dynamic multi-leaf collimator 5 that is controlled by the micro stepper motor 3, where multiple thin, heavy metal leaves 1 are arranged in parallel. There are gear teeth 2 on each individual metal leaf 1. Micro stepper motor 3 also has motor gear 4 at shaft. Leaf gear teeth 2 and motor gear 4 are engaged to each other. A single thin leaf 1 can move forward and backward by using an electric motor mechanism. A hole of the desired shape can be formed on the front side of each leaf based on spatial location of the leaf. An X-ray source tube 8 of an X-ray source is installed next to those leaves 1. The thin, heavy metal leaves 1 can be electrically moved to create holes of desired shapes on exposure. A computer and intelligent algorithm will design an exposure pattern on the exposure panel, depending on the X-ray imaging data. There are two sides of this exposure panel, and each side has an independent movement of leaves 1. Then exposure panel will move to obtain exposure on a patient by combination of panel exposure at the rest of position. The exposure panel system will then create the exposure pattern. The exposure panel has an automatic exposure hole location on top of the leaves. An intelligent algorithm or operator will be able to locate regions of interest manually. After preset of locations of holes on exposure panel, the multi-leaf collimator 5 will perform collimation on multiples exposures dynamically during tomosynthesis scan on patients.

A rack or a frame holder 6 can be used to move leaves of module of the dynamic collimator 5 in the front of the X-ray source tube 8. The module can use individual leaf control signals to move leaves in parallel and perpendicular directions. Control signals

and the processing unit can determine the position of each individual leaf 1. Each individual leaf may be made of thin, heavy metal capable of blocking kV level X-rays. Two opposite banks of leaves 1 may be arranged parallel and stagger formation, and electrical motors can individually drive leaves. The system processor can control one or more leaf positions. When the region of interest (ROI) 11 is identified, the system processor can compute the number of needed leaves 1 and the positions of the leaves 1 so that the necessary X-ray beam 9 can be formed at the ROI 11 location. The module can also serve as collimation shutters for shielding unwanted radiation from the patients.

After shielding unwanted radiation, there will be much less scatter from patients and much less back scatter radiation from other background place. Therefore, images with better signal to noise ratio and better contrast at X-ray flat panel detector 14 can be achieved. Better contrast between various structures will result in increased lesion detection capability, better localization of true malignancy, and reduced operator variability due to more accurate target positioning.

Micro stepper motor 3 is connected to the leaf 1 via gear linkage. The motor controller is in communication with micro stepper motor 3 and position encoder, which reports the position of individual leaf 1. When the leaf is activated, it will move in X, Y-direction. As it moves in X, Y-direction, artificial intelligence or system operator self-learning can determine the region of interest (ROI) 11 and then determine the location of collimation holes dynamically. Therefore, subsequent X-ray imaging scans will be performed with automatic collimation dynamically. X-ray dose on the patient is then significantly reduced. To perform multi-beam scanning, it is necessary to set up multiple

leaf units. The system operator can arrange these leaf units to any area in 3-dimensional space to accomplish complete multi-beam scanning. A self-learning artificial intelligence can use prior data for decision-making to reduce potential misalignment errors. The present invention uses one collimation unit to do dynamic exposure control. Since there is only one beam change from one source for one collimation unit, the alignment error may be minimized.

Pinion gear 4 is supported by a spindle that is connected to the motor housing. The spindle has a gear mechanism that can drive the pinion. The pinion can move in the left or right direction along the track by control electronics. Pinion can drive one leaf via a transmission system with gear teeth 2 on the metal leaf 1. The transmission system transmits the motion of pinion to other leaves 1. Those metal leaves 1 are made of very thin material with high density, for example, lead alloy, copper alloy. Each leaf is moved forward or backward. The final direction depends on whether the pinion moves to the left or right. Two leaves 1 may be combined to form a pair, and they may be driven together by the same motor with different rotation directions. Therefore, multiple pairs of leaves can be driven by multiple pinions, thus creating a group of multiple X-ray exposure holes with the desired shape. Collimation opening size and shape can be altered dynamically during a single exposure scan. Each leaf's opening position and shape are pre-programmed according to the prescription or treatment plan before a scan is performed.

Frame holder 6 are rigid structures of material, for example, stainless steel. Holes are the actual openings on frame walls to allow x-ray beams 9 to pass through. They are large enough for most of patient body parts to fit into. The typical hole size is about 6mm

in diameter. Each hole has a motor controller to open and close the hole. X-ray source tube 8 generates X-ray beams 9 with intensity at an energy level sufficient to penetrate the entire thickness of the patient's body parts that are imaged. The collimator leaves can be adjusted in response to signals from X-ray flat panel detectors 14 to block or expose these unwanted radiations. A signal generator controls each motor controller. The signal generator may use an advanced method of machine learning to decide which motor controller to activate to keep the total dose on the imaged patient to the desired value.

Upper and lower banks of leaves are mounted in parallel to each other. The leaves 1 can move independently in Y directions under the control of an electric motor with controlled speed and position. Leaves are arranged in staggered formation. The front faces of upper and lower banks are connected to form an exposure hole. All leaves on the upper bank are movable up or down with a group. Similarly, all leaves on the lower bank are movable up or down with a group. Thus, upper and lower banks can form an exposure hole in the desired location with a defined shape.

A solid frame holder 6 supports a set of leaves. Each individual leaf 1 can be electrically driven to move in Y direction individually and X direction as group by the motor under the control system control. Thus, a leaf array of multiple leaves can form a collimator that provides a multi-hole collimation pattern on a specified region of interest (ROI) 11 on the patient during X-ray exposure. Therefore, different shape holes can be formed at the ROI 11 for performing multiple projections with the multiple pulsed X ray source-in-motion tomosynthesis imaging system 7. During the initial phase, artificial intelligence will learn from the detector and memorize the pattern of holes required on

specified ROI 11 on the patient after acquiring information from the detector. After the memorized pattern is verified, the next projection scan on specified ROI 11 on the patient will then be done with a dynamic multi-leaf collimator 5 system. Therefore, every time after a scan, a dynamic multi-leaf collimator 5 system will readjust the position of each leaf based on the pattern learned from the initial scan. In this way, the cumulative radiation dose on the specified ROI 11 on the patient will be significantly reduced because ROI view 13 is much smaller than full field of view 12.

The motor has a mechanical control interface for manual control. It allows the operator to interactively control leaf movement at any time during an X-ray scan. This design allows the operator to obtain different leaf pattern patterns at any time during the scanning process. Leaf pattern determines where the X-ray will pass through. The collimator hole pattern that covers the ROI 11 location is selected. Dynamic collimation is performed in both X and Y directions. Both X-direction leaf motions and the Y-direction leaf motions are controlled by electrical motors on each side of the system. Therefore, the dynamic collimation area for this system is a parallelogram shape with variable width. This allows for the specific selection of X-ray exposure area on the region of interest (ROI) 11. Collimation pattern designation is possible before the scan process.

Y-direction represents a vertical direction. The number of thin metal leaves placed at a specific location along the Y direction depends on the X-ray source tube 8 output kV level which varies. In this embodiment, three thin metal leaves 1 are used as an example to simplify the description. After a preliminary scan, ROI 11 can be

calculated by a computer program or radiologist. Then the system operator manually enters these ROIs to corresponding thin metal leaves 1. Using computer software control, each thin metal leaf 1 is driven by a linear actuator with a force sensor at both ends and a motor inside. The actuator can linearly move in the Y direction and produce a straight-line movement on a leaf 1.

X-direction is a movement direction of the X-ray source tube 8, which also means that the disclosed dynamic multi-leaf collimator is also movable. At one time, the leaves move in X-direction and Y-direction for collimation. In other words, after a pair of leaves in Y-direction form a hole and they then move in X-direction to correct location. At a pre-determined fixed position on the x-ray source tube 8, a collimation hole is made. The size of the collimation hole will have their maximum due to limitation of leaf and frame holder size. The lateral distance from this fixed position to a collimation location on the adjacent leaf can be different for different leaves. If leaves are mounted on motorized carriages, then lateral positions can be created with sets of carriages.

Fig. 2 illustrates that multi-leaf collimator 5 metal pieces can move in +X, -X directions as a group and move in +Y, -Y directions individually to create a single X-ray exposure hole. A collimator device, such as a collimator array, is positioned between the patient and the X-ray source tube 8. The collimator is designed to limit the x-ray beam to a region of interest (ROI) 11, including the lung nodule. However, unnecessary radiation exposure also occurs outside the ROI 11. X-ray radiation exposure on patients due to direct and scattered radiation contributes to the total dose and is usually referred to as effective dose (DE). DE includes dose to all tissues and organs, and it will not be

limited by dose on-air in surrounding tissue. Therefore, only reducing the dose of air in surrounding tissue will not significantly reduce DE on patients. Therefore, this one embodiment provides a method for further reducing the radiation dose on patients using a new type of dynamic multi-leaf collimator (DMLC). This one embodiment discloses a dynamic multi-leaf collimator system that can reduce radiation dose significantly. It has at least two opposite banks of thin, heavy metal leaves 1 arranged parallel and stagger formation. Electrical motors 3 individually drive the leaves, move straight in X and Y directions, and create multiple X-ray exposure holes with desired shapes. The leaves 1 are made of thin, heavy metal pieces capable of blocking kV level X-rays.

Independent leaf can be positioned by drive means to create exposure holes. The amount of movement, direction, and shape of the exposure hole can be determined by application software based on ROI 11 location, operator setting, self-learning algorithm, or artificial intelligence. For example, an exposure hole may be located outside the patient's lung region, which is more sensitive to radiation exposure, exposure hole may be used for chest imaging in which all organs in the chest region need to be exposed, and two exposure holes may be used for lungs image in which only right and left lungs need to be exposed. Thus, the one embodiment of the invention is directed to a system and method for simultaneously performing tomosynthesis and collimation in the same imaging procedure. Compared with the prior art, the method in this one embodiment of the invention is to determine the precise location of regions of interest (ROIs) 11 during the scan process and then use multiple X-ray sources tube 8 to perform digital tomosynthesis and a multi-leaf collimator 5 system to perform multiple dynamic collimations. These tomosynthesis system and collimator system work together

can significantly reduce radiation dose on patients and improve safety. The primary objective of this one embodiment of the invention is to design and develop a novel device and method to overcome the shortcomings in the prior art. Using multiple X-ray sources and collimation with motorized leaves 1, we provide a novel device and method to perform radiography and tomosynthesis imaging in the same scanning procedure and acquire a region of interest (ROI) 11 only with a reduced radiation dose.

A motor is used to drive the pair of opposite banks of thin, heavy metal leaves. The motor is driven by a controller, which can receive 110VAC input voltage power supply. Each pair of opposite banks of thin, heavy metal leaves are arranged in parallel and stagger formation. One leaf of each pair will be called an odd leaf, and another leaf will be called an even leaf. The odd leaf and even leaf form a pair. Each leaf is made of thin, heavy metal capable of blocking kV level X-rays. Control electronics electronically control these leaves under the control of the image processing module. Collimation hole positions are adjusted to regions of interest (ROI) 11 based on a knowledge base that stores various regions of interest (ROI) in patient anatomy. Once all collimation holes are calculated, the motor controller provides pulse signals to the motor to control odd leaf and even leaf movement simultaneously. With a multi-leaf system, collimation holes can be set at any shape for the desired region of interest (ROI). It is to be understood that both the preceding general description and the following detailed description are exemplary and explanatory only and are not restrictive of the invention, as claimed. The accompanying drawings, which 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.

A micro-controller or a computer controls the X-ray tube driver and the leaf's motor drivers. The controlling sequence is determined by the operator using the operation terminal. For multi-source DTS, during imaging scan on the region of interest (ROI), the computer reads the precise position of X-ray sources tube 8. Then it will generate a timing signal to control the leaf individually. For example, suppose multiple ROIs are present in one DTS projection. In that case, all leaves can be controlled independently based on their relative position to determine the shape of each ROI 11, thus creating different X-ray exposure holes with desirable shapes on the patient. The leaf is made of thin, heavy metal capable of blocking kV level X-rays. Since the leaves are thin, they can move quickly enough to produce sharp X-ray exposure holes. After the dynamic X-ray exposure, the tomosynthesis image can be reconstructed by a medical computer.

The opening holes of the collimator are shaped with various sizes, determined by shape recognition software. These opening holes can let X-rays go through. The heavy metal leaves are arranged in parallel with staggered formation. They are then driven by motors independently. Thus, after collimation decision by operator or self-learning AI, the leaf closest to the region of interest (ROI) will be selected firstly. Then another leaf is selected at the other side. This leaves only an opening suitable for the region of interest (ROI) while protecting other areas. After all, motors are controlled to open or close their respective leaves; the digital tomosynthesis imaging can start automatically due to dynamic leaf movement. No mechanical seal is needed for this system. Therefore, this system is more reliable and cost-efficient. The leaf movement could also be executed during the image capturing period. So, a correct FOV is ensured. After image capturing

is finished, the leaves will return to the initial position and be ready for the next radiographic scan. X-ray source tube 8 comprises X-ray flat panel detectors (FPDs) 14 that simultaneously collect X-ray emissions and send signals to the signal processing unit for digitization. A computer workstation with a much fast processor with multi-core is used as the signal processing unit.

X-ray beam 9 is shown coming from the top side of the figure and impinging on an adjustable multi-leaf collimator. The primary components of the system are the same regardless of the imaging device used. Each leaf is individually driven by an individual motor such that multiple leaves can be opened and closed in unison to produce multiple X-ray exposure holes. These holes may be shaped in any desired fashion and moved in both X and Y directions. For example, the holes may be shaped like circles, squares, ovals, rectangles, polygons, and other geometric shapes and may be configured to form any shape or pattern desired. In addition, the holes may be located anywhere in the system. For example, they may be arranged in a grid pattern, along one or more edges of the detector array, around the center of the detector array, in a random fashion, or any other manner.

X-direction refers to the horizontal direction. Y-direction refers to the vertical direction. The patient can be located on the bed, standing or seated on a chair. The relationship between patient and X-ray source tube 8 is also flexible. Both two opposite leaves are arranged in parallel. Each leaf has a collimation hole on them. One end of the leaf will form an overlapping area with an adjacent leaf where both leaves overlap, creating an exposure hole. Collimation holes are designed to expose one region of

interest with arbitrary shapes on each leaf. The patient may not be at the center of the exposure hole. The present embodiment uses system intelligence to design exposure holes that block exposure to outer regions while delivering exposure to a specific region of interest within the exposure hole and blocking exposure at other regions within the exposure hole. Collimation is an essential part of radiation protection. Still, the primary purpose of collimation is to deliver a dose to the target volume while reducing exposure to the rest of the body. Therefore, the exposure rate of collimation is usually very high.

Fig. 3 illustrates that in multiple pulsed X-ray source-in-motion tomosynthesis imaging system 7, two regions of interest (ROI) 11 are produced and need to be re-scanned using the dynamic collimation system to achieve better images and shield other nearby regions. Multiple pulsed X-ray source-in-motion tomosynthesis imaging system 7 uses multiple pulsed X-ray sources in motion to perform high-efficient and ultrafast 3D radiography. There are multiple pulsed X-ray sources mounted on a structure in motion to form an array of sources in the system. The multiple X-ray sources move simultaneously relative to an object on a predefined arc track at a constant speed as a group. Each individual X-ray source can also move rapidly around its static position at a small distance. When an individual X-ray source has a speed equal to group speed, but with opposite moving direction, the individual X-ray source and X-ray detector are activated through an external exposure control unit. This arrangement allows the X-ray source to stay relatively standstill during the X-ray source activation and X-ray detector exposure. X-ray receptor is an X-ray flexible curved panel detector. Multiple X-ray source in motion operation results in much-reduced source travel distance for individual X-ray sources. 3D radiography image data can be acquired

with an overall wider sweep angle in a much shorter time, and image analysis can also be done in real-time while the scan goes.

Originally X-ray beam 9 covers a full field of view 12. However, at regions of interest (ROI) 11, there are much narrower ROI view 13. Two ROIs 11 are imaged by specific part of X-ray flat panel detector 14. The multi-leaf collimator (MLC) 5 comprises two opposite banks of thin, heavy metal leaves 1 arranged parallel and stagger formation. Electrical micro stepper motors 3 individually drive the leaves, move straight in Y directions. Frame holder moves in X direction and create multiple X-ray exposure holes with desired shapes. The leaves are made of thin, heavy metal capable of blocking kV level X-rays. Furthermore, the multi-leaf collimator 5 is movable along the axis for fine adjustment of each leaf. The driving mechanism used to control the movement of the multi-leaf collimator 5 is to use a mechanical motor gear 4. The motor is supported by a shaft that can be raised or lowered to position MLC. Power for the motor is supplied from the external power supply unit. The coupling between shaft and motor is made with bearings. The combination of these components enables high accuracy and reliability. A tomosynthesis imaging system and collimation system can form a tomosynthesis multiple leaf collimator (TMLC) imaging system. Multiple X-ray sources tube 8 and collimator 5 systems can also be configured together as an X-ray source block.

An array of collimators is installed along an array of source. Thus, there is a little time as possible between the radiation exposure the data acquisition. An electronic controller with self-learning artificial intelligence can determine the location of the region

of interest (ROI) and then determine the location of collimation holes dynamically. Therefore, subsequent X-ray imaging scans will be performed dynamically with automatic collimation; the X-ray dose on the patient is significantly reduced. Contrary to conventional systems, where predefined collimator hole patterns for different X-ray sources and FOV sizes must be stored in a database and kept updated, therefore current embodiment of the invention eliminates the need for prior art collimator size database, and system-designed limited field of view (FOV) or collimator holes shapes cannot be supported by current system.

Moreover, the current system also does not require any manual tuning of pre-programmed motor speed and distance. Instead, the system operates autonomously after the radiographer sets initial exposure parameters and indicates a region of interest for measurement; the computer controls the whole exposure process, processing and comparing images. Therefore, exposure can be highly flexible depending on the region of interest (ROI) needs.

In response to the detection of a desired region of interest (ROI), the external exposure control unit instructs an associated multi-leaf collimator 5. The multi-leaf collimator is controlled via a computer with appropriate programming to operate according to pre-determined steps. The movement of each of the leaves of the multi-leaf collimator is synchronized with the movements of the gantry. The movement of the multi-leaf collimator 5 is also based on a pre-determined plan. By adopting the position of the leaves with the focal spot of the X-ray source tube 8, a hole is formed for use as a

"viewport" through which the region of interest (ROI) can be subjected to a high-resolution digital X-ray image.

X-ray flat panel detector 14 or solid-state detector arrays may be mounted to or within the collimator and imaged onto a computer system for subsequent image processing. Collimator also may be adapted to be translated about the longitudinal axis. Orientation of the collimator may be determined by a rigid rotational element attached to or formed as part of the support member. The detector and the collimator may move with respect to each other such that a constant distance between the detector and the target area may be maintained during procedures. The fixed geometry of the collimator may allow radiation from a single source or multiple sources to strike a single portion of the target area at one time so that any resulting images captured from those multiple radiation events can be processed to generate a three-dimensional image.

Tomosynthesis image data contains 3-dimensional reconstructed X-ray images, and it's popular for many reasons. Conventional radiography images are limited to the 2-dimensional sectional views along with single viewports. These limitations make it challenging to assess lesions near each other, leading to inappropriate treatment decisions and incorrect treatment courses. The volumetric information of tomosynthesis images allows physicians to make more accurate treatment courses, tumor follow-up, and overall diagnosis. In addition, the 3-dimensional data generated by tomosynthesis devices can be processed into 2-dimensional images for further analysis and interpretation. Since conventional 2-dimensional X-ray imaging systems do not use the tomosynthesis imaging technique, the 2-dimensional image generated by a

tomosynthesis device cannot substitute for conventional 2-dimensional images generated by a non-tomosynthesis imaging system. However, both kinds of 2-dimensional images generated by different imaging systems contain significant amounts of overlapped anatomy and composite artifacts that hinder proper evaluation and management of diseases and diseases progression. In particular, some multi-source digital tomosynthesis (MS-DTS) systems such as MS-DTS described above uses multiple collimation holes to allow regions of interest (ROI) to pass through and expose for multi-sources. If the ROI is big enough, then no exposures outside of ROI will occur, and no excessive dose on the patient will happen.

X-ray tubes source tube 8 are located on the back of the leaf. The collimator has multiple leaves which can move in Y-direction individually. The leaves can also move in X-direction as a group. Individual motors can drive each leaf. A microcontroller performs motor control. Therefore, each leaf 1 can be moved individually, or they can all be moved simultaneously. A computer is provided for the system operator to perform collimation positioning. It is noted that various features of the invention which are, for clarity, described in the context of separate embodiments may also be provided in combination in a single embodiment. Conversely, various features of the invention which are, for brevity, described in the context of a single embodiment may also be provided separately or in any suitable sub-combination. Although the invention has been described in conjunction with specific embodiments thereof, it is evident that many alternatives, modifications, and variations will be apparent to those skilled in the art.

This embodiment of the invention describes a method for significant dose reduction using a dynamic multi-leaf collimator. Dynamic multi-leaf collimators can create multiple X-ray exposure holes with desired shapes, similar to the multi-leaf collimator disclosed in previous patents of the applicant. This technology can significantly reduce the patient dose. After a preliminary X-ray imaging scan, self-learning of artificial intelligence or system operator can determine the location of the region of interest and then dynamically determine the location of collimation holes. Therefore, subsequent X-ray imaging scans will be performed with automatic collimation dynamically; the X-ray dose on the patient is significantly reduced.

X-ray flat panel detector 14 is mounted at the end of the arm. The detector comprises a DTS array for multi-source digital tomosynthesis imaging and image reconstruction. Mounted on the outer surface of the arm are multiple X-ray sources for simultaneous multi-source digital tomosynthesis imaging and image reconstruction. Advantageously, this method can significantly reduce patient radiation dose and proposal as an alternative to traditional radiography follow-up and replace traditional high-dose chest CT. All known systems on prior art require that specific pre-scanned image data be available for patient imaging. The information of ROI used in the above-proposed method will then be determined based on a statistical analysis of pre-scanned images of multiple patients. This method is proven to reduce the patient radiation dose by a large factor compared to a typical high-dose chest CT scan. Thus, this system is ideal as an alternative to high-dose chest CT scan follow-up for pulmonary nodules in a lung cancer screening program.

In Figure 3, it illustrates that two regions of interest are focused on using the dynamic multi-leaf collimator system. The shape of the X-ray exposure holes determines the shape of the X-ray beam passing through the patient or object 10, while the rest of the beam is blocked by the leaves. In one configuration, the top and bottom leaves form an alternating array, with a frame holding the leaves together. The X-ray exposure holes can be formed in any desired position on the X-ray field of view (FOV). After a preliminary DTS scan, in one embodiment, an artificial intelligence (AI) will decide the region of interest based on pre-scan image data and system operator. This embodiment uses a multi-leaf collimator 5 with multiple flexible leaves arranged parallel and stagger formation to create dynamic X-ray exposure holes. The X-ray exposure holes have the same shape as the region of interest (ROI). In this way, the effective dose on the patient is significantly reduced without compromising diagnostic quality. In addition, it is very simple to adjust the shape of the X-ray exposure holes because all the motion mechanism is from motorized drives with precision, so X-ray dose reduction is stable and reliable. The overall system comprises a multi-source digital tomosynthesis imaging system and a multi-leaf collimator 5. During the first phase, the first number of X-ray exposures are taken from a subject to create a set of image data. A portion of the image data that is to be considered as a region of interest (ROI) is determined. Subsequently, during a second phase, the second number of X-ray exposures are taken from the subject using the multi-leaf collimator 5 to expose a region of interest (ROI).

The patient or object 10 is shown at the center of the screen in the current system. There are five source X-ray tubes located around the patient; the source tube

rotates clockwise, their rotation speed and angle are calculated by computer. An operator is given the option to change or choose rotation speed and angle. Because of rotation and translation of five source X-ray tubes and non-symmetrical positioning of X-ray flat panel detector 14, each projection has different radiation angles. So, each projection produces different images with partial overlap. Then, the overlapping images are added together to reconstruct an image with precise anatomical details. Dynamic collimation effectively reduces the dynamic region of interest exposure because of having multiple sources. For example, when performing DTS for detecting pulmonary nodules, a specific region of interest (ROI) is only 10cm×10cm, so after automatic learning using tomographic images, the X-ray collimator will be adjusted automatically to 10cm×10cm field of view (FOV) size for each source. At each source position, frames are taken to generate DTS image. At each frame, a different FOV can be selected automatically. If an anatomically critical structure is found, the collimator will be changed dynamically. So, at each source position, FOV is selected automatically to take DTS image sequentially. Therefore, each projection will not be shown on the screen at the same time.

Multi-leaf collimator (MLC) 5 is an alternative solution. It is motorized to perform x-ray exposure dynamically and block unwanted exposure areas on patients while exposing the region of interest (ROI) 11. The multi-leaf collimator 5 can be realized with different leaf-shape and materials, and therefore can be designed to expose different shapes of ROI, such as quadrant-shaped, wedge-shaped, etc. This will be particularly important for a field-size reduction in DTS systems. Furthermore, this embodiment of the invention covers many leaf geometries that can achieve dynamic X-ray exposure

due to motorized design. These leaves may be made of thin heavy metal sheets and be motorized for dynamic movement in Y and X directions to create multiple exposure holes for the tomosynthesis imaging task.

The motor may be a stepper motor, or other motors capable of moving one or more metal leaves in X-ray exposure holes. Similarly, although not shown, motors may be used to move metal leaves in the X, Y-direction of the view plane. The control unit's motor and electronic components may be mounted on or affixed to the frame and interconnected via a wired or wireless connection. The control unit's motor and electronic components may be mounted on or affixed to the frame and connected to the bus via wired or wireless connection. One skilled in the art will recognize that many interconnecting components are available, and such techniques are not described herein. Metal leaves may be made of any heavy metal capable of blocking kV level X-rays, for example, lead, tungsten, copper, etc.

Imaging detector may be implemented as a single large array detector or multiple detector arrays. When implemented as multiple detector arrays, the imaging detector may have a region of interest (ROI) that includes sub-arrays or sub-regions. Sub-arrays may be associated with sub-regions on the patient. The present system provides a method for performing multi-source digital tomosynthesis by detecting x-ray transmission intensity through an X-ray transmission object. A dynamic multi-leaf collimator may be placed before the imaging detector to provide a collimation function for multi-source tomosynthesis. Motors drive the multi-leaf collimator to create a dynamic set of holes. Holes are created with desired shapes by moving the leaves in X,

Y directions. The control unit controls the motors. The dynamic multi-leaf collimator is operated during each exposure step to form at least one hole corresponding to the region of interest of the patient. This way, only the region of interest (ROI) 11 will be exposed. The rest of the region outside the region of interest can be coaxially blocked or under-exposed.

It is to be understood that both the preceding general description and the following detailed description are exemplary and explanatory only and are not restrictive of the invention, as claimed. Further, elements or components may be omitted or substituted for those described herein, other elements or components may be added to it, and the arrangement of elements or components may be altered without departing from the scope of the invention.

Typical operation procedure of a dynamic multi-leaf collimator system may be following. In select task, before the patient enters the room, a preliminary X-ray imaging scan is performed. After that, a full-body multi-source tomosynthesis scan is performed for definitive diagnosis. The operator can select tasks based on the preliminary imaging results and evaluation from a system operator or automated intelligent learning. The region of interest will be chosen in the body organs or anatomic structures of interest, depending on the examination objective. Other areas can be ignored during further examinations. In addition, if prior art has been used to diagnose the disease, the region of interest will also be determined according to previous diagnostic results. Finally, a multiple-source tomosynthesis scan is performed based on selected tasks and tasks.

The system acquires several initial projection images from selected tubes to locate the target area, an example of these initial projection images. This invention does not limit the number of tubes, but five tubes are selected for illustration purposes. These tubes are arranged in parallel to the X-ray source array. Next step, the system learns the target location of the region of interest by pattern recognition method. After learning, the pattern recognition module transfers the coordinate information of the target region of interest to a control circuit. Then control circuit moves a dynamic multi-leaf collimator and performs a final scan with multiple sources. Therefore, patient dose can be reduced dramatically. When an imaging task is completed, the system returns to the initial scanning state. Then, the next task can be started. In another embodiment, one or more sources can be replaced by a combined fluoroscopy unit. In another aspect of the present invention, a dynamic multi-leaf collimator for X-ray exposure on the region of interest in conjunction with a multi-source tomosynthesis imaging system is disclosed. The system comprises two opposite banks of thin, heavy metal leaves arranged in parallel and stagger formation. Electrical motors drive the leaves, move straight in X and Y directions, and create multiple X-ray exposure holes with desired shapes. The leaves are made of thin, heavy metal capable of blocking kV level X-rays.

The system accumulates all projection images and reconstructs 3D tomosynthesis image volume. Artificial intelligence engine is the artificial intelligence engine responsible for making complex decisions, providing outputs to control other system components, providing inputs to the decision-making process. The main tasks of the artificial intelligence engine are to identify regions of interest in projection images, analyze regions of interest using deep learning technology, control other system

components, and perform processing of medical images and radiation dose management. The tomosynthesis image volume can be displayed with visualization tools such as line representation and the surface mesh model of ROI 11. The visualization tools show how big is the region of interest and its border and orientation with respect to X-ray tube location. The leaves are individually driven by electrical motors capable of moving straight lines in X and Y directions and creating multiple X-ray exposure holes with desired shapes. Thin, heavy metal plates make up the backside of each leaf and block the high-level X-rays. After a preliminary X-ray imaging scan, artificial intelligence or system operator self-learning can determine the location of the region of interest and then dynamically determine the location of collimation holes. Therefore, subsequent X-ray imaging scans will be performed with automatic collimation dynamically; the X-ray dose on the patient is significantly reduced.

The system analyzes image volume to find out ROI 11. When exposure is planned, the system sets collimation to prevent exposure of region outside ROI 11. The patient dose will be reduced if ROI 11 is well located in the system or kept unchanged if well-set initially. If a region outside ROI 11 has to be exposed to create other views, the exposure area will be adjusted by moving the heavy metal leaves.

If application is for lung cancer screen etc., onboard AI system automatically searches lung nodules in pre-defined lung zones or breathing motion zones using X-ray tomosynthesis images. A targeted ROI 11 with a suspected lung nodule is selected, a set of differential projection data with pre-selected size and shape is extracted from the ROI 11. A collimation hole is created by moving the array of leaves with respect to a

gantry angle axis using a linear array of leaves, with each leaf containing a transparent X-ray plate at its backside. In a preferred embodiment, dual-source DTS systems, the array is designed symmetrically with two equal banks of leaves on both sides of a centerline of the X-ray source tube 8.

Various modifications and alterations of the invention will become apparent to those skilled in the art without departing from the spirit and scope of the invention, which is defined by the accompanying claims. It should be noted that steps recited in any method claims below do not necessarily need to be performed in the order they are recited.

Those of ordinary skill in the art will recognize variations in performing the steps from the order in which they are recited. In addition, the lack of mention or discussion of a feature, step, or component provides the basis for claims where the absent feature or component is excluded by way of a proviso or similar claim language.

While various embodiments of the present invention have been described above, it should be understood that they have been presented by way of example only and not of limitation. The various diagrams may depict an example architectural or other configuration for the invention, which is done to understand the features and functionality that may be included in the invention. The invention is not restricted to the illustrated example architectures or configurations, but the desired features may be implemented using a variety of alternative architectures and configurations.

Indeed, it will be apparent to one of skill in the art how alternative functional, logical, or physical partitioning and configurations may be implemented to implement the desired features of the present invention. Also, many different constituent module

names other than those depicted herein may be applied to the various partitions. Additionally, with regard to flow diagrams, operational descriptions, and method claims, the order in which the steps are presented herein shall not mandate that various embodiments be implemented to perform the recited functionality in the same order unless the context dictates otherwise.

Although the invention is described above in terms of various exemplary embodiments and implementations, it should be understood that the various features, aspects, and functionality described in one or more of the individual embodiments are not limited in their applicability to the particular embodiment with which they are described, but instead may be applied, alone or in various combinations, to one or more of the other embodiments of the invention, whether or not such embodiments are described and whether or not such features are presented as being a part of a described embodiment. Thus, the breadth and scope of the present invention should not be limited by any of the above-described exemplary embodiments.

Terms and phrases used in this document, and variations thereof, unless otherwise expressly stated, should be construed as open-ended as opposed to limiting. As examples of the previous: the term "including" should be read as meaning "including, without limitation" or the such as; the term "example" is used to provide exemplary instances of the item in the discussion, not an exhaustive or limiting list thereof; the terms "a" or "an" should be read as meaning "at least one," "one or more" or the such as; and adjectives such as "conventional," "traditional," "normal," "standard," "known" and terms of similar meaning should not be construed as limiting the item described to a given time or to an item available as of a given time, but instead should be read to

encompass conventional, traditional, normal, or standard technologies that may be available or known now or at any time in the future. Hence, where this document refers to technologies that would be apparent or known to one of ordinary skill in the art, such technologies encompass those apparent or known to the skilled artisan now or at any time in the future.

A group of items linked with the conjunction "and" should not be read as requiring that every one of those items be present in the grouping, but rather should be read as "and/or" unless expressly stated otherwise. Similarly, a group of items linked with the conjunction "or" should not be read as requiring mutual exclusivity among that group, but rather should also be read as "and/or" unless expressly stated otherwise. Furthermore, although items, elements, or components of the invention may be described or claimed in the singular, the plural is contemplated to be within the scope thereof unless limitation to the singular is explicitly stated.

The presence of broadening words and phrases such as "one or more," "at least," "but not limited to" or other such as phrases in some instances shall not be read to mean that the narrower case is intended or required in instances where such broadening phrases may be absent. The term "module" does not imply that the components or functionality described or claimed as part of the module are all configured in a common package. Indeed, any or all of the various components of a module, whether control logic or other components, may be combined in a single package or separately maintained and may further be distributed across multiple locations.

Additionally, the various embodiments set forth herein are described in exemplary block diagrams, flow charts, and other illustrations. As will become apparent to one of ordinary skill in the art after reading this document, the illustrated embodiments and their various alternatives may be implemented without confinement to the illustrated examples. For example, block diagrams and their accompanying description should not be construed as mandating a particular architecture or configuration.

The previous description of the disclosed embodiments enables any person skilled in the art to make or use the present invention. Various modifications to these embodiments will be readily apparent to those skilled in the art. The generic principles defined herein may be applied to other embodiments without departing from the spirit or scope of the invention.

Thus, the present invention is not intended to be limited to the embodiments shown herein but is accorded the most comprehensive scope consistent with the principles and novel features disclosed herein.

While there has been shown several and alternate embodiments of the present invention, it is to be understood that specific changes can be made as would be known to one skilled in the art without departing from the underlying scope of the invention as discussed set forth above and below. Furthermore, the embodiments described above are only intended to illustrate the principles of the present invention. They are not intended to limit the scope of the invention to the disclosed elements.

Claims

What is claimed is:

1. A method of imaging an object radiographically with multiple X-ray source-in-motion tomosynthesis imaging system, comprising:

scanning an object with an X-ray full view using multiple X-ray source-in-motion tomosynthesis imaging system;

locating region of interest using artificial intelligence after an initial scan;

determining a dynamic collimation map for each of X-ray tubes;

applying a dynamic collimation map to motion control of the X-ray tubes; and

re-scanning the object using a multi-leaf dynamic collimator with X-ray beam only limited on the region of interest.

2. The method of claim 1, comprising mounting oppositely positioned heavy metal thin leaves with notches between the leaves to block radiation leakage.

3. The method of claim 1, comprising providing leaves-on-one-rack as one structure, wherein the rack is moved by a stepper motor.

4. The method of claim 1, comprising mounting one or a plurality of X-ray blocking leaves on a multi-leaf frame and moving the multi-leaf frame in a first direction

5. The method of claim 4, comprising moving one or more X-ray blocking leaves in a second direction.

6. The method of claim 1, comprising moving one or more x-ray blocking leaves to form an X-ray exposure window for a multiple X-ray source-in-motion tomosynthesis imaging system.

7. The method of claim 1, comprising moving multiple X-ray sources simultaneously around an object on a pre-defined track.

8. The method of claim 1, comprising mounting multiple pulsed X-ray sources on a mobile structure to form a source array and wherein each X-ray source is pulsed independently through an external exposure control unit.

9. The method of claim 8, wherein each individual X-ray source moves around a first position and when synchronized with the source array moving around a second position, controlling the X-ray sources to stay still during X-ray exposure.

10. The method of claim 1, comprising:

acquiring initial projection images from selected X-ray sources until a predetermined projection image threshold is met;

reconstructing a 3D tomosynthesis image volume from the projection images; and

searching for one or more lung nodules from the reconstructed 3D tomosynthesis image volume using machine learning.

11. An X-ray imaging apparatus, comprising:

a multiple pulsed X-ray source-in-motion tomosynthesis imaging system；

a or a plurality of dynamic collimators in front of each of X-ray tubes and including:

a plurality of heavy metal thin leaves each movable in a first direction; and

a frame that holds the heavy metal thin leaves moveable in a second direction.

a or a plurality of motor controllers to control multiple motors to move the frame and the leaves; and

a processor to control the multiple motors.

12. The system of claim 11, wherein oppositely positioned leaves with notches between the leaves are positioned to block radiation leakage from a multiple pulsed X-ray source-in-motion tomosynthesis imaging system.

13. The system of claim 11, wherein leaves are mounted on a rack as one structure, wherein the rack is moved by a stepper motor.

14. The system of claim 11, comprising one or a plurality of X-ray blocking leaves mounted on a multi-leaf frame and the multi-leaf frame moved in a first direction

15. The system of claim 14, wherein one or a plurality of X-ray blocking leaves are moved in a second direction.

16. The system of claim 11, wherein one or a plurality of x-ray blocking leaves are moved to form an X-ray exposure window.

17. The system of claim 11, comprising a motor to move multiple pulsed X-ray sources simultaneously around an object on a pre-defined track.

18. The system of claim 11, comprising multiple pulsed X-ray sources mounted on a mobile structure to form a source array.

19. The system of claim 18, wherein each X-ray source is pulsed independently through an external exposure control unit and wherein each individual X-ray source moves around a first position and when synchronized with the source array moving around a second position, controlling the X-ray sources to stay still during X-ray imaging.

20. The system of claim 11, wherein the processor executes computer readable code to:

acquire initial projection images from selected X-ray sources until a predetermined projection image threshold is met;

reconstruct a 3D tomosynthesis image volume from the projection images; and

identify one or more lung nodules from the reconstructed 3D tomosynthesis image volume using machine learning.

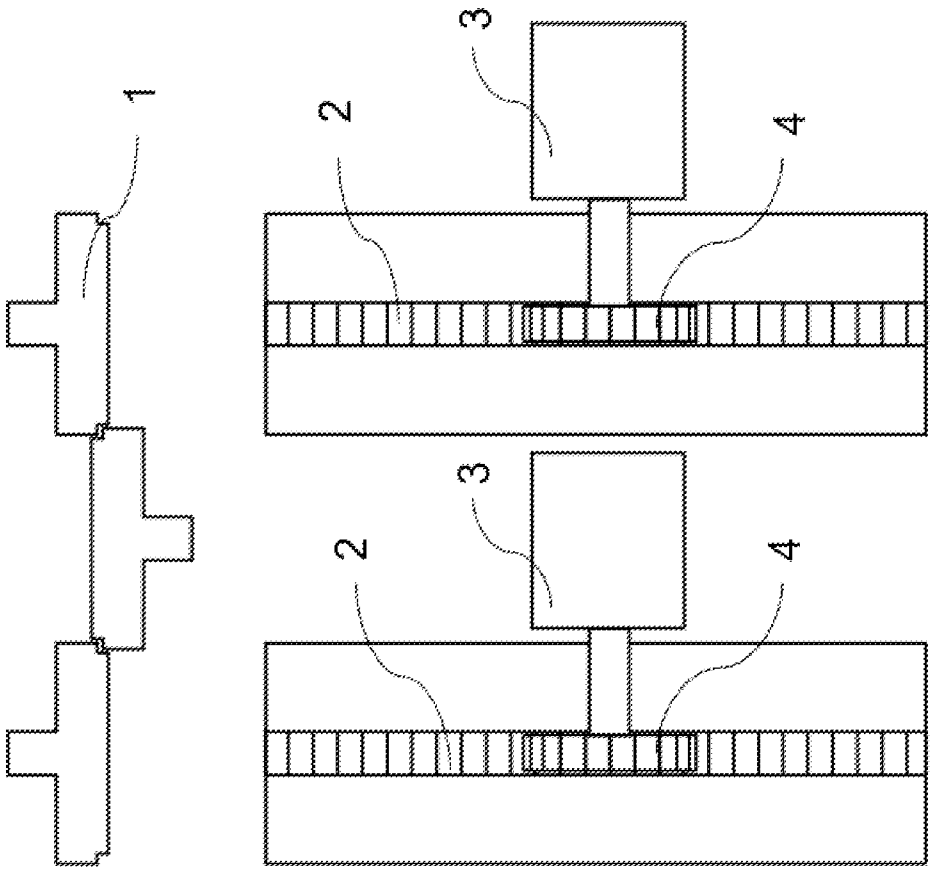

FIG. 1

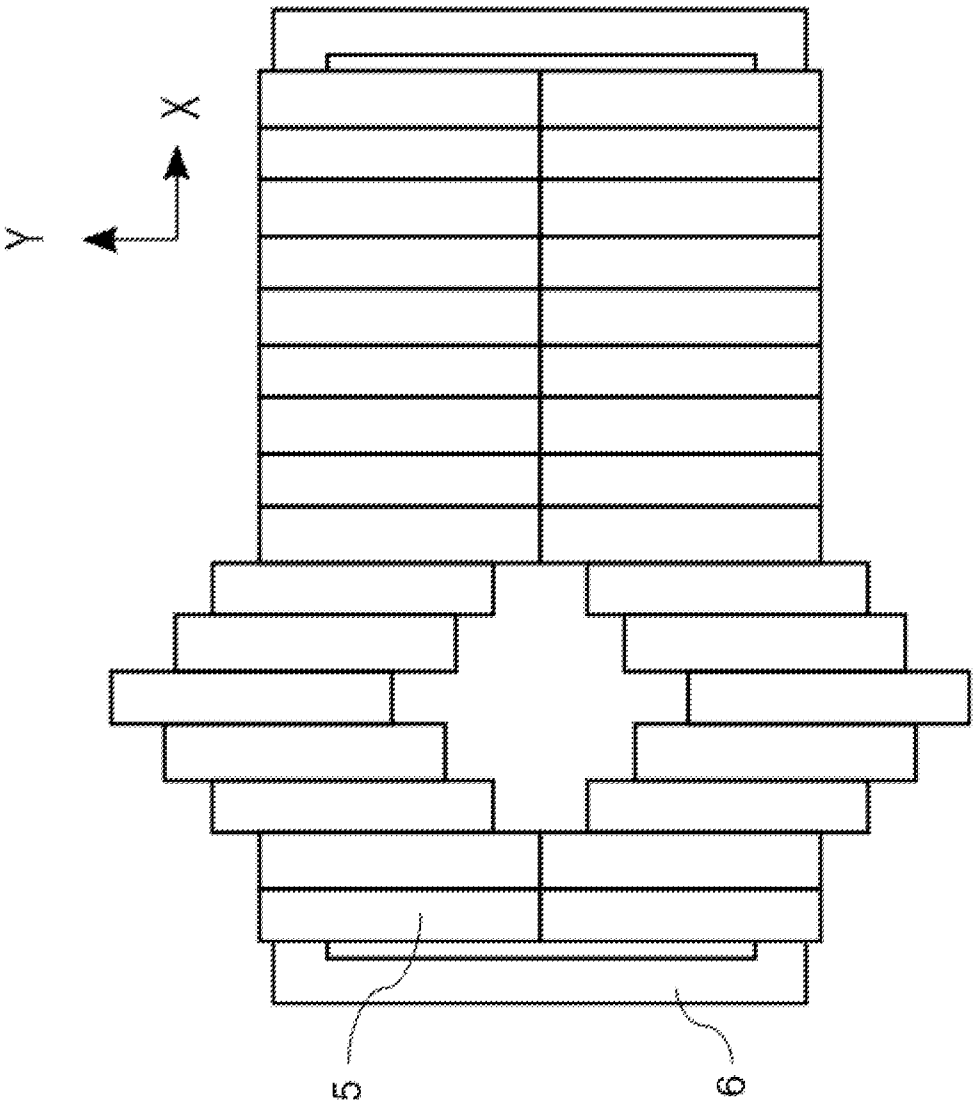

FIG. 2

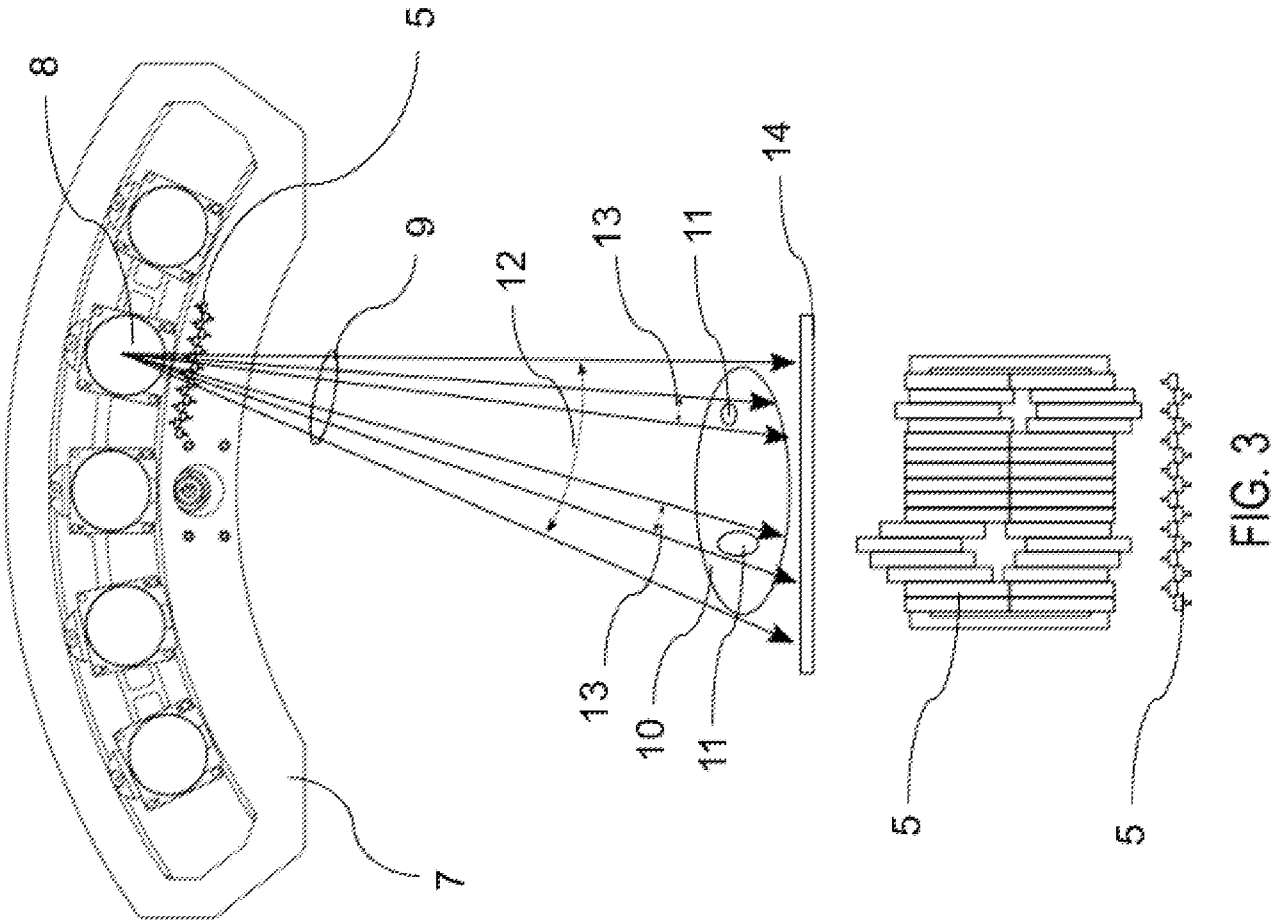

FIG. 3

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US 22/20128

A. CLASSIFICATION OF SUBJECT MATTER

IPC - G21K 1/04, G21K 1/02; A61B 6/02 (2022.01)

CPC - G21K 1/04, G21K 1/025, G21K 1/02; A61B 6/025, A61B 6/4007

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
See Search History document

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

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

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y --- A	US 2020/0345318 A1 (TURNER INNOVATIONS, LLC) 05 November 2020 (05.11.2020), para [0005], [0029], [0031], [0032], [0048], [0051], [0053], [0057], [0061]; Fig 6, 10	11-18, 20 --- 8, 9, 19
Y --- A	US 4,868,843 A (NUNAN) 19 September 1989 (19.09.1989), col 4, ln 16-18, 36-43, 61; col 9, ln 40-47; col 10, ln 7-11; col 12, ln 7-8; col 15, ln 29-32; col 16, ln 23-24; col 17, ln 12-14, 28-30; col 19, ln 61-64; Fig 23	2-5, 11-18, 20 --- 19
Y --- A	US 2016/0262710 A1 (RAYENCE CO.,LTD.) 15 September 2016 (15.09.2016), para [0011], [0042], [0044]; Fig 3	1-7, 10 --- 8, 9
Y --- A	US 2020/0016432 A1 (REFLEXION MEDICAL, INC.) 16 January 2020 (16.01.2020), para [0002], [0006], [0027], [0050]	1-7, 10 --- 8, 9
Y --- A	US 2020/0167917 A1 (DOUGLAS et al.) 28 May 2020 (28.05.2020), para [0002], [0004], [0013], [0038]	1-7, 10 --- 8, 9
Y	US 2019/0325621 A1 (RENSSELAER POLYTECHNIC INSTITUTE) 24 October 2019 (24.10.2019), para [0003], [0061], [0062]	10, 20

☐ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

* Special categories of cited documents:
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"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
"O" document referring to an oral disclosure, use, exhibition or other means
"P" document published prior to the international filing date but later than the priority date claimed
"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
14 June 2022	JUL 26 2022
Name and mailing address of the ISA/US Mail Stop PCT, Attn: ISA/US, Commissioner for Patents P.O. Box 1450, Alexandria, Virginia 22313-1450 Facsimile No. 571-273-8300	Authorized officer Kari Rodriquez Telephone No. PCT Helpdesk: 571-272-4300