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

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
5 December 2013 (05.12.2013)

WIPO | PCT

(10) International Publication Number
WO 2013/179221 A1

(51) International Patent Classification:
A61N 5/10 (2006.01) *A61B 8/00* (2006.01)
A61N 7/02 (2006.01) *A61B 8/08* (2006.01)

(21) International Application Number:
PCT/IB2013/054402

(22) International Filing Date:
28 May 2013 (28.05.2013)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
61/652,471 29 May 2012 (29.05.2012) US

(71) Applicant: **KONINKLIJKE PHILIPS N.V.** [NL/NL]; High Tech Campus 5, NL-5656 AE Eindhoven (NL).

(72) Inventor: **BHARAT, Shyam**; c/o High Tech Campus, Building 5, NL-5656 AE Eindhoven (NL).

(74) Agents: **STEFFEN, Thomas** et al.; High Tech Campus, Building 5, NL-5656 AE Eindhoven (NL).

(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, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IS, JP, KE, KG, KN, KP, KR, KZ, LA, LC, LK, LR, LS, LT, 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, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

(84) Designated States *(unless otherwise indicated, for every kind of regional protection available)*: ARIPO (BW, GH, GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, 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).

Declarations under Rule 4.17:

— *as to applicant's entitlement to apply for and be granted a patent (Rule 4.17(ii))*

— *as to the applicant's entitlement to claim the priority of the earlier application (Rule 4.17(iii))*

Published:

— *with international search report (Art. 21(3))*

WO 2013/179221 A1

(54) Title: ELASTICITY IMAGING-BASED METHODS FOR IMPROVED GATING EFFICIENCY AND DYNAMIC MARGIN ADJUSTMENT IN RADIATION THERAPY

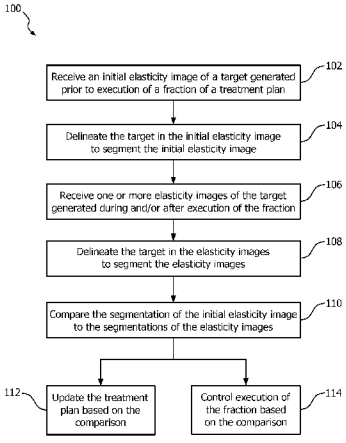

FIG. 2

(57) Abstract: A therapy planning system (10) includes at least one processor (74, 72) programmed to receive an initial elasticity image of the target generated prior to execution of a fraction of a treatment plan for the target. The target is delinated in the initial elasticity image to segment the initial elasticity image. One or more elasticity images of the target generated during and/or after execution of the fraction are received and delineated to segment the elasticity images. The segmentation of the initial elasticity image is compared against the segmentations of the additional elasticity images to identify motion of the target and/or changes of the target. Based on the comparison, the treatment plan is updated and/or execution of the fraction is controlled.

ELASTICITY IMAGING-BASED METHODS FOR IMPROVED GATING EFFICIENCY AND DYNAMIC MARGIN ADJUSTMENT IN RADIATION THERAPY

The present application relates generally to radiation therapy. It finds particular application in conjunction with radiation beam gating and dynamic margin adjustment and will be described with particular reference thereto. However, it is to be understood that it also finds application in other usage scenarios and is not necessarily limited to the aforementioned application.

In radiation therapy, spatially targeted doses of radiation are applied to a target, such as tumors, containing cancerous or malignant tissue of a patient. Growing and rapidly multiplying cancer cells tend to be more susceptible to damage from radiation, as compared with normal cells, such that dosages administrated by proper planning preferentially kill cancerous or malignant tissue. Current clinical workflow in radiation therapy typically involves the use of a three-dimensional image to develop a treatment plan, the treatment plan including a planning target volume (PTV), margins around the target, and a plurality of fractions, each fraction specifying beam directions and energies for treating the target.

One challenge for radiation therapy is interfraction motion (i.e., motion between fractions) and intrafraction motion (i.e., motion during fractions), such as respiratory and cardiac motion. Ideally, the entire dose for a treatment plan is delivered to the target and no dose is delivered in surrounding normal tissue and/or organs at risk. However, due to interfraction and intrafraction motion, this is typically not possible and deviations between the radiation dose delivered to the patient and the planned radiation dose are common.

To address the effects of interfraction and intrafraction motion, treatment plans typically include margins around the target to ensure the target is fully irradiated. However, the addition of margins leads to the irradiation of normal tissue and/or organs at risk (OARs) proximate the target. Further, the margins are typically generic to a patient population. That is to say, the margins are typically not specific to the patient. This can lead to further irradiation of normal tissue and/or OARs proximate the target.

Additionally, gating is commonly used in radiation therapy delivery protocols to address the effects of interfraction and intrafraction motion. Gating stops delivery of radiation to the target when the target moves out of alignment with the PTV of the treatment plan. Typically, one or more external surrogates for the target (e.g., skin markers, bee bees, etc.) are employed to monitor the motion of the target. However, recent research has demonstrated the feasibility of monitoring the motion of internal surrogates for the target (e.g., markers implanted within the patient close to the target) using telerobotic ultrasound (US) imaging.

Telerobotic US imaging uses a robotic manipulator to control the pitch and pressure of an abdominal US transducer and to avoid obstructing the radiation beam with the US transducer. The treatment plan can also be designed to avoid beam directions that contain the US transducer. The dosage volume histograms (DVHs) resulting from such customized treatment plans are virtually identical to the DVHs resulting from standard treatment plans (i.e., treatment plans without restrictions on beam directions). Further, even if standard treatment plans are employed, it has been shown that the dose delivered is not significantly affected by the US transducer. The functioning of the US system is also unaffected by the beam.

While telerobotic US imaging for gating represents a significant advancment towards live volumetric target imaging, it still requires the use of internal surrogates (as opposed to using the target itself) due to inherent problems of US. Namely, the specular nature of US and the similar echogenecity levels of many tumors and surrounding normal tissue may cause difficulty in demarcating the target on conventional brightness mode (B-mode) US images. The present application provides a new and improved system and method which overcome the above-referenced problems and others.

In accordance with one aspect, a therapy planning system is provided. The therapy system includes at least one processor programmed to receive initial elasticity data indicative of a location of the target generated prior to execution of a fraction of a treatment plan for the target. Further, additional elasticity data indicative of a location of the target generated during and/or after execution of the fraction is received. The initial elasticity data and the additional elasticity data are compared to identify motion of the target and/or changes of the target. Based on the comparison, the treatment plan is updated and/or execution of the fraction is controlled.

In accordance with another aspect, a therapy planning method is provided. The therapy method includes receiving initial elasticity data indicative of a location of the target generated prior to execution of a fraction of a treatment plan for the target. Further, additional elasticity data indicative of a location of the target generated during and/or after execution of the fraction is received. The initial elasticity data and the additional elasticity data are compared to identify motion of the target and/or changes of the target. Based on the comparison, the treatment plan is updated and/or execution of the fraction is controlled.

In accordance with another aspect, a therapy planning system is provided. The therapy system includes at least one processor programmed to receive elasticity images of the target in real-time during execution of a fraction of a treatment plan for the target. The target is delineated in the received elasticity images to segment the elasticity images. A reference segmentation is compared against the segmentations of the elasticity images to identify motion of the target and/or changes of the target. The reference segmentation delineates the target in an elasticity image. Based on the comparison, the treatment plan is updated and/or execution of the fraction is controlled.

One advantage resides in directly monitoring motion of the target with ultrasound.

Another advantage resides in gating based on positional information obtained directly from the target.

Another advantage resides in direct visualization of radiation-related changes to the target.

Another advantage resides in the use of elasticity (or strain) images.

Still further advantages of the present invention will be appreciated to those of ordinary skill in the art upon reading and understand the following detailed description.

The invention may take form in various components and arrangements of components, and in various steps and arrangements of steps. The drawings are only for purposes of illustrating the preferred embodiments and are not to be construed as limiting the invention.

FIGURE 1 illustrates a block diagram of a therapy system for treating a target of a patient.

FIGURE 2 illustrates a block diagram of a method for treating a target of a patient.

With reference to FIGURE 1, a therapy system **10** includes a planning imaging modality **12** generating a planning image, such as a three-dimensional image, of a target and, commonly, one or more organs at risk (OARs) of a patient **14.** The target is an organ or other tissue region which contains a lesion, such as a tumor, to be treated. The planning imaging modality **12** is suitably one or more of a computed tomography (CT) scanner, a positron emission tomography (PET) scanner, a magnetic resonance (MR) scanner, a single photon emission computed tomography (SPECT) scanner, a cone-beam computed tomography (CBCT) scanner, and the like. The generated planning image is typically stored in a planning image memory **16** of the therapy system **10**.

A planning system **18** of the therapy system **10** receives the planning image from the planning imaging modality **12**, typically via the planning image memory **16**. Using the planning image, the planning system **18** generates and/or updates a treatment plan for the patient **14**. As to the former, the planning image is generated prior to therapy delivery. As to the latter, the planning image is typically generated between fractions, such as, for example, after a predetermined number of fractions have been completed. To facilitate planning, the planning system **18** includes one or more of a segmentation module **20**, a user interface module **22**, and an optimization module **24**.

The segmentation module **20** receives an image, such as the planning image, and delineates one or more regions of the image, such as the target and/or the OARs. The regions are typically delineated with contour(s) tracing the boundaries of the regions in the image. Delineation can be performed automatically and/or manually. As to automatic delineation, any number of known segmentation algorithms can be employed. As to manual delienation, the segmentation module **20** cooperates with the user interface module **22** to allow clinicians to manually delineate the regions in the image and/or manually adjust automatic delineations of the regions in the image.

The user interface module **22** presents a user interface to an associated user with a display device **26** of the planning system **18**. The user interface can allow the user to at least one of delineate regions of an image, modify delineations of regions of an image, and view delineations of regions of an image. Typically, the user delineates a region of an image by drawing a contour along the boundary of the region on the image using a user input device **28** of the planning system **18**. Further, a delineation of a region in an image is typically viewed by overlaying a representative contour on the image, and modified by resizing and/or

reshaping the representative contour using the user input device **28**. The user interface can also allow the user to enter and/or define parameters for generating and/or updating the treatment plan using the user input device **28**.

The optimization module **24** receives plan parameters for the treatment plan, typically from the user interface module **22**, as well as contours delineating the target and/or the OARs in the planning image from the segmentation module **20**. The optimization module **24** can also receive other relevant inputs, such as a delivered dose distribution indicating dose delivered to the target. Based on the plan parameters, the contours and any other relevant inputs, the optimization module **24** generates and/or updates the treatment plan so it complies with the plan parameters. The treatment plan suitably includes a planning target volume (PTV), margins around the target, and a plurality of fractions, each fraction specifying beam directions and energies for treating the target. The treatment plan generated by the optimization module **24** is suitably stored in a treatment plan memory **30**.

The therapy system **10** further includes an elasticity imaging modality **32** generating one or more elasticity (or strain) images of the target and/or the OARs. The elasticity images are typically three dimensional images, but two dimensional images are also contemplated. Elasticity images provide information on size and boundary of the target and/or the OARs that may not be available in other types of images. Namely, the target may be differentiable from surrounding normal tissue with higher contrast, depending on the underlying mechanical properties of the target. For example, malignant liver tumors are known to be significantly stiffer (approximately 10 kilopascals) than normal liver tissue (e.g., approximately 2 kilopascals).

The elasticity imaging modality **32** is typically an ultrasound (US) imaging modality (as illustrated), but other types of imaging modalities capable of generating elasticity images, such as an MR imaging modality, are contemplated. Further, it is to be appreciated that the elasticity imaging modality **32**, typically, also generates other types of images. For example, where the elasticity imaging modality **32** is a US imaging modality, the elasticity imaging modality **32** can also generate brightness mode (B-mode) images. Even more, the elasticity imaging modality **32** and the planning imaging modality **12** can be one and the same. However, for ease of discussion, the elasticity imaging modality **32** and the planning imaging modality **12** are described separately.

To generate the elasticity images, a sensing device **34**, such as a US transducer, of the elasticity imaging modality **32** generates spatially encoded data representing sensed elasticity properties of the target and/or the OARs. The spatially

encoded data is typically generated during therapy delivery (i.e., execution of the treatment plan), but can also be generated before therapy delivery and/or after therapy delivery.

An elasticity imaging system **36** of the elasticity imaging modality **32** acquires the spatially encoded data from the sensing device **34**, using, for example, a receiver **38**, and processes the spatially encoded data into the elasticity images. The processing includes reconstructing the spatially encoded data into the elasticity images, using, for example, a reconstruction processor **40** of the elasticity imaging system **36**, and varies depending upon the sensing device **34**. The elasticity imaging system **36** processes the spatially encoded data in real-time as it is generated, but could generate elasticity images at a later time. Typically, the spatially encoded data and/or the elasticity images are stored in a data buffer memory **42** and an elasticity image memory or buffer **44**, respectively, of the elasticity imaging system **36**. The elasticity imaging system **36** further transmits excitation signals, such as radio frequency signals, into the target and/or the OARs to prompt generation of the spatially encoded data. The excitation signals can be transmitted, for example, using a transmitter **45** and/or the sensing device **34**.

When the sensing device **34** is a US transducer, the sensing device **34** can take a variety of forms. According to one form, the sensing device **34** is formed of a one dimensional array of transducer elements generating the spatially encoded echo data. Such a sensing device is mechanically moved to generate spatially encoded data for identifying a current location of the target or the OARs (e.g., with a three dimensional image). Further, such a sensing device can be positioned at a fixed position to generate spatially encoded data for a two dimensional image. According to another form, the sensing device **34** is formed of a two dimensional array of transducer elements generating the spatially encoded data. Such a sensing device can be positioned at a fixed position and electronically swept to generate spatially encoded data for a two or three dimensional image or other indicator of location or distance.

A sensor-positioning device **46** of the elasticity imaging modality **32** moves the sensing device **34**. Typically, the sensor-positioning device **46** is a robotic arm (as illustrated), but other mechanical devices for positioning and/or moving the sensing device **34** are contemplated. The sensor-positioning device **46** is only necessary to the extent that the sensing device **34** needs to be moved to generate the elasticity images. For example, as noted above, the sensing device **34** needs to be moved to create a three dimensional image and, in some instances, a two dimensional image when the sensing device **34** is a US transducer formed of a one dimensional array of transducer elements.

A tissue-pressure device **34, 46** (e.g., a US transducer array) of the elasticity imaging modality **32** applies pressure to the target and/or the OARs. It is contemplated that the tissue-pressure device **34, 46** can mechanically apply pressure to the target and/or the OARs using, for example, a robotic arm. When the elasticity imaging modality **32** includes the sensor-positioning device **46**, the tissue-pressure device **34, 46** can be formed of the sensor-positioning device **46** and the sensing device **34**, and apply pressure to the target and/or the OARs via the sensing device **34**. For example, the sensor-positioning device **46** can move the sensing device **34** to compress the target and/or the OARs. It is also contemplated that the tissue-pressure device **34, 46** can acoustically apply pressure to the target and/or the OARs. When the sensing device **34** is a US transducer, the sensing device **34** can be employed to acoustically apply pressure to the target and/or the OARs.

During the acquisition of spatially encoded data, the elasticity imaging system **36** controls one or more of the sensing device **34**, the sensor-positioning device **46**, and the tissue-pressure device **34, 46**. In that regard, the elasticity imaging system **36** controls the tissue-pressure device **34, 46** to appropriately apply pressure to the target and/or the OARs when acquiring spatially encoded data for an elasticity image. For example, the elasticity imaging system **36** can control the tissue-pressure device **34, 46** according to an acoustic radiation force impulse (ARFI) imaging technique. Further, where the elasticity imaging modality **32** includes the sensor-positioning device **46**, the elasticity imaging system **36** controls the sensor-positioning device **46** to appropriately move the sensing device **34** when generating spatially encoded data for an elasticity image. Even more, the elasticity imaging system **36** can control the sensor-positioning device **46** and/or the tissue-pressure device **34, 46** to ensure the therapy beam is not obstructed by, for example, the sensing device **34**. Similarity, the optimization module **24** can generate the treatment plan using the known location and/or motion pattern of the sensing device **34** to ensure the therapy beam is not obstructed.

Where the elasticity imaging modality **32** includes the sensor-positioning device **46** and/or the tissue-pressure device **34, 46** mechanically applies pressure to the target and/or the OARs, the elasticity imaging system **36** can track the motion of the sensor-positioning device **46** and/or the motion of the tissue-pressure device **34, 46** to ensure the correct motion of the sensing device **34** and/or application of force. Further, the optimization module **24** can determine the location of the sensor-positioning device **46** to ensure the therapy beam is not obstructed. The motion is typically tracked using an optical tracker **48**, but other devices for tracking are contemplated.

A controller **49** of the elasticity imaging system **36** controls the constituent components of the elasticity imaging system **36**, such as the transmitter **45**, to carry out the above described functionality. For example, the controller **49** controls the constituent components to generate the elasticity images. To do so, the controller includes at least one memory and at least one processor. The memory includes processor executable instructions embodying the above described functionality of the elasticity imaging system **36**, and the processor executes the processor executable instructions.

In addition to, or as an alternative to, receiving the planning image and generating and/or updating the treatment plan based on the planning image, the planning system **18** receives one or more elasticity images from the elasticity imaging modality **32** and updates the treatment plan based on the elasticity images. Typically, the updating entails updating the margins of the treatment plan, but other updates are contemplated. Elasticity images are suitable for updating the margins of the treatment plan since elasticity images can illustrate radiation-related changes to the target, such as size reduction, as the treatment plan is executed. Elasticity images can capture radiation-related change since ionizing radiation is known to change the levels of hemoglobin and water content in the irradiated regions, thereby changing the mechanical properties of the irradiated regions.

To update the treatment plan, the patient **14** is set-up on a treatment couch **50** of a therapy delivery apparatus **52** before beginning therapy delivery. An elasticity module **54** of the planning system **18** then receives an elasticity image (hereafter the "initial elasticity image"), such as a three-dimensional elasticity image, of the target and/or the OARs from the elasticity imaging modality **32**. The initial elasticity image provides baseline elastic modulus variations for the target and surrounding normal tissue. Further, the target is delinated in the initial elasticity image using the segmentation module **20** of the planning system **18** to create an initial segmentation.

Thereafter, during therapy delivery and/or between treatment fractions, the elasticity module **54** receives elasticiy images from the elasticity imaging modality **32**. As to receiving during therapy delivery, elasticity images can be received periodically at a rate determined by an operator of the planning system **18**. The elasticity images are suitably of the same type as the intial elasticity image. Upon receiving one of the elasticity images, the target is delinated in the elasticity image using the segmentation module **20** of the planning system **18** to create a current segmentation. It is contemplated that the segmentation module **20** can be employed to create the current segmentation by updating the initial segmentation based on changes in target position.

Having determined the current segmentation, the elasticity module **54** compares the target, as identified by the current segmentation, with the target, as identified by the initial segmentation. Based on this comparison, a determination is made as to whether the target is shrinking and/or otherwise changing in size. Typically, intra-fraction elasticity imaging can reveal real-time changes occurring in the target due to therapy delivery, and inter-fraction elasticity imaging can reveal target shrinkage (if any). If the target is deemed to have shrunk or otherwise changed in size, the margins of the treatment plan can be adjusted accordingly and the treatment plan can be re-optimized using the optimization module **24** of the planning system **18**.

The elasticity module **54** can also be employed for determining a delivered dose distribution for the target and and updating the treatment plan based on the delivered dose distribution. This includes determining a cumulative motion pattern, such as a probability density function, of the target for each of the completed fractions of the treatment plan. A cumulative motion pattern for a fraction is determined by accumulating the locations of the target, as determined by the current segmentation, in the elasticity images received during the fraction. The more elasticity images that are received during the fraction, the more accurate the cumulative motion pattern.

The determined cumulative motion patterns are then convolved with corresponding planned dose distributions. For example, a cumulative motion pattern for a fraction is convolved with the planned dose distribution for the fraction. The motion compensated dose distributions are then accumulated to get the delivered dose distribution. Further, the delivered dose distribution is provided to the optimization module **24** of the planning system **18** and the treatment plan is re-optimized based on the delivered dose distribution.

At a scheduled day and time for a therapy session of the patient **14**, the therapy delivery apparatus **52** of the therapy system **10**, such as a linear particle accelerator, delivers therapy, such as ablation therapy, external beam radiation therapy and/or brachytherapy, to the patient **14**. The therapy typically includes radiation, such as one or more of x-rays, protons, high-intensity focused ultrasound (HIFU), and the like. The therapy delivery apparatus **52** is controlled by a delivery control system **56** of the therapy system **10** in accordance with the treatment plan, optionally as updated between fractions and/or during fractions. The treatment plan can be received from, for example, the treatment plan memory **30**.

A segmentation module **58** of the delivery control system **56** (or the elasticity imaging system **36**) receives an elasticity image of the target and/or the OARs from the elasticity imaging modality **32** and delineates the target in the elasticity image. The target is typically delineated with contour(s) tracing the boundary of the target in the elasticity image. Delineation can be performed automatically and/or manually. As to automatic delineation, any number of known segmentation algorithms can be employed. Alternatively, a registration map between the elasticity image and the planning image can be generated using any number of known registration aglorithms, such as deformable image registration algorithms. The delineation of the target in the planning image can then be mapped to the elasticity image using the registration map. As to manual delineation, the segmentation module **58** cooperates with a user interface module **60** of the delivery control system **56** to allow clinicians to manually delineate the target in the elasticity image and/or manually adjust an automatic delineation of the target in the elasticity image.

The user interface module **60** presents a user interface to an associated user with a display device **62** of the delivery control system **56**. The user interface allows the user to at least one of delineate the target in the elasticity image, modify a delineation of the target in the elasticity image, and view a delineation of the target in the elasticity image. Typically, the user delineates the target by drawing a contour along the boundary of the target on the elasticity image using a user input device **64** of the delivery control system **56**. Further, a delineation is typically viewed by overlaying a representative contour on the elasticity image, and modified by resizing and/or reshaping the representative contour using the user input device **64**.

Before beginning therapy delivery, the patient is set-up on the treatment couch **50** of the therapy delivery apparatus **52**. An elasticity image (hereafter the "initial elasticity image"), such as a three-dimensional elasticity image, or other position indicating data of the target and/or the OARs is then received from the elasticity imaging modality **32**. Further, the target is delinated in the initial elasticty image using the segmentation module **58** to create an initial segmentation, and the margins of the treatment plan are combined with the initial segmentation to identify the planning target volume in the initial elasticity image.

During therapy deliery, a gating module **66** of the delivery control system **56** receives a series of elasticity images, such as three-dimensional elasticity images, of the target from the elasticity imaging modality **32** or other measures of target location. For example, the elasticity images can be received periodically at a rate determined by an operator of the delivery control system **56**. The periodicity is selected to be short relative to

anticipated patient motion (e.g., short compared to the respiratory cycle). The elasticity images are suitably of the same type as the intial elasticity image. Upon receiving an elasticity image, the target is delinated in the elasticity image using the segmentation module **58** of the delivery control system **56** to create a current segmentation. It is contemplated that the segmentation module **58** can be employed to create the current segmentation by updating the initial segmentation based on changes in target position. Alternatively, the elasticity imaging system **36** can be used to measure changes in distance or location of the target relative to the sensing device **34**, for example, operating in the ARFI mode.

Having determined the current segmentation, the gating module **66** compares the location of the target, as identified by the current segmentation, with the location of the planning target volume, as identified in the initial elasticity image. Based on this comparison, a decision is made as to whether to turn the therapy beam OFF or keep it ON. Typically, the decision criterion differs based on clinical needs. However, one example is to turn the therapy beam OFF if there is less than 90% overlap between the planning target volume and the target; otherwise, the beam may be kept ON.

The planning system **18** and the delivery control system **56** include one or more memories **68, 70** and one or more processors **72, 74**. The memories **68, 70** store processor executable instructions for carrying out the functions associated with the planning system **18** and the delivery control system **56**, including those associated with the segmentation modules **20, 58**, the user interface modules **22, 60**, the optimization module **24**, the elasticity module **54**, and the gating module **66**. The processors **72, 74** execute the processor executable instructions stored on the memories **68, 70**. The planning system **18** and/or the therapy control system **56** further include one or more system buses **76, 78** facilitating communication between the processors **72, 74**, the memories **68, 70**, the user input devices **28, 64** and the display devices **26, 62**.

With reference to FIGURE 2, a block diagram of a therapy method **100** for treating the target is provided. The processors **72, 74** of the planning system **18** and the delivery control system **56** suitably perform the method **100**. The method **100** includes receiving **102** an initial elasticity image of the target from the elasticity imaging modality **32**. The initial elasticity image is generated prior to execution of a fraction of the treatment plan, typically once the patient **14** has been aligned on the treatment couch **50** of the therapy delivery apparatus **52** for the fraction. The target is then delineated **104** in the initial elasticity image using the segmentation modules **20, 58** to segment the initial elasticity image. One or more elasticity images of the target are then received **106**. The elasticity

images are generated during and/or after execution of the fraction, but typically prior to execution of the next fraction. The target is then delineated **108** in the elasticity images using the segmentation modules **20, 58** to segment the elasticity images. The segmentation of the initial elasticity image is compared **110** against the segmentations of the elasticity images to identify motion of the target and/or changes of the target. Based on the comparison, the treatment plan is updated **112** and/or execution of the fraction is controlled **114**. The updating **112** includes, for example, updating margins of the treatment plan, and the controlling **114** includes, for example, gating the therapy beam.

It is to be appreciated that the concepts of the present disclosure as applied to therapy delivery are severable from the concepts of the present disclosure as applied to planning. For example, dynamic gating as described herein can be used independent of dynamic margin adjustment. Also, the planning system **18** and the delivery control system **56** can be combined into a common system.

Even more, it is to be appreciated that the concepts of the present disclosure can improve the efficiency of therapy delivery gating. This is achieved by directly utilizing positional information of the target instead of using external or internal surrogates for target motion. The positional information of the target can be determined from real-time elasticity images (independently or as a complement to other types of images), which are known to image cancerous tumors with high contrast.

Further, it is to be appreciated that the concepts of the present disclosure can reduce unnecessary harmful dose to normal tissue surrounding the target. This is achieved by dynamically adjusting the margins in-between and/or during fractions. If target shrinkage is observed in response to therapy delivery, the treatment plan can be made to account for this change in the target shape and size.

As used herein, a memory includes one or more of a non-transient computer readable medium; a magnetic disk or other magnetic storage medium; an optical disk or other optical storage medium; a random access memory (RAM), read-only memory (ROM), or other electronic memory device or chip or set of operatively interconnected chips; an Internet/Intranet server from which the stored instructions may be retrieved via the Internet/Intranet or a local area network; or so forth. Further, as used herein, a processor includes one or more of a microprocessor, a microcontroller, a graphic processing unit (GPU), an application-specific integrated circuit (ASIC), a field-programmable gate array (FPGA), and the like; a controller includes at least one memory and at least one processor, the processor executing processor executable instructions on the memory; a user input device

includes one or more of a mouse, a keyboard, a touch screen display, one or more buttons, one or more switches, one or more toggles, and the like; and a display device includes one or more of a LCD display, an LED display, a plasma display, a projection display, a touch screen display, and the like.

The invention has been described with reference to the preferred embodiments. Modifications and alterations may occur to others upon reading and understanding the preceding detailed description. It is intended that the invention be construed as including all such modifications and alterations insofar as they come within the scope of the appended claims or the equivalents thereof.

CLAIMS:

1. A therapy planning system **(10)** comprising:

at least one processor **(74, 72)** programmed to:

receive initial elasticity data indicative of a location of the target generated prior to execution of a fraction of a treatment plan for the target;

receive additional elasticity data indicative of a location of the target generated during and/or after execution of the fraction;

compare the initial elasticity data and the additional elasticity data to identify motion of the target and/or changes of the target; and,

based on the comparison, update the treatment plan and/or control execution of the fraction.

2. The therapy planning system **(10)** according to claim 1, wherein the processor **(74, 72)** is further programmed to:

delineate the target in an initial elasticity image of the initial elasticity data to segment the initial elasticity image;

delineate the target in one or more elasticity images of the additional elasticity data to segment the elasticity images; and,

compare the segmentation of the initial elasticity image against the segmentations of the additional elasticity images.

3. The therapy planning system **(10)** according to either one of claims 1 and 2, wherein the processor **(74, 72)** is further programmed to:

update planning target volume (PTV) margins of the treatment plan based on the comparison, the updated PTV margins employed by one or more subsequent fractions of the treatment plan.

4. The therapy planning system **(10)** according to claim 3, wherein the updating includes at least one of:

reducing the PTV margins in response to identifying a size reduction of the target; and,

determinig location of a sensing device **(34)** generating the additional elasticity data.

5. The therapy planning system **(10)** according to any one of claims 1-4, wherein the processor **(74, 72)** is further programmed to:

gate a therapy beam treating the target during execution of the fraction based on the comparison.

6. The therapy planning system **(10)** according to any one of claims 1-5, wherein the treatment plan is for one of ablation therapy, external beam radiation therapy and brachytherapy.

7. The therapy planning system **(10)** according to any one of claims 1-6, further including:

an ultrasound (US) imaging modality **(32)**, wherein the initial elasticity data and the additional elasticity data are generated by the US imaging modality **(32)**.

8. The therapy planning system **(10)** according to any one of claims 1-7, further including:

a sensing device **(34)** generating spatially encoded data, wherein the initial elasticity data and the additional elasticity data are generated from the spatially encoded data; and,

a sensor-positioning device **(46)** moving the sensing device **(34)** during acquisition of the spatially encoded data.

9. The therapy planning system **(10)** according to claim 8, wherein the sensor-positioning device **(46)** moves the sensing device **(34)** during acquisition of the spatially encoded data to apply varying degrees of pressure on the target and surrounding normal tissue.

10. The therapy planning system **(10)** according to any one of claims 1-8, wherein the initial elasticity data and the additional elasticity data include three-dimensional images of the target.

11. A therapy planning method **(100)** comprising:

receiving **(102)** initial elasticity data indicative of a location of the target generated prior to execution of a fraction of a treatment plan for the target;

receiving **(106)** additional elasticity data indicative of a location of the target generated during and/or after execution of the fraction;

compare **(110)** the initial elasticity data and the additional elasticity data to identify motion of the target and/or changes of the target; and,

based on the comparison, updating **(112)** the treatment plan and/or controlling **(114)** execution of the fraction.

12. The therapy planning method **(100)** according to claim 11, further including:

delineating **(104)** the target in the initial elasticity image to segment the initial elasticity image;

delineating **(108)** the target in the additional elasticity images to segment the additional elasticity images;

comparing **(110)** the segmentation of the initial elasticity image against the segmentations of the additional elasticity images

13. The therapy planning method **(100)** according to either one of claims 11 and 12, further including:

updating planning target volume (PTV) margins of the treatment plan based on the comparison, the updated PTV margins employed by one or more subsequent fractions of the treatment plan.

14. The therapy planning method **(100)** according to any one of claims 11-13, further including:

gating a therapy beam treating the target during execution of the fraction based on the comparison.

15. The therapy planning method **(100)** according to any one of claims 11-14, wherein the initial elasticity data and the additional elasticity data are generated by an ultrasound imaging modality **(32)**, and wherein the initial elasticity data and the additional elasticity data include three-dimensional images of the target.

16. The therapy planning method **(100)** according to any one of claims 11-15, wherein the initial elasticity data and the additional elasticity data are generated from spatially encoded data generated by a sensing device **(34)**, the sensing device **(34)** moved by a sensor-positioning device **(46)** during acquisition of the spatially encoded data.

17. The therapy planning method **(100)** according to claim 16, wherein the sensor-positioning device **(46)** moves the sensing device **(34)** during acquisition of the spatially encoded data to apply varying degrees of pressure on the target and surrounding normal tissue.

18. At least one processor **(72, 74)** programmed to perform the therapy planning method **(100)** according to any one of claims 11-17.

19. A non-transitory computer readable medium **(68, 70)** carrying software which controls at least one processor **(72, 74)** to perform the therapy planning method **(100)** according to any one of claims 11-17.

20. A therapy planning system **(10)** comprising:

at least one processor **(74, 72)** programmed to:

receive elasticity images of the target in real-time during execution of a fraction of a treatment plan for the target;

delineate the target in the received elasticity images to segment the elasticity images;

compare a reference segmentation against the segmentations of the elasticity images to identify motion of the target and/or changes of the target, the reference segmentation delineating the target in an elasticity image; and,

based on the comparison, updating the treatment plan and/or controlling execution of the fraction.

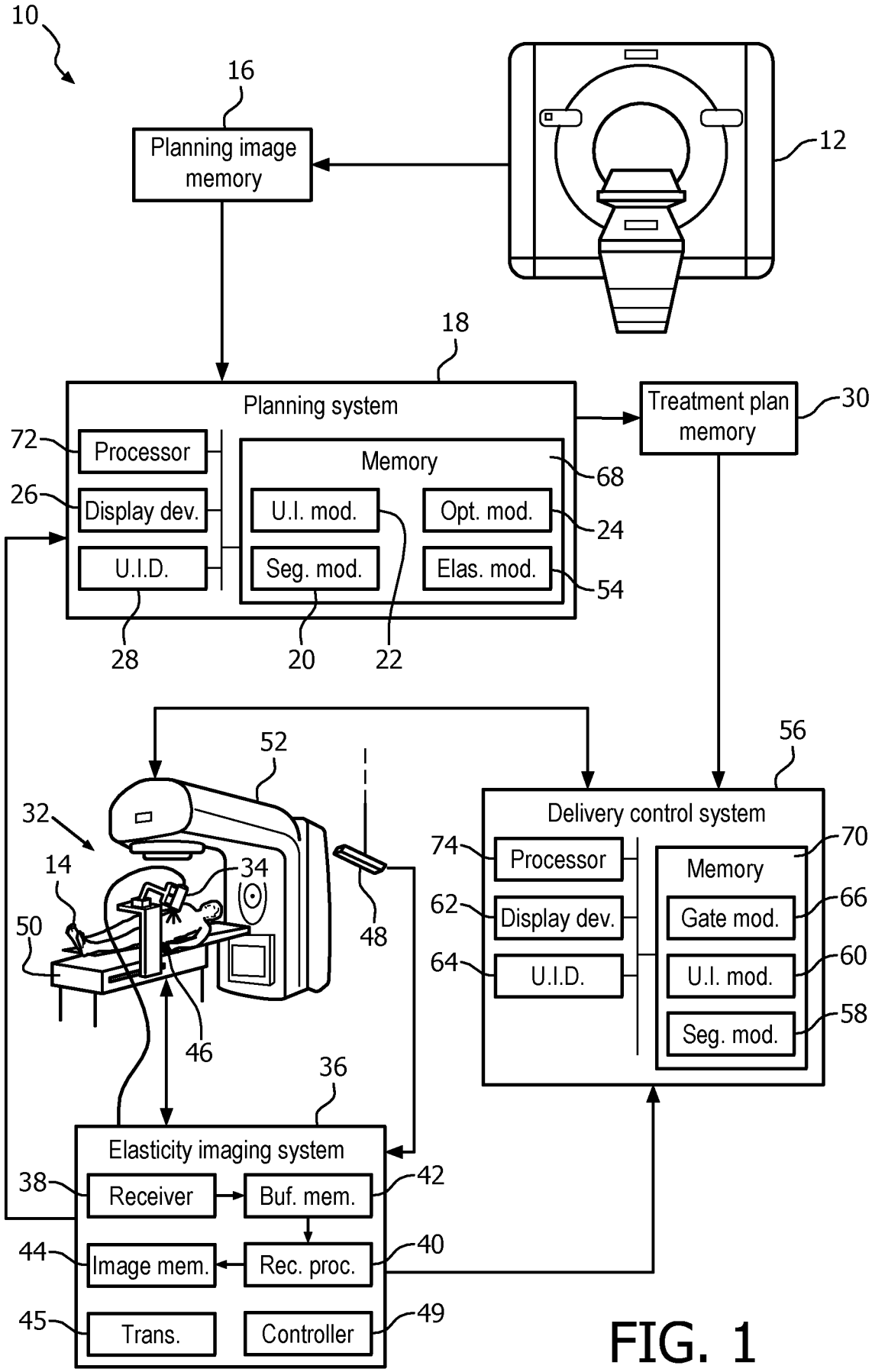
10
16
Planning image memory
12
18
Planning system
Processor
Display dev.
U.I.D.
Memory
U.I. mod.
Opt. mod.
Seg. mod.
Elas. mod.
72
26
68
24
54
28
20
22
Treatment plan memory
30
52
56
32
14
34
50
48
46
36
Delivery control system
74
Processor
62
Display dev.
64
U.I.D.
Memory
Gate mod.
U.I. mod.
Seg. mod.
70
66
60
58
Elasticity imaging system
38
Receiver
Buf. mem.
42
44
Image mem.
Rec. proc.
40
45
Trans.
Controller
49

FIG. 1

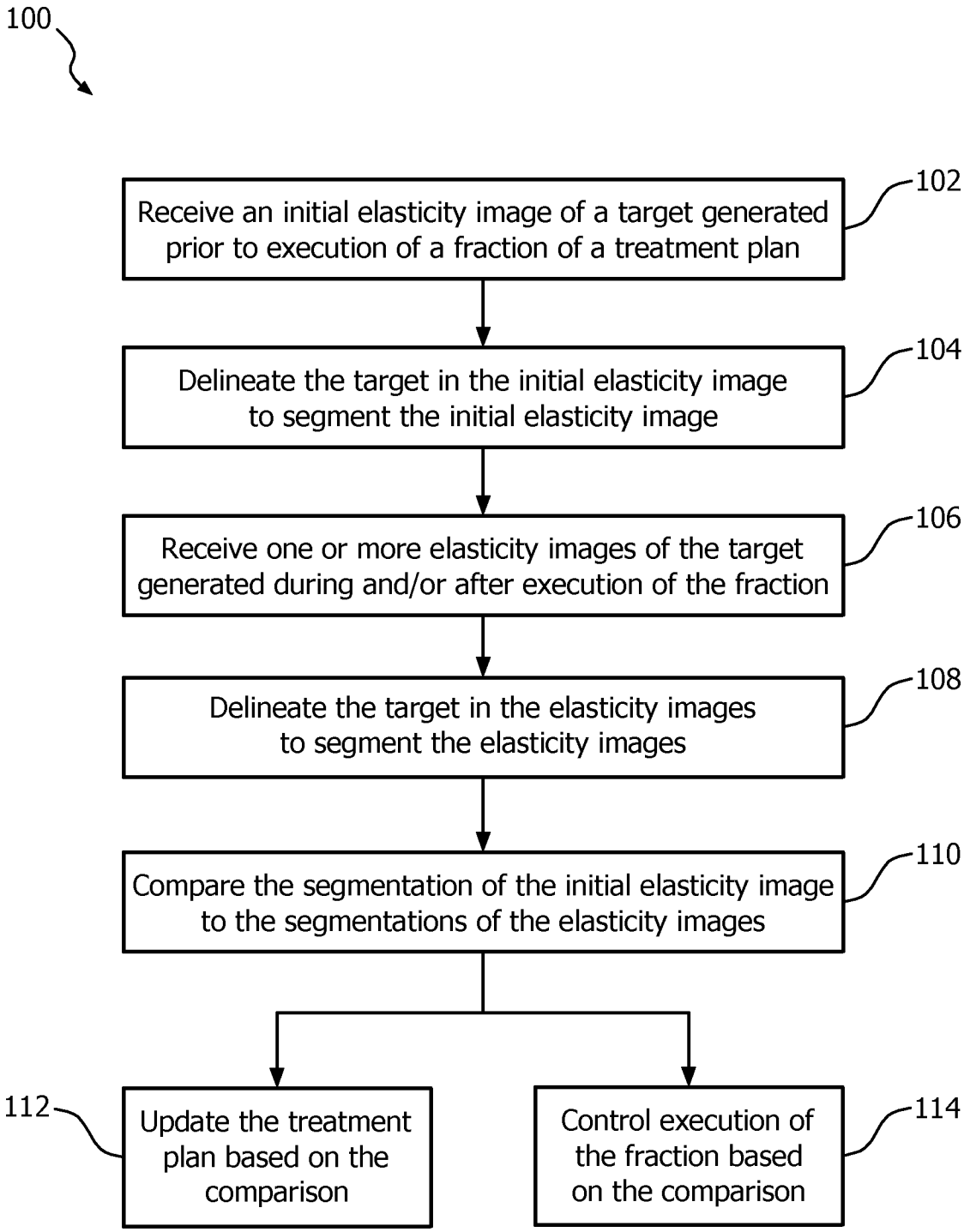
100
Receive an initial elasticity image of a target generated prior to execution of a fraction of a treatment plan
102
Delineate the target in the initial elasticity image to segment the initial elasticity image
104
Receive one or more elasticity images of the target generated during and/or after execution of the fraction
106
Delineate the target in the elasticity images to segment the elasticity images
108
Compare the segmentation of the initial elasticity image to the segmentations of the elasticity images
110
112
Update the treatment plan based on the comparison
Control execution of the fraction based on the comparison
114

FIG. 2

INTERNATIONAL SEARCH REPORT

International application No
PCT/IB2013/054402

A. CLASSIFICATION OF SUBJECT MATTER
INV. A61N5/10 A61N7/02 A61B8/00 A61B8/08
ADD.

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)
A61N A61B

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)
EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2011/060222 A1 (THITTAI ARUN K [US] ET AL) 10 March 2011 (2011-03-10) abstract; claims 12-17; figure 1 paragraphs [0065], [0107], [0136] - [0140], [0175], [0176]	1-10,20
A	US 2010/317971 A1 (FAN LIEXIANG [US] ET AL) 16 December 2010 (2010-12-16) paragraphs [0020], [0033]; figure 1	1-10,20

-/--

[X] Further documents are listed in the continuation of Box C.

[X] See patent family annex.

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier application or patent but published on or after the international filing date

"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
11 September 2013	19/09/2013

Name and mailing address of the ISA/	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Kajzar, Anna

3

Form PCT/ISA/210 (second sheet) (April 2005)

INTERNATIONAL SEARCH REPORT

International application No
PCT/IB2013/054402

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	GARRA ET AL: "Elastography: Current Status, Future Prospects, and Making It Work for You", ULTRASOUND QUARTERLY, RAVEN PRESS, NEW YORK, NY, US, vol. 27, no. 3, 1 September 2011 (2011-09-01), pages 177-186, XP009161774, ISSN: 0894-8771 abstract -----	1-10,20

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/IB2013/054402

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 2011060222 A1	10-03-2011	NONE	
US 2010317971 A1	16-12-2010	NONE	

INTERNATIONAL SEARCH REPORT

International application No.
PCT/IB2013/054402

Box No. II Observations where certain claims were found unsearchable (Continuation of item 2 of first sheet)

This international search report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. [X] Claims Nos.: 11-19
because they relate to subject matter not required to be searched by this Authority, namely:

Rule 39.1(iv) PCT - Method for treatment of the human or animal body by therapy

2. [ ] Claims Nos.:
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:

3. [ ] Claims Nos.:
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box No. III Observations where unity of invention is lacking (Continuation of item 3 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

1. [ ] As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.

2. [ ] As all searchable claims could be searched without effort justifying an additional fees, this Authority did not invite payment of additional fees.

3. [ ] As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:

4. [ ] No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

Remark on Protest

[ ] The additional search fees were accompanied by the applicant's protest and, where applicable, the payment of a protest fee.

[ ] The additional search fees were accompanied by the applicant's protest but the applicable protest fee was not paid within the time limit specified in the invitation.

[ ] No protest accompanied the payment of additional search fees.