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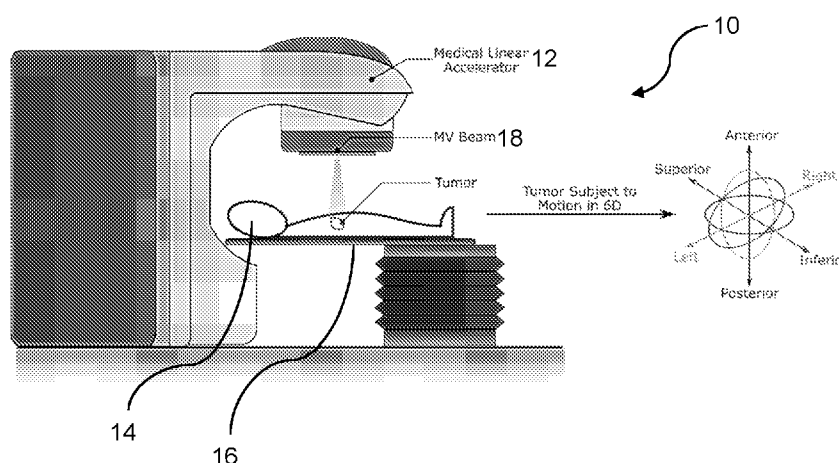


FIG. 1

(57) Abstract: Disclosed is a system for monitoring dosimetry and motion tracking of a guided radiation therapy system. The system includes a phantom configured to be sensed by a tracking system associated with the guided radiation therapy system; and a manipulator to which the phantom is mounted, and which is configured to move the phantom along at least 3 axes and about at least 1 axis. A radiation detector may also be associated with the phantom to sense radiation received from the guided radiation therapy system. A method for dosimetry and motion tracking is also disclosed.

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DOSIMETRY MONITORING AND MOTION TRACKING OF A GUIDED RADIATION THERAPY SYSTEM

Field of the disclosure

The present disclosure relates to systems and methods for use in relation to guided
5 radiation therapy systems. In one form there is disclosed a system monitoring dosimetry and
motion tracking of a guided radiation therapy system. In another form there are provided
methods for monitoring one or both of dosimetry and motion tracking. A phantom is also
disclosed.

Background of the disclosure

10 Radiation therapy or radiotherapy is a treatment modality used to treat tumours. It
generally involves producing high energy conformal beams of X-rays to the target (tumour)
using a medical linear accelerator. The radiation interacts with the tissues to create double strand
DNA breaks to kill tumour cells. Radiotherapy requires high precision to deliver the dose to the
tumour and spare healthy tissue, particularly that of organs surrounding the tumour. Each
15 treatment is tailored to a patient-by-patient basis.

Tumour motion during treatment can cause large radiation doses to be delivered to
critical structures and healthy tissue, leading to suboptimal dosimetry (dose coverage outside the
tumour). Motion management in radiation therapy also known as motion adaptive radiotherapy
has become vital in delivering accurate dose coverage and limiting toxicities to healthy tissue.
20 With the increase use of stereotactic body radiation therapy (SBRT), which delivers high doses
in small fractions within a small field size (small X-ray beam size), motion management
becomes extremely significant to allow conformal high doses to be delivered to the target site
whilst sparing healthy tissue.

In radiotherapy each treatment is personalised to the individual patient. Some patient
25 plans require the treatment system to operate near the limits of its capability. Consequently there
is a need to check that the machine can handle the individual plans in order to maintain accurate
radiation delivery. Quality assurance (QA) is a rehearsal for the actual treatment to ensure that

the optimal radiation dose is correctly delivered to the patient. Thus, quality assurance is an extremely important component of radiation therapy and is required for every patient.

Motion adaptive radiotherapy has created a problem with quality assurance, since these systems can track tumour motion, validation of the geometric accuracy (tracking tumour motion) is needed in addition to measuring the prescribed radiation dose. Also, tracking systems add uncertainty to each treatment plan delivery, thus commissioning of each system becomes extremely important to make sure these new radiotherapy systems can perform over the range of patient plans and complex tumour motions.

During quality assurance, a phantom is used to mimic the patient. An ideal quality assurance motion phantom needs three functionalities:

- 1) Equivalence to human tissue in terms of how an X-ray beam interacts with it;
- 2) Ability to mimic patient motion (geometric quality assurance), for example, breathing or other organ motion; and
- 3) Ability to determine the delivered radiation dose to the patient (dosimetric quality assurance).

A variety of motion management systems are currently used for prostate and lung cancer patients undergoing radiation therapy. These include CyberKnife (Accuray, Sunnyvale, CA), Calypso (Varian, Palo Alto, CA), MHI Vero tracking gimbaled linear accelerator (Mitsubishi Heavy Industries, Ltd., Japan and BrainLAB AG, Feldkirchen, Germany), and MRIdian (Viewray, Oakwood, OH).

Recently a new approach to monitoring patient motion has been developed named Kilovoltage Intrafraction Monitoring (KIM). KIM is a real-time image guidance technique that utilises existing radiotherapy technologies found in cancer care centres (i.e. on-board X-ray images). KIM exploits fiducial markers implanted inside the tumour (organ) and reconstructs their location by acquiring multiple images of the target using the on-board kilovoltage (kV) beam which is a low energy X-ray imager and determines any motion in the left-right (LR), superior-inferior (SI), and anterior-posterior (AP) directions.

KIM tracking has also been developed which dynamically modifies the multileaf collimator (MLC) position while delivering the treatment dose base of the tumour position reconstructed by KIM. KIM-gated radiation therapy is currently used to treat prostate cancer patients at multiple cancer centres and could also be expanded to treat lung cancer patients in the near future. In KIM, tumour motion is monitored in real-time while both the treatment X-ray beam is delivering the treatment dose and the imaging X-ray beam is imaging the tumour target. If significant motion away from the treatment beam occurs the treatment is paused and the patient is repositioned before the treatment is continued.

MLC tracking is another motion adaptive radiotherapy technology that can move the radiation beam and follow the tumour motion. This technology is currently used to treat lung cancer patients (LIGHT-SABR trial) under TROG. Adaptive CT acquisition for personalised thoracic imaging (ADAPT trial) is a new technology that is used to account for motion in the CT scans before treatment.

There are a limited number of commercially available quality assurance motion phantoms. These existing systems are restricted in either flexibility in angular rotation, axis of motion, and/or ability to perform both geometric and dosimetric measurements. The HexaMotion (HexaMotion™, Scandidos, Uppsala, Sweden) system is a current motion platform available for quality assurance. However, the system is only limited to five degrees of freedom, i.e. motion along three linear axes and about two rotational axes. It is also limited in angular rotation with angles of $\pm 10^\circ$ and $+3^\circ/-6^\circ$, in the Superior/Inferior (SR) and Left/Right (LR) directions respectively with no yaw motion available about the Anterior/Posterior (AP) axis. Larger angular flexibility is required to simulate true organ motion, as prostate rotations are observed over 15° , with lung tumour rotations along the LR direction observed to move up to 45° . CIRS Dynamic Platform (CIRS Inc., Norfolk VA, USA) is another motion system for quality assurance however the system is only limited in two degrees of freedom (2D) (movement along the SI and AP axes) with no rotational capabilities.

The lack of an available quality assurance device has limited the adoption of this technology across radiotherapy centres in Australia and throughout the world.

Accordingly, it would be beneficial to have an improved phantom for quality assurance for a radiation therapy system, and methods of use thereof, which address at least one of the aforementioned deficiencies of the prior art.

Reference to any prior art in the specification is not an acknowledgment or suggestion that this prior art forms part of the common general knowledge in any jurisdiction or that this prior art could reasonably be expected to be understood, regarded as relevant, and/or combined with other pieces of prior art by a skilled person in the art. Summary of the disclosure

In a first aspect, the present disclosure provides a system for monitoring dosimetry and motion tracking of a guided radiation therapy system, said system comprising:

a phantom configured to be sensed by a tracking system associated with the guided radiation therapy system;

a manipulator to which the phantom is mounted, and which is configured to move the phantom along at least 3 axes and about at least 1 axis; and

a radiation detector associated with the phantom to sense radiation received from the guided radiation therapy system.

In an embodiment, the phantom includes at least one marker configured to be sensed by the tracking system to facilitate tracking of the phantom by the tracking system.

In an embodiment, the at least one marker is arranged in a predetermined geometric configuration to facilitate determination of the orientation and/or location of the phantom by the tracking system.

In an embodiment, the phantom includes a body which carries the radiation detector. The body may have a recess within which it houses the radiation detector. The body may also be detectable by the tracking system.

In an embodiment, the at least one marker includes a non-uniformity in a material property of the body that is detectable by the tracking system to facilitate determination of the orientation and/or location of the phantom.

In an embodiment, the manipulator has at least one foot on which the manipulator is supported in use and a holder which supports the phantom in use and is movable relative to the foot. The holder carrying the phantom may be supported by at least one of: an arm; a gantry; a turret; cantilevered beam; or like structure, away from the at least one foot.

5 In an embodiment, the manipulator includes a robotic arm.

In an embodiment, the manipulator is configured to move the phantom along at 3 axes and about 3 axes.

In an embodiment, the radiation detector is an X-ray detector, configured to generate an output indicative of X-rays incident upon the detector.

10 In an embodiment, the system may further include a control system configured to drive the manipulator so that the phantom performs a predetermined movement.

Any two or more of the above embodiments of the system may be combined in further embodiments of the system.

15 In a second aspect, the present disclosure provides a phantom for use in dosimetry and/or motion tracking of a guided radiation therapy system, said phantom comprising:

a body;

at least one marker in a fixed geometrical configuration with respect to the body and configured to be sensed by the tracking system to facilitate tracking of the phantom by the tracking system; and

20 a radiation target zone in a fixed geometrical configuration with respect to the at least one marker.

In an embodiment, the phantom further includes a radiation detector in the radiation target zone.

In an embodiment, the at least one marker is arranged in a predetermined geometric configuration to facilitate determination of the orientation and/or location of the phantom by the tracking system.

5 In an embodiment, the at least one marker includes a non-uniformity in a material property of the body that is detectable by the tracking system to facilitate determination of the orientation and/or location of the phantom.

In an embodiment, the body includes a mounting portion in a fixed geometrical relationship with respect to the at least one marker.

10 In an embodiment, the phantom further includes a receiver arranged to hold a radiation detector in the radiation target zone. The receiver may include a socket into which a radiation detector can be inserted.

Any two or more of the above embodiments of the phantom may be combined in further embodiments of the phantom.

15 In a third aspect, the present disclosure provides a method of dosimetry in a guided radiation therapy system that is configured to monitor the position of a target tissue to be irradiated, predict movement of the target tissue and guide at least one radiation beam in response to said prediction, said method comprising:

providing a moveable phantom to be irradiated;

20 controlling the phantom to perform a predetermined movement along 3 axes and about 3 axes while irradiating the phantom;

detecting radiation received by the phantom; and

comparing the radiation received by the phantom to a predetermined radiation dose.

25 In an embodiment, the method further includes: determining the predicted movement of the phantom generated by the guided radiation therapy system; and comparing the movement of the phantom to the predicted movement of the phantom generated by the guided radiation therapy system.

In a fourth aspect, the present disclosure provides a method of checking the tracking accuracy in a guided radiation therapy system that is configured to monitor the position of a target tissue to be irradiated, predict movement of the target tissue and guide at least one radiation beam in response to said prediction, said method comprising:

5 providing a moveable phantom to be irradiated;

controlling the phantom to perform a predetermined movement along 3 axes and about at least 1 axis while irradiating the phantom;

determining the predicted movement of the phantom generated by the guided radiation therapy system

10 comparing the movement of the phantom to the predicted movement of the phantom generated by the guided radiation therapy system.

In an embodiment, the method further includes controlling the phantom to perform a predetermined movement along 3 axes and about 3 axes while irradiating the phantom.

15 In an embodiment, the method further includes performing dosimetry by: detecting radiation received by the phantom; and comparing the radiation received by the phantom to a predetermined radiation dose.

20 In an embodiment of the third and fourth aspects of the disclosure, the guided radiation therapy system includes a first source of radiation for treating the target tissue by application of first radiation, and a second source of radiation for applying second radiation for imaging at least the target tissue, said first and second sources of radiation being used to irradiate at least the target tissue discontinuously. In this embodiment, the method may further include determining when the phantom is being irradiated by one or both of the first and second radiation. The method may further include one or more of: correcting the determined level of radiation received by the phantom to exclude the contribution of the second radiation received by the radiation
25 detector; or determining a total dosage of radiation received by the phantom including the contribution of the second radiation received by the radiation detector.

As used herein, except where the context requires otherwise, the term "comprise" and variations of the term, such as "comprising", "comprises" and "comprised", are not intended to exclude further additives, components, integers or steps.

Further aspects of the present disclosure and further embodiments of the aspects
5 described in the preceding paragraphs will become apparent from the following description, given by way of example and with reference to the accompanying drawings.

Brief description of the drawings

Figure 1 is a schematic illustration of a guided radiation therapy system 10;

Figure 2 is a perspective view of a system for monitoring dosimetry and motion tracking
10 of the guided radiation therapy system of Figure 1 according to an embodiment of the disclosure;

Figure 3 is a top-down view of the system of Figure 2;

Figure 4 is a side perspective view of the system of Figures 2 and 3;

Figure 5 is a perspective view of a phantom of the system of Figures 2 to 4;

Figure 6 is a front-view of the phantom of Figure 5;

15 Figure 7 is a perspective view of a radiation detector of the system of Figures 2 to 5;

Figure 8 is a flow-chart detailing a method of dosimetry utilising the guided radiation therapy system of Figure 1 according to an embodiment of the disclosure;

Figure 9 is a flow-chart detailing additional optional steps of the method of dosimetry of Figure 8;

20 Figure 10 is a flow-chart detailing additional optional steps of the method of dosimetry of Figure 8;

Figure 11 is a flow-chart detailing a method of checking accuracy in a guided radiation therapy system;

Figure 12 is a flow-chart detailing additional optional steps of the method of checking accuracy of Figure 11; and

Figure 13 is a flow-chart detailing additional optional steps of the method of checking accuracy of Figure 11.

5 Detailed description of the embodiments

Patients undergoing radiotherapy treatment are subject to movement both in the setup on the treatment bed and by way of organ and tumour motion during treatment delivery. The inventors have realised that because motion can occur in all dimensions of space (rotational and translational), i.e. in six degrees of freedom (6D), the ideal phantom used for quality assurance
10 (QA) should also do so.

Figure 1 depicts a guided radiation therapy system 10 that is configured to monitor the position of a target tissue or tumour to be irradiated, predict movement of the target tissue or tumour, and guide at least one radiation beam in response to the prediction.

The guided radiation therapy system 10 includes a medical linear accelerator 12 setup for
15 guided radiation delivery to a patient 14 located upon a supporting surface or treatment bed 16. The medical linear accelerator 12 provides a first source of radiation configured to treat a target tumour 18 located within the patient 14 by the application of first radiation in the form of high-energy megavoltage (MV) beams of X-ray radiation. The target tumour 18 is subject to linear and rotational movement in 6D as shown in the axes in Figure 1, i.e. along and about the
20 Superior/Inferior axis, the Left/Right axis, and the Anterior/Posterior axis.

As described above, motion of the tumour 18 during setup of the patient 14 on the treatment bed 16 and during treatment delivery can cause large undesirable radiation doses to be delivered to non-target tissue, i.e. non-tumour or healthy tissue. As such, quality assurance by the use of a phantom to mimic the patient 14, in particular, the motion of the tumour 18 within the
25 patient 14 is extremely important.

Quality assurance is performed by comparing an actual movement of a phantom 20 (Figure 2), as controlled by a manipulator, to a predicted movement of the phantom 20. The

predicted movement of the phantom 20 is determined by acquiring multiple images of the phantom 20 using a kilovoltage (kV) beam of X-ray radiation from a second source.

Accordingly, in one aspect, the present disclosure provides a system for monitoring dosimetry and motion tracking of a guided radiation therapy system, such as the guided radiation therapy system 10 depicted in Figure 1. Referring to Figure 2, the system for monitoring dosimetry and motion tracking comprises a phantom 20, a manipulator 22, and a radiation detector 24.

In the illustrated embodiment, the phantom 20 comprises a body 26 in the form of a generally rectangular prism. The body 26 has a generally rectangular opening or recess 28 (Figure 4) at a distal end, i.e. distal to the manipulator 22. The body 26 is formed from PMMA acrylic that has a very similar density to tumour tissue, but may be formed from any other suitable material known to those skilled in the art.

The phantom 20 includes at least one marker configured to be sensed by a tracking system (not shown) associated with the guided radiation therapy system 10 to facilitate tracking of the phantom 20 by the tracking system. The tracking system may, for example, utilise KIM tracking for geometric quality assurance, as disclosed in Huang, C.Y., et al., *Six degrees-of-freedom prostate and lung tumor motion measurements using kilovoltage intrafraction monitoring*. Int J Radiat Oncol Biol Phys, 2015. **91**(2): p. 368-75, and Keall, P.J., et al., *The first clinical treatment with kilovoltage intrafraction monitoring (KIM): a real-time image guidance method*. Med Phys, 2015. **42**(1): p. 354-8, the entire disclosures of which are herein incorporated by reference. But other motion tracking methodologies could be used.

In the present example, the phantom 20 includes three gold-plated fiducial markers 30 embedded within the body 26 (Figures 5 and 6) in a predetermined fixed geometric configuration with respect to the body 26 to facilitate determination of the orientation and/or location of the phantom 20 by the tracking system (i.e. geometric quality assurance). The markers 30 are embedded within the body 26 such that a centroid of the markers 30 represents an isocentre of the phantom 20 (i.e. a point in space where a central ray of radiation from the first and/or second source of radiation passes). Referring to Figure 6, two of the three markers 30 are embedded within the body 26 in a common plane above the generally rectangular opening 28, a first one of

the two markers 30 being disposed closer to the opening 28 than a second one of the two markers 30 (Figure 5). The other one of the three markers 30 is embedded within the body 26 below the generally rectangular opening 28 and is disposed approximately centrally between the two markers 30 located above the rectangular opening 30 (Figure 6).

5 In the present embodiment, the markers 30 are gold-plated, but may be plated and/or formed from any other suitable material detectable by the tracking system, and in particular, any suitable material that is non-uniform with respect to a material property of the body 26 of the phantom 20 so that it can be seen in an image of the phantom.

10 The generally rectangular opening 28 in the body 26 of the phantom 20 provides a socket 32 (Figure 6) that acts as a receiver for the radiation detector 24 (Figures 2 and 3) for dosimetric quality assurance. The radiation detector may be removable if dosimetry is not needed, or to enable changing of the detector. The radiation detector 24 is configured to sense radiation received from the guided radiation therapy system 10 and includes a first rectangular portion 34 (formed, for example on a circuit board substrate) configured to be substantially disposed within
15 the socket 32 of the phantom 20 during use, and a second rectangular portion 36 configured to be accessible (i.e. located outside the socket 32) when the first portion 34 is disposed within the socket 32 (Figures 2 and 3).

20 The first portion 34 includes a rectangular radiation sensor 38 configured to detect X-rays, and the second portion 36 includes at least one data connector 40 (in the present embodiment, three data connectors 40 are illustrated) to output data indicative of X-rays incident upon the sensor 38. The radiation sensor 38 is located in a radiation target zone 70 defined by the body 26 and socket 32, the radiation target zone 70 being in a fixed geometric configuration with respect to the markers 30 embedded within the body 26. When the radiation detector 24 is received within the socket 32, the radiation sensor 38 is located within the radiation target zone
25 70 (Figures 2 and 3) which is generally at the isocentre of the phantom 20 (i.e. at the point where the central ray of radiation from the first and/or second sources of radiation passes).

 The MagicPlate-512 (Figure 7) is a semiconductor detection system has been developed at CMRP at the University of Wollongong and represents an exemplary radiation detector 24 that can be used for dosimetric quality assurance for the phantom 20. The MagicPlate-512 (M512)

provides high spatial and temporal resolution making it suitable for accurate dosimetry measurement during motion of the phantom 20. The acquisition of signals from the radiation sensor 38 of the M512 can be synchronised with the medical linear accelerator 10 (pulse-by-pulse) or by an internal trigger with a frequency of up to 10 kHz. This is very beneficial for dosimetric quality assurance if the kV beam (the second radiation or imaging beam) and the MV (the first radiation or treatment beam) are on at the same time. Additionally and advantageously, the M512 is configured to differentiate and measure both of the kV and MV beams during acquisition, thereby providing accurate dosimetry with or without the effects of the delivered dose from the kV beam.

The M512 includes a 2D monolithic (single large block) silicon diode array with a physical radiation sensor 38 area of $52 \times 52 \text{ mm}^2$ and 2 mm pixel pitch (resolution), connected to an analogue front end data acquisition system (AFE0064, Texas Instruments) via data connectors 40 to readout the data from the radiation sensor 38. The phantom 20 is modular such that the M512 may be removed and/or replaced by a solid piece of PMMA acrylic for performing geometric quality assurance only or by another type of radiation sensor.

According to some embodiments of the present disclosure, the phantom 20 including the radiation detector 24 is mounted to a manipulator 22 in the form of a robotic arm 50 (Figure 2). The robotic arm 50 is configured to move the phantom 20 along at least three axes and about at least one axis, but in the illustrated and preferred embodiment moves the phantom 20 along and about at least three axes (i.e. the robotic arm 50 moves the phantom in 6 degrees of freedom and thus may be termed a “6D” robotic arm). A control system (not shown) is configured to drive the robotic arm 50 so that the phantom 20 performs a predetermined movement.

The robotic arm 50 includes a foot or base 52, a first arm length 54 upstanding from and fixed to the base 52, a second arm length 56 rotatably connected to the first arm length 54, and a third arm length 58 rotatably connected to the second arm length 54. A distal end of the third arm length 54 includes a rotatable holder 60 (Figure 3) configured to support the phantom 20 when in use. The second and third arm lengths 56 and 58 respectively and the holder 60 are configured to move relative to the foot or base 52. In the default position shown in Figure 2, the third arm length 58 is generally orthogonal to at least the first arm length 54 such that the holder 60 is located away from the foot or base 52. Advantageously, during use, the first, second, and third

arm lengths 54, 56, and 58 respectively are located generally outside of the kV imaging beam (the second radiation) thus not affecting imaging quality during marker 30 segmentation or tracking.

The LBR iiwa robotic arm (KUKA, Augsburg, Germany) (Figures 2 to 4) represents an exemplary 6D manipulator 22 that can be utilised in the dosimetry monitoring and tracking system. The LBR robotic arm has a small footprint and is relatively lightweight (22 kg), which allows for easy storage and transportation. The LBR robotic arm has excellent position repeatability (± 0.1 mm) and can hold a payload of 7 kg. Advantageously, the LBR robotic arm has full flexibility in angular motion (360° rotations in all axes) as compared to prior bench motion platforms that are limited to approximately $\pm 15^\circ$ of rotation.

The above described system comprising the phantom 20, the manipulator 22, and the radiation detector 24 may be utilised in a method of dosimetry in a guided radiation therapy system, such as the system 10. Accordingly, in a second aspect, the present disclosure provides a method of dosimetry in a guided radiation therapy system. The method comprises the steps outlined in Figure 8, and includes the step 80 of providing a moveable phantom, such as the phantom 20, to be irradiated. The moveable phantom may be moveable by virtue of a manipulator, such as the manipulator 22 (or robotic arm 50), and may be irradiated by a medical linear accelerator, such as the accelerator 12.

The method also includes the step 82 of controlling the phantom to perform a predetermined movement along three axes and about 3 axes while irradiating the phantom. The predetermined movement is preferably programmable by a computer (not shown) that includes a processor and a communication interface configured to communicate with a controller that controls the movement of the phantom, for example, a controller of the manipulator 22 (or robotic arm 50). The predetermined movement may correspond to an equation of motion, may represent a random movement within a defined set of parameters, or may apply a model of tumour movement or reproduce (at least in part) a recorded tumour motion within a subject.

The method also includes the step 84 of detecting radiation received by the phantom and the step 86 of comparing the radiation received by the phantom to a predetermined radiation dose. The radiation may be detected by a radiation detector, such as the radiation detector 24

received within the body 26 of the phantom 20, and the predetermined radiation dose may correspond to an ideal radiation dosage as determined by a physician for treating a tumour.

Referring to Figure 9, the method of dosimetry may also include the step 88 of determining the predicted movement of the phantom generated by the guided radiation therapy system, and the step 90 of comparing the movement of the phantom to the predicted movement of the phantom generated by the guided radiation therapy system. The movement of the phantom may be predicted by a tracking system, such as the above described KIM tracking system of the guided radiation therapy system 10 in which the location of fiducial markers, such as the markers 30 implanted in the phantom 20, is reconstructed by acquiring multiple images of the phantom 20 by irradiating the phantom with a kV X-ray beam. The computer that controls the movement of the phantom may also compare the movement of the phantom to the predicted movement of the phantom (step 90).

As described above, the guided radiation therapy system 10 includes a first source of radiation for applying first radiation in the form of high-energy MV X-ray beams for treating the target tissue or tumour, and a second source of radiation for applying second radiation in the form of kV X-ray beams for imaging at least the target tissue or tumour. Accordingly, the method of dosimetry provided by the present disclosure may also include the step 92 (Figure 10) of determining when the phantom is being irradiated by one or both of the first and second radiation, for example, by the radiation detector 24. The method may also include the step 94 of correcting the determined level of radiation received by the phantom to exclude the contribution of the second radiation received by the radiation detector, or the step 96 of determining a total dosage of radiation received by the phantom including the contribution of the second radiation received by the radiation detector.

The above described system comprising the phantom 20, the manipulator 22, and the radiation detector 24 may also be utilised in a method of checking the accuracy in a guided radiation therapy system, such as the system 10. Accordingly, in a third aspect, the present disclosure provides a method of checking accuracy in a guided radiation therapy system. The method comprises the steps outlined in Figure 11, and includes the step 100 of providing a moveable phantom to be irradiated. The moveable phantom 20 may be moveable by virtue of a

manipulator, such as the manipulator 22 (or robotic arm 50), and may be irradiated by a medical linear accelerator, such as the accelerator 12.

The method also includes the step 102 of controlling the phantom to perform a predetermined movement along three axes and about three axes while irradiating the phantom.

- 5 The predetermined movement is preferably programmable by a computer that includes a processor and a communication interface configured to communicate with a controller that controls the movement of the phantom, for example, a controller of the manipulator 22 (or robotic arm 50). The predetermined movement may correspond to an equation of motion, may represent a random movement within a defined set of parameters, or may mimic actual recorded
- 10 tumour motion within a patient. The predetermined movement may also be based on quality assurance standards developed for the Calypso system, and adapted for use with KIM as disclosed in *Ng, J.A., et al., Quality assurance for the clinical implementation of kilovoltage intrafraction monitoring for prostate cancer VMAT. Med Phys, 2014. 41(11): p. 111712* the entire disclosure of which is hereby incorporated by reference.

- 15 The method also includes the step of 104 of determining the predicted movement of the phantom generated by the guided radiation therapy system, and the step 106 of comparing the movement of the phantom to the predicted movement of the phantom generated by the guided radiation therapy system. The movement of the phantom may be predicted by a tracking system, such as the above described KIM tracking system. The computer that controls the movement of
- 20 the phantom may also compare the movement of the phantom to the predicted movement of the phantom as generated by the tracking system.

Referring to Figure 12, the method of checking tracking accuracy may also include performing dosimetry by the step 108 of detecting radiation received by the phantom, and by the step 110 of comparing the radiation received by the phantom to a predetermined radiation dose.

- 25 The radiation may be detected by a radiation detector, such as the radiation detector 24 received within the body 26 of the phantom 20, and the predetermined radiation dose may correspond to an ideal radiation dosage as determined by a physician for treating a tumour.

As described above, the guided radiation therapy system 10 includes a first source of radiation for applying first radiation in the form of high-energy MV X-ray beams for treating the

target tissue or tumour, and a second source of radiation for applying second radiation in the form of kV X-ray beams for imaging at least the target tissue or tumour. Therefore, the method of checking accuracy in the guided radiation therapy system 10 may also include, with reference to Figure 13, the step 112 of determining when the phantom is being irradiated by one or both of
5 the first and second radiation, for example, by the radiation detector 24. The method may also include the step 114 of correcting the determined level of radiation received by the phantom to exclude the contribution of the second radiation received by the radiation detector, or the step 116 of determining a total dosage of radiation received by the phantom including the contribution of the second radiation received by the radiation detector.

10 Importantly, the accuracy and reproducibility of the above described system is evaluated in terms of geometric and dosimetric quality assurance as outlined in the above described methods. In particular, the accuracy and reproducibility of the system may, in some embodiments be against one or more of the following quality assurance tests: static localisation accuracy, dynamic localisation accuracy, treatment interruption accuracy, latency measurement,
15 and clinical conditions accuracy, as understood by a person skilled in the art.

Advantageously, the above described system and methods provide excellent dosimetric and/or geometric quality assurance of a guided radiation therapy system, which is crucial in ensuring that an accurate dose of radiation is delivered to a target tissue of a patient during radiotherapy treatment.

20 It will be understood that the invention disclosed and defined in this specification extends to all alternative combinations of two or more of the individual features mentioned or evident from the text or drawings. All of these different combinations constitute various alternative aspects of the invention.

CLAIMS

1. A system for monitoring dosimetry and motion tracking of a guided radiation therapy system, said system comprising:

a phantom configured to be sensed by a tracking system associated with the guided
5 radiation therapy system;

a manipulator to which the phantom is mounted, and which is configured to move the phantom along at least 3 axes and about at least 1 axis; and

a radiation detector associated with the phantom to sense radiation received from the guided radiation therapy system.

10 2. The system of claim 1 wherein the phantom includes at least one marker configured to be sensed by the tracking system to facilitate tracking of the phantom by the tracking system.

3. The system of claim 2 wherein the at least one marker is arranged in a predetermined geometric configuration to facilitate determination of the orientation and/or
15 location of the phantom by the tracking system.

4. The system of any one of claims 1 to 3 wherein the phantom includes a body which carries the radiation detector.

5. The system of any one of claims 1 to 3 wherein the phantom has a body which detectable by the tracking system.

20 6. The system of claim 4 or 5 wherein the at least one marker includes a non-uniformity in a material property of the body that is detectable by the tracking system to facilitate determination of the orientation and/or location of the phantom.

7. The system of any one of claims 1 to 6 wherein the manipulator has at least one foot on which the manipulator is supported in use and a holder which supports the phantom in
25 use and is movable relative to the foot.

8. The system of claim 7 wherein the holder carrying the phantom is supported by at least one of:

an arm; a gantry; a turret; cantilevered beam; or like structure,

away from the at least one foot.

5 9. The system of any one of claims 1 to 8 wherein the manipulator includes a robotic arm.

10. The system of any one of claims 1 to 9 wherein the manipulator is configured to move the phantom along at 3 axes and about 3 axes.

10 11. The system of any one of claims 1 to 10 wherein the radiation detector is an X-ray detector, configured to generate an output indicative of X-rays incident upon the detector.

12. The system of any one of claims 1 to 3 wherein the phantom includes a body having a recess within which it houses the radiation detector.

13. The system of any one of claims 1 to 12 which further includes a control system configured to drive the manipulator so that the phantom performs a predetermined movement.

15 14. A phantom for use in dosimetry and/or motion tracking of a guided radiation therapy system, said phantom comprising:

a body;

at least one marker in a fixed geometrical configuration with respect to the body and configured to be sensed by the tracking system to facilitate tracking of the phantom by the
20 tracking system; and

a radiation target zone in a fixed geometrical configuration with respect to the at least one marker.

15. The phantom of claim 14 which further includes a radiation detector in the radiation target zone.

16. The phantom of claim 14 or 15 wherein the at least one marker is arranged in a predetermined geometric configuration to facilitate determination of the orientation and/or location of the phantom by the tracking system.

17. The phantom of any one of claims 14 to 16 wherein the at least one marker
5 includes a non-uniformity in a material property of the body that is detectable by the tracking system to facilitate determination of the orientation and/or location of the phantom.

18. The phantom of any one of claims 14 to 17 wherein the body includes a mounting portion in a fixed geometrical relationship with respect to the at least one marker.

19. The phantom of claim 14 which further includes a receiver arranged to hold a
10 radiation detector in the radiation target zone.

20. The phantom of claim 19 wherein the receiver includes a socket into which a radiation detector can be inserted.

21. A method of dosimetry in a guided radiation therapy system that is configured to monitor the position of a target tissue to be irradiated, predict movement of the target tissue and
15 guide at least one radiation beam in response to said prediction, said method comprising:

providing a moveable phantom to be irradiated;

controlling the phantom to perform a predetermined movement along 3 axes and about 3 axes while irradiating the phantom;

detecting radiation received by the phantom; and

20 comparing the radiation received by the phantom to a predetermined radiation dose.

22. The method of claim 21 wherein the method further includes:

determining the predicted movement of the phantom generated by the guided radiation therapy system; and

comparing the movement of the phantom to the predicted movement of the phantom
25 generated by the guided radiation therapy system.

25. A method of checking the tracking accuracy in a guided radiation therapy system that is configured to monitor the position of a target tissue to be irradiated, predict movement of the target tissue and guide at least one radiation beam in response to said prediction, said method comprising:

5 providing a moveable phantom to be irradiated;

controlling the phantom to perform a predetermined movement along 3 axes and about at least 1 axis while irradiating the phantom;

determining the predicted movement of the phantom generated by the guided radiation therapy system; and

10 comparing the movement of the phantom to the predicted movement of the phantom generated by the guided radiation therapy system.

26. The method of claim 25 wherein the method includes controlling the phantom to perform a predetermined movement along 3 axes and about 3 axes while irradiating the phantom.

27. The method of claim 25 or 26 which further includes performing dosimetry by:

15 detecting radiation received by the phantom;

comparing the radiation received by the phantom to a predetermined radiation dose.

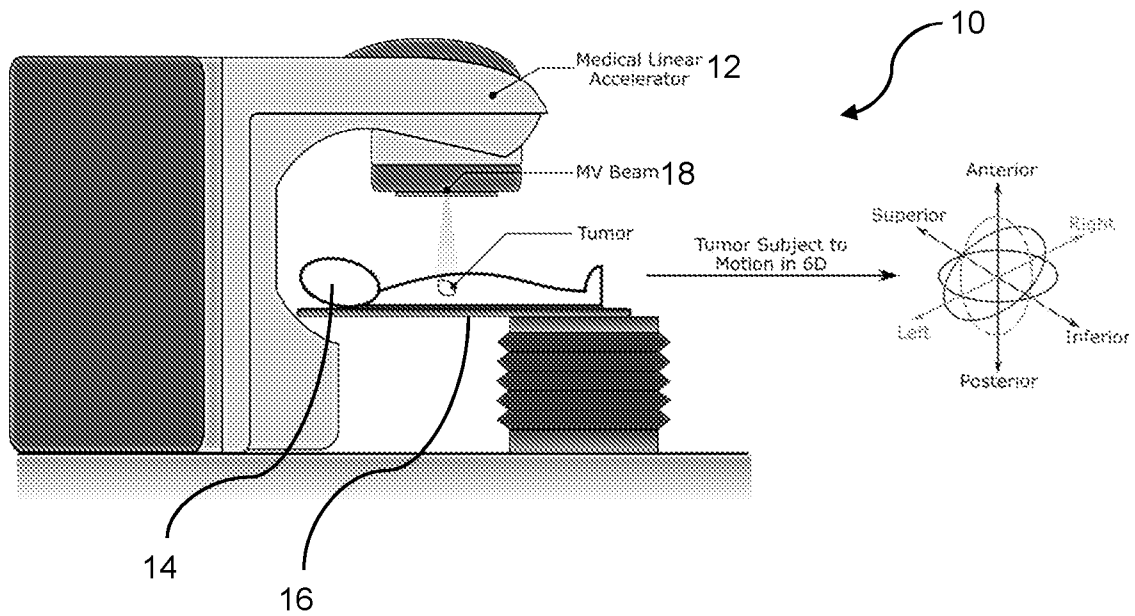
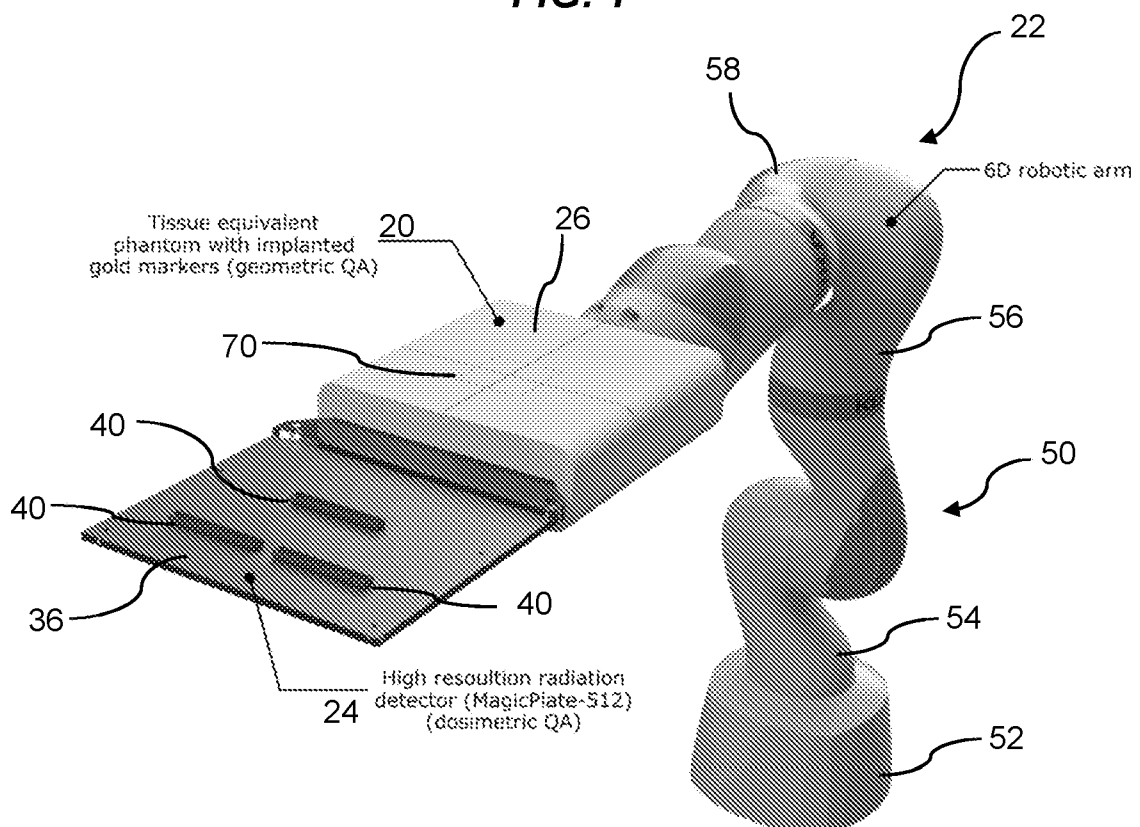
28. The method of claim 21 or 27 wherein the guided radiation therapy system includes a first source of radiation for treating the target tissue by application of first radiation, and a second source of radiation for applying second radiation for imaging at least the target
20 tissue, said first and second sources of radiation being used to irradiate at least the target tissue discontinuously, said method including:

determining when the phantom is being irradiated by one or both of the first and second radiation.

29. The method of claim 28 wherein the method further includes one or more of:

correcting the determined level of radiation received by the phantom to exclude the contribution of the second radiation received by the radiation detector; or

determining a total dosage of radiation received by the phantom including the contribution of the second radiation received by the radiation detector.

**FIG. 1****FIG. 2**

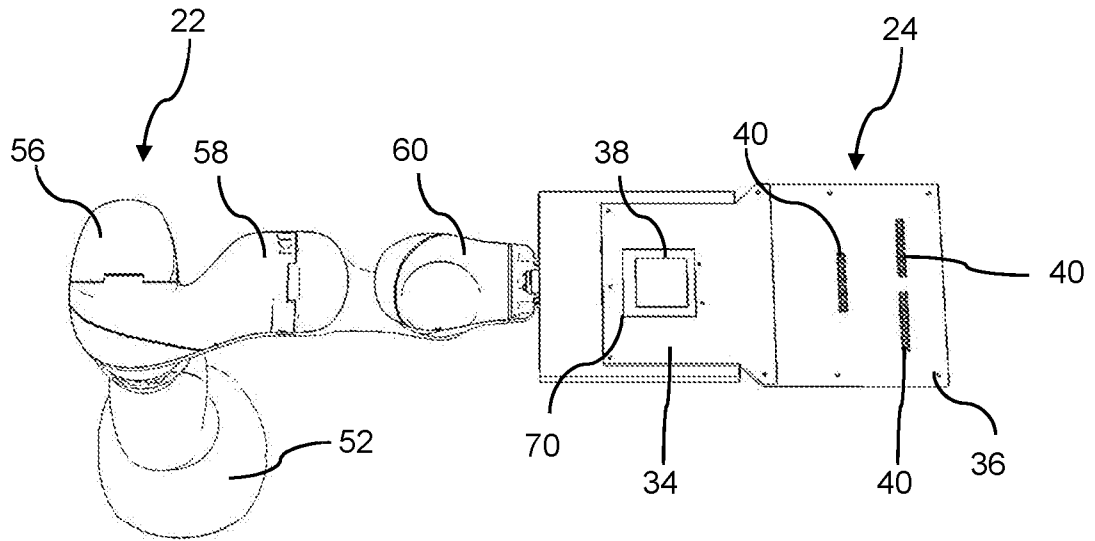


FIG. 3

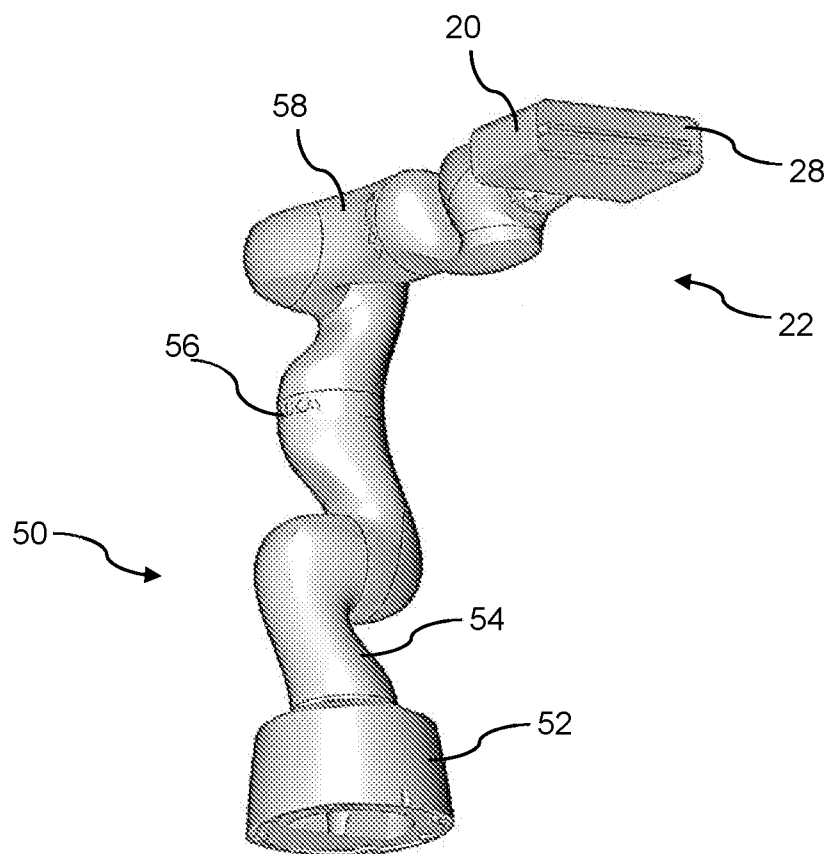
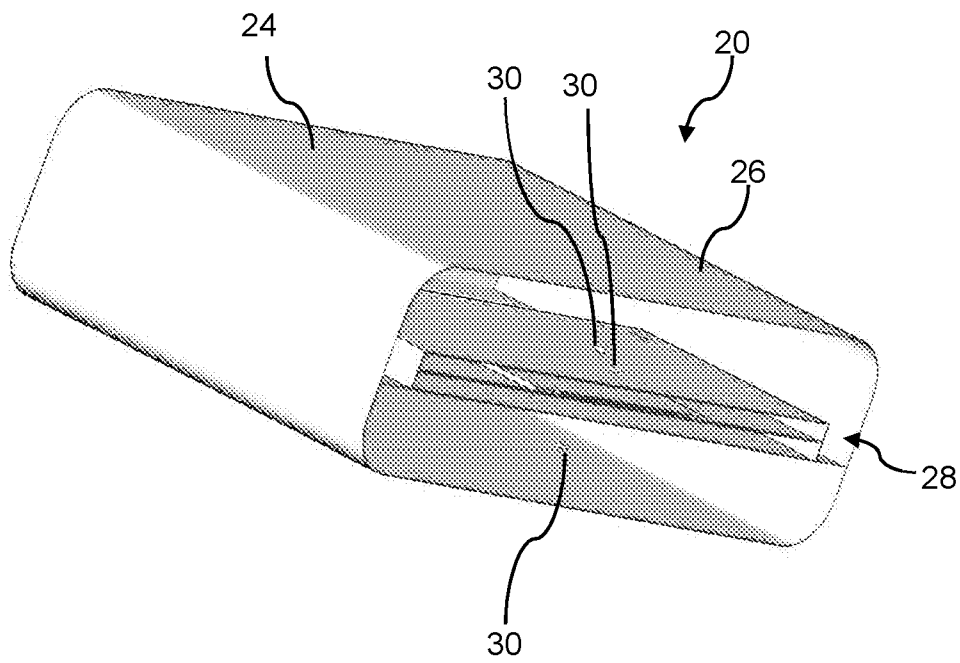
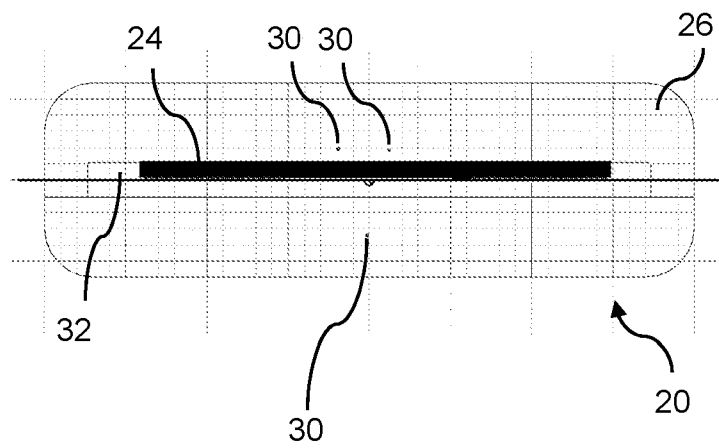
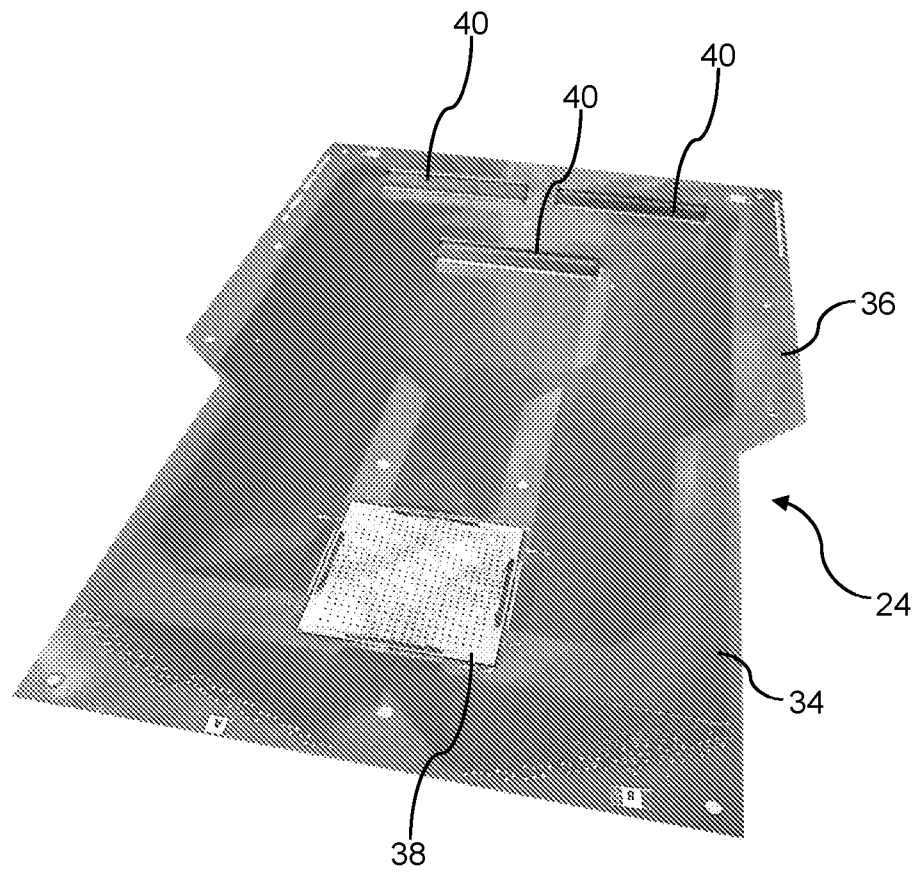
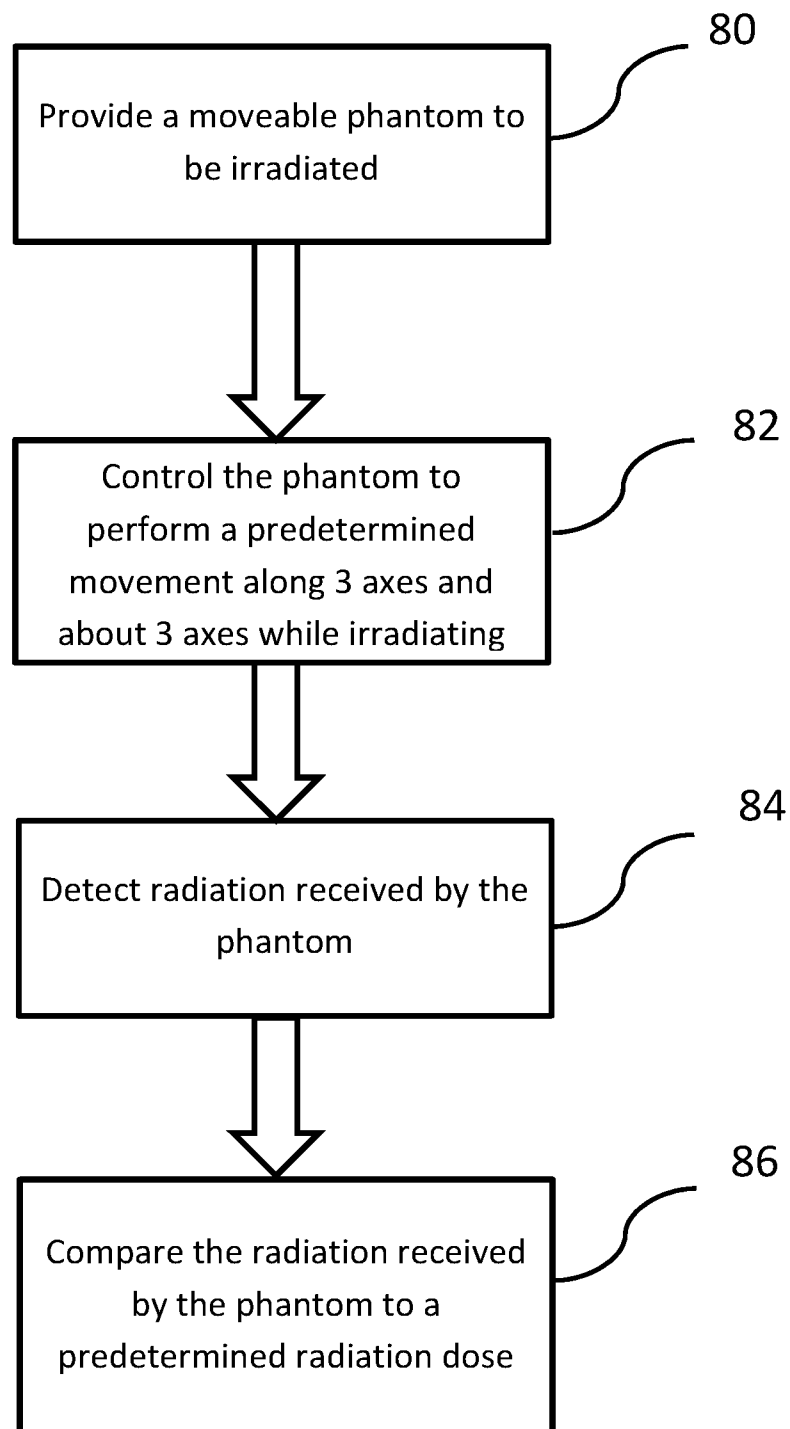
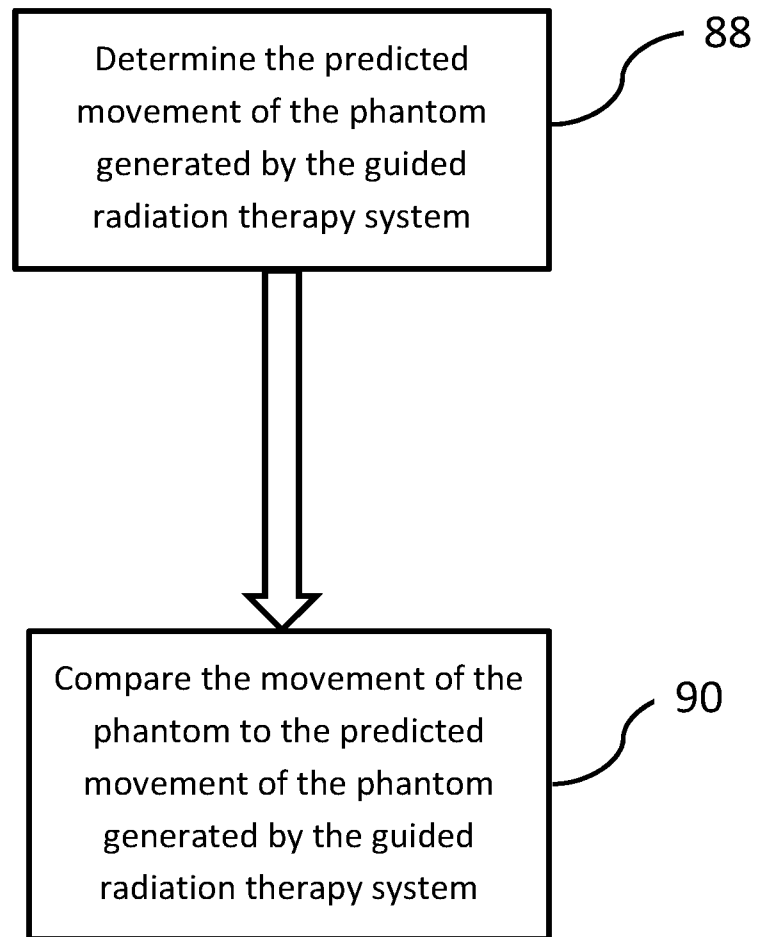


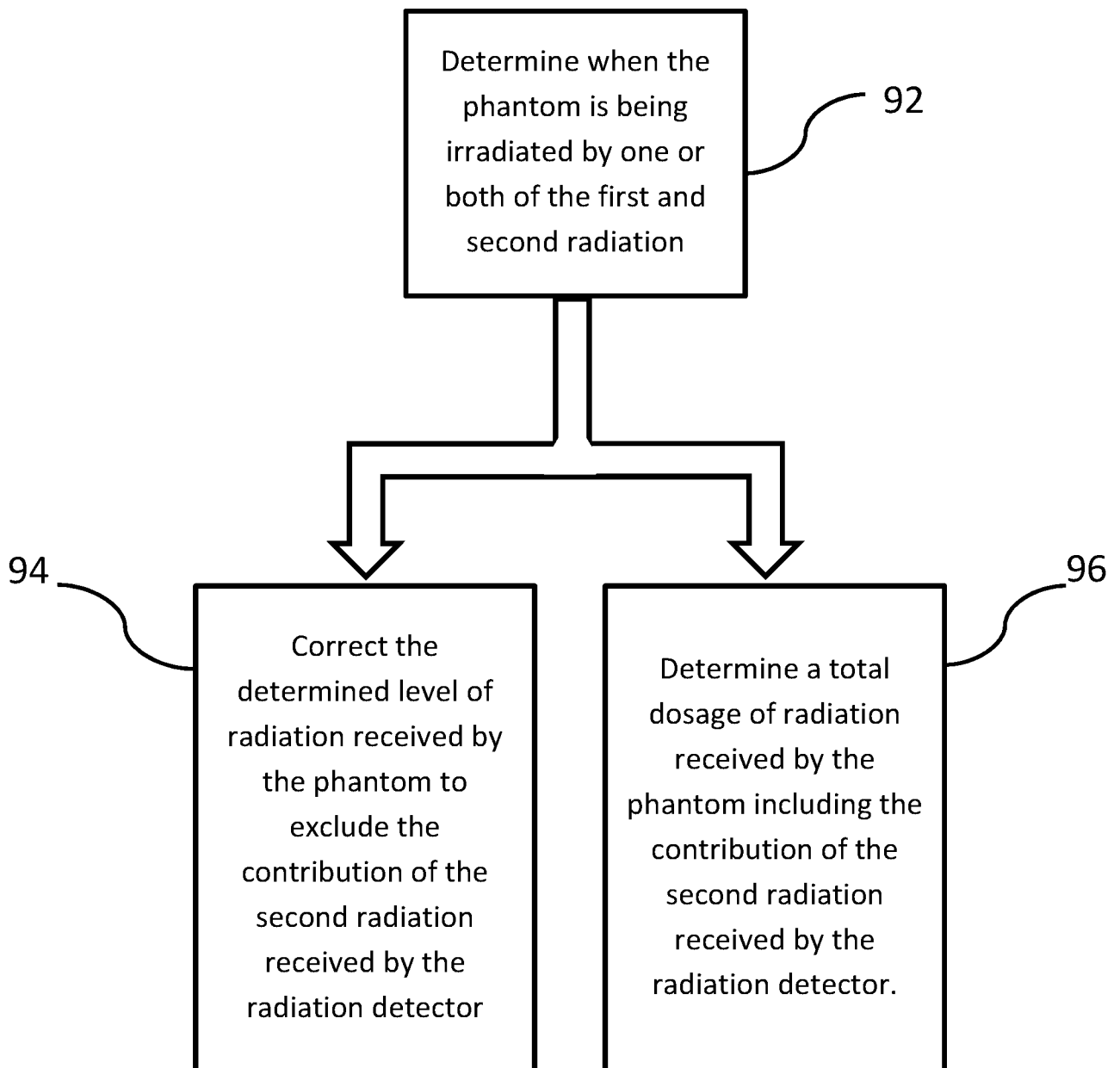
FIG. 4

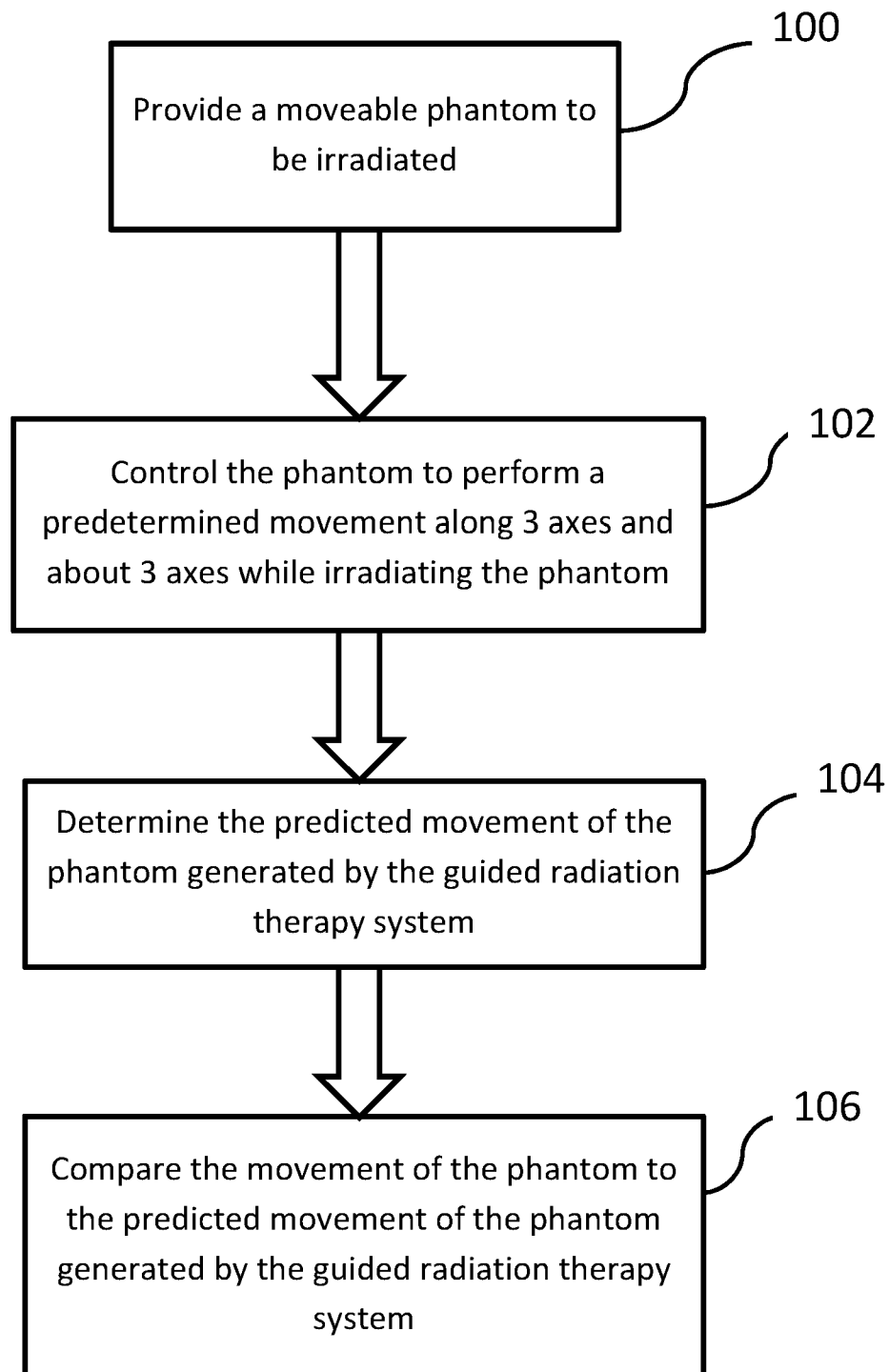
**FIG. 5****FIG. 6**

**FIG. 7**

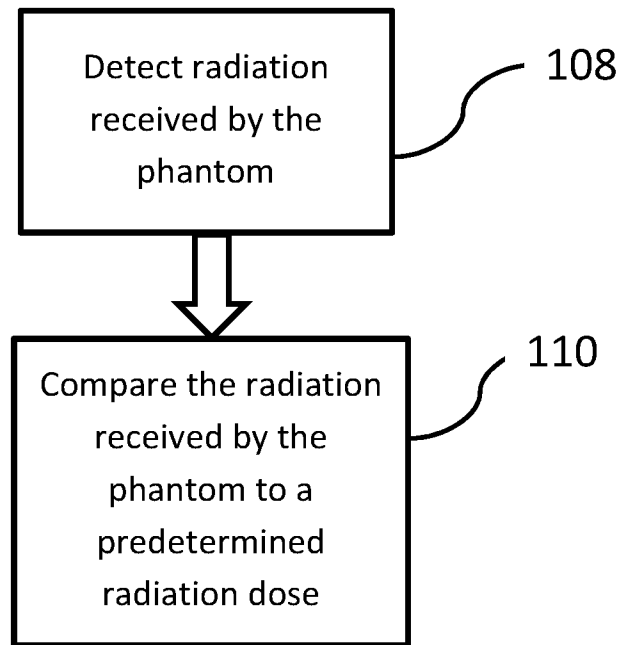
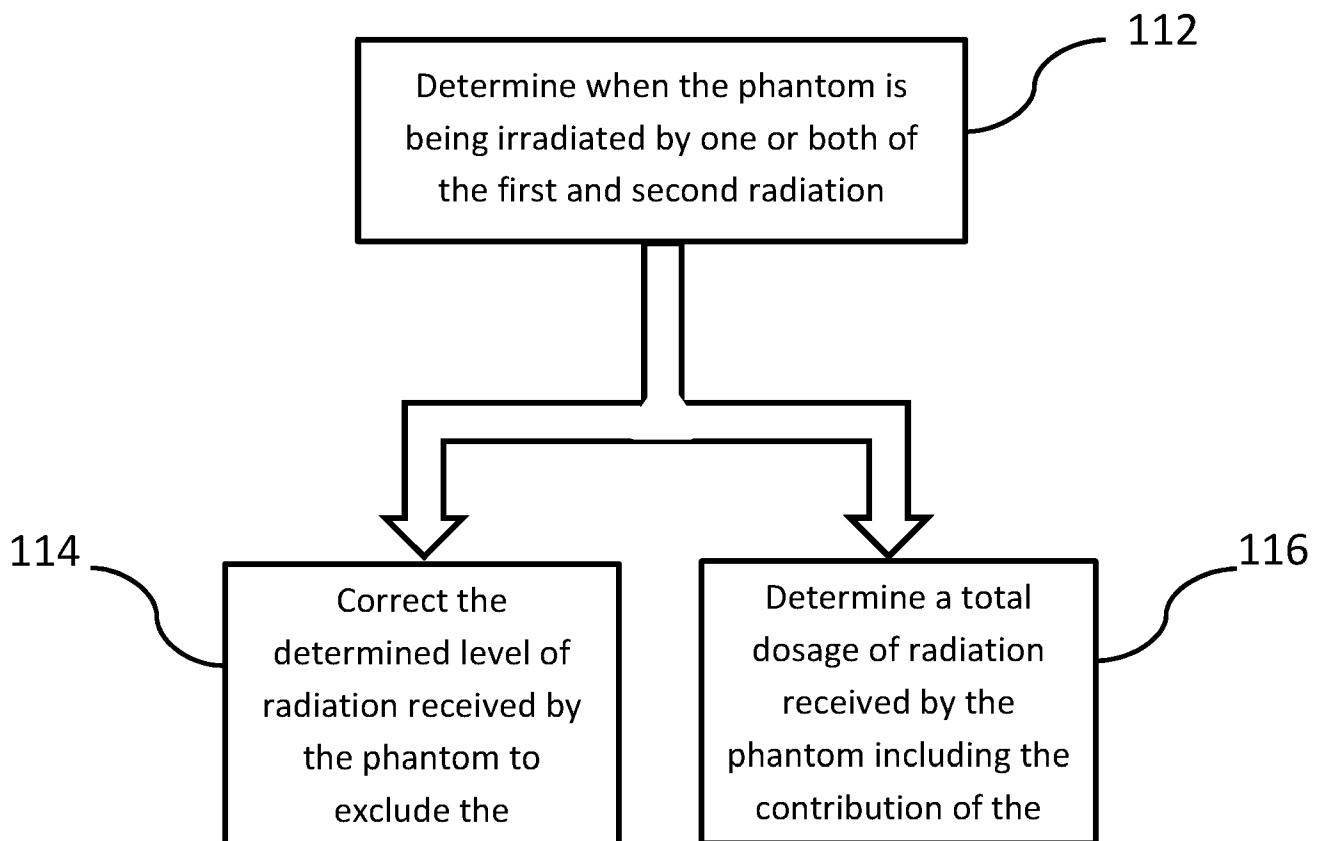
**FIG. 8**

**FIG. 9**

**FIG. 10**

**FIG. 11**

9/9

**FIG. 12****FIG. 13**

INTERNATIONAL SEARCH REPORT

International application No.
PCT/AU2018/050216

A. CLASSIFICATION OF SUBJECT MATTER

A61N 5/10 (2006.01) G01D 18/00 (2006.01) B25J 13/08 (2006.01) B25J 3/00 (2006.01)

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)

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

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

Database PATENW (EPOQUE -specific): IPCs & CPCs marks (searching included sub-classes): A61N5/00, A61N5/10, A61N5/1048, A61N5/1049, A61N5-, G01D-, G01T-, B25J-, G05-, A61B6-, G05B19-, G05B2219/45117, G05B2219/50132, G05B2219/49257 & the like. Keywords: phantom, radiation therapy, motion degree of freedom, manipulator, actuator, positioning device, radiation target, moving, pre-determined, accuracy, quality assurance, quality analysis, markers, tracking, determine, arm, gantry, turret, cantilever, dosimetry & the like. Google Patents Keywords: phantom, manipulator, robotic, arm, radiation detector, radiation sources, trajectory motion, multiple radiation sources & the like in various combinations. EP Database: ESPACENET (esp@cenet) - Advanced: Keywords: inventor's names & IPC A61N5/1 & the like; WIPO Patenscope: "Field combination" Keywords: Applicant's Filed: University of Wollongong, or University of Sydney combined with words/terms such as "robot arm" or "manipulator" & "phantom" English Abstract's field & the like. Applicant(s)/Inventor(s) name searched in internal databases provided by IP Australia.

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
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Further documents are listed in the continuation of Box C



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Date of the actual completion of the international search
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Date of mailing of the international search report
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INTERNATIONAL SEARCH REPORT		International application No.
C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT		PCT/AU2018/050216
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
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Y	Entire document	28, 29
X	US 2012/0080578 A1 (THIEME-MARTI) 05 April 2012 Abstract, Fig. 9, para[0031]-[0035], claims 18, 19, para[0027], [0018]-[0022], "6DoF", Figs. 1-6. elements (108), (102), (104), (116), (118)	1-22, 25-27
Y	Entire document	28, 29
X	US 2008/0219410 A1 (GUNZERT-MARX et al.) 11 September 2008 Abstract, Figs. 2-5 para[0007], [0015], [0017], [0028], [0029], [0039], [0041], elements (51), (55), (57), (41), (39), (65), Claim 12	1-20
X	US 2012/0273666 A1 (BERT et al.) 01 November 2012 Abstract, Figs. 1-5, elements (14)-(44), para[0010]-[0066]	14-22, 25-27
Y	Entire document	28, 29
Y	US 2013/0208867 A1 (BECKMAN) 15 August 2013 Abstract, para[0033]-[0057], Figs. 1-19, esp. Figs. 3-5, 7 and 16-19, elements (1613), (1615), (1617).	28, 29
A	US 5627367 A (SOFIELD) 06 May 1997 Entire Document	

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INTERNATIONAL SEARCH REPORT		International application No. PCT/AU2018/050216	
Information on patent family members			
This Annex lists known patent family members relating to the patent documents cited in the above-mentioned international search report. The Australian Patent Office is in no way liable for these particulars which are merely given for the purpose of information.			
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		WO 2011038802 A1	07 Apr 2011
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		US 8948341 B2	03 Feb 2015
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End of Annex			
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INTERNATIONAL SEARCH REPORT Information on patent family members		International application No. PCT/AU2018/050216	
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Patent Document/s Cited in Search Report		Patent Family Member/s	
Publication Number	Publication Date	Publication Number	Publication Date
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