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(54) Title: SYSTEM AND METHODS FOR PERCUTANEOUS TREATMENT PLANNING AND TREATMENT MONITORING

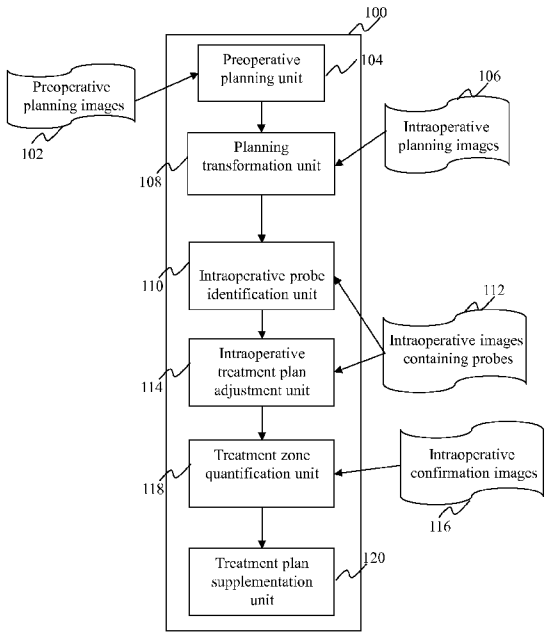


Fig. 1

(57) Abstract: The present teaching relates to surgical procedure assistance. In one example, a first image of a patient captured prior to a surgical procedure is received. A treatment plan is generated based on the first image. The treatment plan includes information related to one or more surgical instruments. A second image of the patient captured after the surgical procedure has been initiated is received. The treatment plan is dynamically adjusted based on a pose of any of the one or more surgical instruments identified from the second image. A third image of the patient captured after a lesion is treated by at least one of the surgical instruments based on the adjusted treatment plan is received. Whether a further treatment to the lesion is needed is determined based on the third image. Upon determining a further treatment is needed, an updated treatment plan is dynamically generated based on the third image.

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SYSTEM AND METHODS FOR PERCUTANEOUS TREATMENT PLANNING AND TREATMENT MONITORING

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] The present application claims priority to U.S. Provisional Application Ser. No. 61/991,308, filed May 9, 2014, entitled "System and Methods for Percutaneous Treatment Planning and Treatment Monitoring," and U.S. Non-Provisional Application Ser. No. 14/707,692, filed May 8, 2015, entitled "System and Methods for Percutaneous Treatment Planning and Treatment Monitoring" which are incorporated herein by reference in their entireties.

BACKGROUND

Technical Field

[0002] The present teaching relates to surgical procedure assistance. More specifically, the present teaching is pertaining to percutaneous treatment planning and treatment monitoring for surgical procedures.

Discussion of Technical Background

[0003] In interventional procedures, one or more probes may be placed into the tumor. Through proper setting of the ablation device, such as the voltage and the duration in a microwave ablation device, the tumor tissue is killed by heating or freezing. Such interventional treatment procedures need a good treatment-planning method that can ensure proper tumor coverage with a safety margin and at the same time avoid the damage of critical organs. The planning method may provide an estimate of how many ablation probes may be needed for a tumor and how each probe may be positioned. But in the actual treatment, the planning may not be able to be exactly followed.

[0004] However, there is a lack of systems and methods for effectively and efficiently treatment planning and monitoring of interventional procedures. Therefore, there is a need to provide an improved solution to solve the above-mentioned problems.

SUMMARY

[0005] The present teaching relates to surgical procedure assistance. More specifically, the present teaching is pertaining to percutaneous treatment planning and treatment monitoring for surgical procedures.

[0006] In one example, a method implemented on a computing device having at least one processor, storage, and a communication platform connected to a network for surgical procedure assistance is disclosed. A first image of a patient captured prior to a surgical procedure is received. A treatment plan is generated based on the first image. The treatment plan includes information related to one or more surgical instruments. A second image of the patient captured after the surgical procedure has been initiated is received. The treatment plan is dynamically adjusted based on a pose of any of the one or more surgical instruments identified from the second image. A third image of the patient captured after a lesion is treated by at least one of the one or more surgical instruments based on the adjusted treatment plan is received. Whether a further treatment to the lesion is needed is determined based on the third image. Upon determining a further treatment is needed, an updated treatment plan is dynamically generated based on the third image.

[0007] In a different example, a system for surgical procedure assistance is disclosed. The system includes a preoperative planning unit, an intraoperative treatment plan adjusting unit, a treatment zone quantification unit, and a treatment plan supplementation unit. The preoperative planning unit is configured to receive a first image of a patient captured prior to a surgical procedure and generate a treatment plan based on the first image. The treatment plan includes information related to one or more surgical instruments. The intraoperative treatment plan adjusting unit is configured to receive a second image of the patient captured after the surgical procedure has been initiated, and dynamically adjust the treatment plan based on a pose of any of the one or more surgical instruments identified from the second image. The treatment zone quantification unit is configured to receive a third image of the patient captured after a lesion is treated by at least one of the one or more surgical instruments based on the adjusted treatment plan, and determine whether a further treatment to the lesion is needed based on the third image. The treatment plan supplementation unit is configured to, upon determining a further treatment is needed, dynamically generate an updated treatment plan based the third image.

[0008] Other concepts relate to software for implementing the present teaching on surgical procedure assistance. A software product, in accord with this concept, includes at least one non-transitory machine-readable medium and information carried by the medium. The information carried by the medium may be executable program code data, parameters in association with the executable program code, and/or information related to a user, a request, content, or information related to a social group, etc.

[0009] In one example, a non-transitory machine readable medium having information recorded thereon for surgical procedure assistance is disclosed. The recorded information, when read by the machine, causes the machine to perform a series of processes. A first image of a patient captured prior to a surgical procedure is received. A treatment plan is generated based on the first image. The treatment plan includes information related to one or more surgical instruments. A second image of the patient captured after the surgical procedure has been initiated is received. The treatment plan is dynamically adjusted based on a pose of any of the one or more surgical instruments identified from the second image. A third image of the patient captured after a lesion is treated by at least one of the one or more surgical instruments based on the adjusted treatment plan is received. Whether a further treatment to the lesion is needed is determined based on the third image. Upon determining a further treatment is needed, an updated treatment plan is dynamically generated based on the third image.

[0010] Additional features will be set forth in part in the description which follows, and in part will become apparent to those skilled in the art upon examination of the following and the accompanying drawings or may be learned by production or operation of the examples. The features of the present teachings may be realized and attained by practice or use of various aspects of the methodologies, instrumentalities and combinations set forth in the detailed examples discussed below.

BRIEF DESCRIPTION OF THE DRAWINGS

[0001] The methods, systems, and/or programming described herein are further described in terms of exemplary embodiments. These exemplary embodiments are described in detail with reference to the drawings. These embodiments are non-limiting exemplary embodiments, in which like reference numerals represent similar structures throughout the several views of the drawings, and wherein:

[0002] Fig. 1 shows an exemplary system diagram for treatment planning and treatment monitoring according to one embodiment of the present teaching;

[0003] Figs. 2A-2B show exemplary flow charts of treatment planning and treatment monitoring according to one embodiment of the present teaching;

[0004] Fig. 3 shows an exemplary flow chart of treatment analysis according to one embodiment of the present teaching;

[0005] Fig. 4A shows an exemplary treated zone to compute "maximum-of-minimum distance," according to one embodiment of the present teaching;

[0006] Fig. 4B shows an exemplary treated zone to compute "minimum-of-minimum distance," according to one embodiment of the present teaching; and

[0007] Fig. 5 depicts the architecture of a computer which can be used to implement a specialized system incorporating the present teaching.

DETAILED DESCRIPTION

[0008] In the following detailed description, numerous specific details are set forth by way of examples in order to provide a thorough understanding of the relevant teachings. However, it should be apparent to those skilled in the art that the present teachings may be practiced without such details. In other instances, well known methods, procedures, systems, components, and/or circuitry have been described at a relatively high-level, without detail, in order to avoid unnecessarily obscuring aspects of the present teachings.

[0009] The present teaching is directed to methods, systems, and programing for percutaneous treatment planning, treatment plan adjustment, and treatment monitoring during surgical procedures. The method and system of the present teaching can automatically plan the needle path, estimate the coverage zone during the surgical procedures, and monitor the treatment effect to achieve safe and efficient treatment. The method and system of the present teaching are able to automatically adjust the plan during the procedure, so that the treatment zone corresponding to the actual probe position may be estimated before the ablation starts. After the procedure, the method and system of the present teaching can automatically compare the predicted treatment zone with the actual treatment zone to assess the treatment effect. In case there is an under-treated tumor region, additional probes may be placed for further treatment. For the newly placed probes, a combined treatment zone may be automatically estimated.

[0010] The system 100 in this embodiment includes a preoperative planning unit 104, a planning transformation unit 108, an intraoperative probe identification unit 110, an intraoperative treatment plan adjustment unit 114, a treatment zone quantification unit 118, and a treatment plan supplementation unit 120. The treatment planning unit 104 takes preoperative planning images 102 to generate a 2D and/or 3D model of the anatomical structures of a patient. The model may include the lesion and a safety margin with respect to the lesion as well. A treatment plan may be generated through the treatment planning unit 104. This may include information related to the probes and the lesion. For example, the information may include the number of treatment probes, the planned treatment zone for each probe, the planned setting of each probe (e.g., ablation duration and power of an ablation probe), the planned path of each probe, the planned pose (position and orientation) of each probe, a planned coverage area of the

lesion, etc. The planning transformation unit 108 may transform the preoperative plan onto the intraoperative images 106 acquired intra-operatively during the surgical procedures, e.g., in the operation room. The intraoperative probe identification unit 110 identifies probes in the intraoperative images 112. Based on the identified probe in the intraoperative images 112, a treatment plan adjustment unit 114 adjusts the treatment plan based on the actual probe pose identified from the intraoperative images 112. The treatment zone quantification unit 118 may quantify the actual treatment zone from the intraoperative confirmation images 116. Based on the quantification result, the treatment plan supplementation unit 120 may plan extra probe placement for further treatment of untreated lesion area. It is understood that although "probe" is described in the present teaching, the system and method disclosed in the present teaching can be applied to any suitable surgical instrument used in interventional procedures, such as but not limited to probes, needles, knifes, catheters, etc.

[0011] Figs. 2A-2B are exemplary flow charts of the system 100, according to an embodiment of the present teaching. At 202, lesions and other anatomical structures may be segmented from preoperative images taken in any suitable modalities before the surgical procedure starts. At 203, a safety margin may be set for the lesion to be treated. The safety margin defines the total region to be treated, which may be larger than the lesion size. Based on the planned treatment zone, the number of probes, the probe path, and the treatment zone for each probe may be determined at 204. This may be performed automatically or interactively in 3D or 2D. At 206, the preoperative planning images may be registered with the intraoperative images taken in any suitable modalities during the surgical procedure. At 208, the treatment plan made based on the preoperative images may be transformed to the intraoperative image space. This may include, for example, skin entrance position for the probes, probe paths and planned treatment zone. Other anatomical structures, such as vascular structures and lesions, may be transformed from the preoperative images to the intraoperative images. Since intraoperative images are usually not contrast enhanced, such structures may not be clearly visible in the intraoperative images. The transformation of such anatomical structures may help better visualize critical anatomical structures.

[0012] At 209, the transformed treatment plan may be adjusted due to possible patient position change between the preoperative images and intraoperative images. For example, if the preoperative images were acquired in a supine view and the intraoperative images are acquired in a prone view, there may be possible organ's relative position change, which may render a treatment plan adjustment. This may include a change in probes' pose, the safety margin, and the treatment zone size. At 210, the physician performs the probe placement according to the

adjusted treatment plan. After the probe(s) are placed into the patient's body at the targeted treatment position, at 211, a scan of the patient may be performed with probe(s) contained in the patient body. Then at 212, the probe(s) may be segmented from the newly acquired intraoperative images. This may be performed either automatically or interactively. At 213, the planned probe path for each probe may be adjusted automatically according to the identified probe location. The adjustment may align the planned pose (position and orientation) of the probe(s) to be the same as the actual probe pose (position and orientation). At 214, the treatment zone may be adjusted based on the actual probe pose. This may also include the change of pose (position and orientation) of the planned treatment zone to be aligned with the actual probe pose. At 216, the lesion coverage area may be re-estimated based on the adjusted treatment zone. The estimation may trigger a re-adjustment of the treatment zone size by changing the setting of the surgical instrument (e.g., ablation device). For example, the treatment zone may become larger than that was planned.

[0013] At 217, the physician may perform the treatment. After the treatment, a confirmation scan of the patient may be performed at 218 to obtain intraoperative confirmation images in any suitable modalities. At 220, the treated area may be segmented, either manually or automatically. At 221, the treatment effect may be quantified and analyzed. At 222, it may be determined whether an extra treatment may be needed. The analysis result from 221 may reveal that there may be untreated area within the planned treatment zone. At 224, based on the untreated area, new probe(s) may be planned. This may include an extra number of probes, the associated probe paths, the pose of each probe, and the treatment zone size of each probe. At 226, the treatment cycle may be restarted based on the plan. The same treatment monitoring method may then be applied.

[0014] Fig. 3 illustrates an exemplary flowchart of treatment analysis (e.g., 221 in Fig. 2B), according to an embodiment of the present teaching. At 302, an overlap ratio between the segmented treatment zone and the lesion may be computed. This ratio may be computed as the ratio (e.g., in percentage) of the volume of the overlap region divided by the lesion volume. For example, a value of 100% means that the lesion is completely covered by the treated region; a value less than 100% means partial coverage. At 304, the untreated lesion volume may be computed if the coverage is less than 100%. If there exists an untreated lesion area, a "maximum-of-minimum distance" between the surface of the treatment zone inside the lesion and the lesion surface may be computed. Fig. 4A illustrates one example of the "maximum-of-minimum distance," where 402 is the lesion, 404 is the treatment zone, and 406 is the "maximum-of-minimum distance" computed as the maximum value of the various distances

between surface points of the treatment zone inside the lesion and the lesion surface. This value may be used to estimate how many probes may be used to treat the untreated area.

[0015] If there is no untreated lesion area, a "minimum-of-minimum distance" may be computed, at 308, as the minimum value of the various distances between the voxels on the treatment zone and the lesion surface. Fig. 4B illustrates one example of the "minimum-of-minimum distance", where 402 is the lesion, 404 is the treatment zone, 406 is the "minimum-of-minimum distance." This value may be used to indicate the minimum value of the safety margin of the treatment. Based on the "maximum-of-minimum distance" and the "minimum-of-minimum distance," a decision may be made as to whether a further treatment is needed by placing extra probes, as well as how many probes may be needed.

[0016] Besides the quantitative measurements, the coverage may be examined visually by overlapping the planned treatment zone onto the intraoperative confirmation images. The planned treated zone and the actually treated zone may be visualized in a 2D or 3D space to examine the overlap. The "maximum-of-minimum" distance and "minimum-of-minimum" distance may be indicated on the intraoperative confirmation image. This may be performed at 312.

[0017] To implement various modules, units, and their functionalities described in the present disclosure, computer hardware platforms may be used as the hardware platform(s) for one or more of the elements described herein (e.g., the system 100 described with respect to Figs. 1-4). The hardware elements, operating systems and programming languages of such computers are conventional in nature, and it is presumed that those skilled in the art are adequately familiar therewith to adapt those technologies to surgical procedure assistance as described herein. A computer with user interface elements may be used to implement a personal computer (PC) or other type of work station or terminal device, although a computer may also act as a server if appropriately programmed. It is believed that those skilled in the art are familiar with the structure, programming and general operation of such computer equipment and as a result the drawings should be self-explanatory.

[0018] Fig. 5 depicts the architecture of a computing device which can be used to realize a specialized system implementing the present teaching. Such a specialized system incorporating the present teaching has a functional block diagram illustration of a hardware platform which includes user interface elements. The computer may be a general purpose computer or a special purpose computer. Both can be used to implement a specialized system for the present teaching. This computer 500 may be used to implement any component of surgical procedure assistance techniques, as described herein. For example, the system 100 may

be implemented on a computer such as computer 500, via its hardware, software program, firmware, or a combination thereof. Although only one such computer is shown, for convenience, the computer functions relating to surgical procedure assistance as described herein may be implemented in a distributed fashion on a number of similar platforms, to distribute the processing load.

[0019] The computer 500, for example, includes COM ports 502 connected to and from a network connected thereto to facilitate data communications. The computer 500 also includes a central processing unit (CPU) 504, in the form of one or more processors, for executing program instructions. The exemplary computer platform includes an internal communication bus 506, program storage and data storage of different forms, e.g., disk 508, read only memory (ROM) 510, or random access memory (RAM) 512, for various data files to be processed and/or communicated by the computer, as well as possibly program instructions to be executed by the CPU 504. The computer 500 also includes an I/O component 514, supporting input/output flows between the computer and other components therein such as user interface elements 516. The computer 500 may also receive programming and data via network communications.

[0020] Hence, aspects of the methods of surgical procedure assistance and/or other processes, as outlined above, may be embodied in programming. Program aspects of the technology may be thought of as "products" or "articles of manufacture" typically in the form of executable code and/or associated data that is carried on or embodied in a type of machine readable medium. Tangible non-transitory "storage" type media include any or all of the memory or other storage for the computers, processors or the like, or associated modules thereof, such as various semiconductor memories, tape drives, disk drives and the like, which may provide storage at any time for the software programming.

[0021] All or portions of the software may at times be communicated through a network such as the Internet or various other telecommunication networks. Such communications, for example, may enable loading of the software from one computer or processor into another. Thus, another type of media that may bear the software elements includes optical, electrical and electromagnetic waves, such as used across physical interfaces between local devices, through wired and optical landline networks and over various air-links. The physical elements that carry such waves, such as wired or wireless links, optical links or the like, also may be considered as media bearing the software. As used herein, unless restricted to tangible "storage" media, terms such as computer or machine "readable medium" refer to any medium that participates in providing instructions to a processor for execution.

[0022] Hence, a machine-readable medium may take many forms, including but not limited to, a tangible storage medium, a carrier wave medium or physical transmission medium. Non-volatile storage media include, for example, optical or magnetic disks, such as any of the storage devices in any computer(s) or the like, which may be used to implement the system or any of its components as shown in the drawings. Volatile storage media include dynamic memory, such as a main memory of such a computer platform. Tangible transmission media include coaxial cables; copper wire and fiber optics, including the wires that form a bus within a computer system. Carrier-wave transmission media may take the form of electric or electromagnetic signals, or acoustic or light waves such as those generated during radio frequency (RF) and infrared (IR) data communications. Common forms of computer-readable media therefore include for example: a floppy disk, a flexible disk, hard disk, magnetic tape, any other magnetic medium, a CD-ROM, DVD or DVD-ROM, any other optical medium, punch cards paper tape, any other physical storage medium with patterns of holes, a RAM, a PROM and EPROM, a FLASH-EPROM, any other memory chip or cartridge, a carrier wave transporting data or instructions, cables or links transporting such a carrier wave, or any other medium from which a computer may read programming code and/or data. Many of these forms of computer readable media may be involved in carrying one or more sequences of one or more instructions to a physical processor for execution.

[0023] Those skilled in the art will recognize that the present teachings are amenable to a variety of modifications and/or enhancements. For example, although the implementation of various components described above may be embodied in a hardware device, it may also be implemented as a software only solution - e.g., an installation on an existing server. In addition, the surgical procedure assistance system as disclosed herein may be implemented as a firmware, firmware/software combination, firmware/hardware combination, or a hardware/firmware/software combination.

[0024] While the foregoing has described what are considered to constitute the present teachings and/or other examples, it is understood that various modifications may be made thereto and that the subject matter disclosed herein may be implemented in various forms and examples, and that the teachings may be applied in numerous applications, only some of which have been described herein. It is intended by the following claims to claim any and all applications, modifications and variations that fall within the true scope of the present teachings.

WE CLAIM:

1. A method, implemented on a computing device having at least one processor, storage, and a communication platform capable of connecting to a network for surgical procedure assistance, comprising:

receiving a first image of a patient captured prior to a surgical procedure;

generating a treatment plan based on the first image, wherein the treatment plan includes information related to one or more surgical instruments;

receiving a second image of the patient captured after the surgical procedure has been initiated;

dynamically adjusting the treatment plan based on a pose of any of the one or more surgical instruments identified from the second image;

receiving a third image of the patient captured after a lesion is treated by at least one of the one or more surgical instruments based on the adjusted treatment plan;

determining whether a further treatment to the lesion is needed based on the third image; and

upon determining a further treatment is needed, dynamically generating an updated treatment plan based on the third image.

2. The method of claim 1, wherein the step of determining comprises:

automatically quantifying an actual treatment zone in relationship to the lesion.

3. The method of claim 2, wherein automatically quantifying an actual treatment zone further comprises:

segmenting the actual treatment zone from the third image;

computing an overlap ratio based on the segmented actual treatment zone and the lesion; and

determining whether a further treatment to the lesion is needed based on the overlap ratio.

4. The method of claim 3, further comprising:

calculating a first distance based on distances between a surface of the actual treatment zone inside the lesion and a surface of the lesion; or

calculating a second distance based on distances between voxels on the actual treatment zone and the surface of the lesion.

5. The method of claim 3, wherein the overlap ratio is computed by dividing a volume of an overlap region between the segmented actual treatment zone and the lesion by a volume of the lesion.

6. The method of claim 1, wherein generating a treatment plan comprises:

segmenting the lesion and anatomical structures from the first image;

determining a safety margin with respect to the lesion; and

generating a model based on the lesion, anatomical structures, and safety margin.

7. The method of claim 1, wherein the information related to the one or more surgical instruments includes at least one of:

the number of the one or more surgical instruments;

a planned pose of any of the one or more surgical instruments;

a planned path of any of the one or more surgical instruments;

a planned treatment zone of any of the one or more surgical instruments; and

a planned setting of any of the one or more surgical instruments.

8. The method of claim 1, further comprising:

receiving a fourth image of the patient captured prior to the one or more surgical instruments are placed into the patient's body during the surgical procedure;

transforming the treatment plan to a space of the fourth image by registering the first image with the fourth image; and

adjusting the transformed treatment plan based on the first and fourth images.

9. The method of claim 1, wherein dynamically adjusting the treatment plan comprises adjusting at least one of the followings based on a pose of the corresponding surgical instrument identified from the second image:

a planned pose of any of the one or more surgical instruments;

a planned path of any of the one or more surgical instruments;

a planned treatment zone of any of the one or more surgical instruments; and

a planned setting of any of the one or more surgical instruments.

10. The method of claim 4, further comprising:

providing the third image overlapped with at least one of:

the actual treatment zone,

the planned treatment zones, and

an indication of the first distance and/or the second distance.

11. A system for surgical procedure assistance, comprising:

a preoperative planning unit configured to receive a first image of a patient captured prior to a surgical procedure and generate a treatment plan based on the first image, wherein the treatment plan includes information related to one or more surgical instruments;

an intraoperative treatment plan adjusting unit configured to receive a second image of the patient captured after the surgical procedure has been initiated, and dynamically adjust the treatment plan based on a pose of any of the one or more surgical instruments identified from the second image;

a treatment zone quantification unit configured to receive a third image of the patient captured after a lesion is treated by at least one of the one or more surgical instruments based on the adjusted treatment plan, and determine whether a further treatment to the lesion is needed based on the third image; and

a treatment plan supplementation unit configured to, upon determining a further treatment is needed, dynamically generate an updated treatment plan based on the third image.

12. The system of claim 11, wherein the treatment zone quantification unit is further configured to automatically quantify an actual treatment zone in relationship to the lesion.

13. The system of claim 12, wherein the treatment zone quantification unit is further configured to:

segment the actual treatment zone from the third image;

compute an overlap ratio based on the segmented actual treatment zone and the lesion; and

determine whether a further treatment to the lesion is needed based on the overlap ratio.

14. The system of claim 13, wherein the treatment zone quantification unit is further configured to:

calculate a first distance based on distances between a surface of the actual treatment zone inside the lesion and a surface of the lesion; or

calculate a second distance based on distances between voxels on the actual treatment zone and the surface of the lesion.

15. The system of claim 13, wherein the overlap ratio is computed by dividing a volume of an overlap region between the segmented actual treatment zone and the lesion by a volume of the lesion.

16. The system of claim 11, wherein the preoperative planning unit is further configured to:

segment the lesion and anatomical structures from the first image;

determine a safety margin with respect to the lesion; and

generate a model based on the lesion, anatomical structures, and safety margin.

17. The system of claim 11, wherein the information related to the one or more surgical instruments includes at least one of:

the number of the one or more surgical instruments;

a planned pose of any of the one or more surgical instruments;

a planned path of any of the one or more surgical instruments;

a planned treatment zone of any of the one or more surgical instruments; and

a planned setting of any of the one or more surgical instruments.

18. The system of claim 11, further comprising a planning transformation unit configured to:

receive a fourth image of the patient captured prior to the one or more surgical instruments are placed into the patient's body during the surgical procedure;

transform the treatment plan to a space of the fourth image by registering the first image with the fourth image; and

adjust the transformed treatment plan based on the first and fourth images.

19. The system of claim 11, wherein the intraoperative treatment plan adjustment unit is configured to adjust at least one of the followings based on a pose of the corresponding surgical instrument identified from the second image:

a planned pose of any of the one or more surgical instruments;

a planned path of any of the one or more surgical instruments;

a planned treatment zone of any of the one or more surgical instruments; and

a planned setting of any of the one or more surgical instruments.

20. The system of claim 14, wherein the treatment zone quantification unit is further configured to provide the third image overlapped with at least one of:

the actual treatment zone,

the planned treatment zones, and

an indication of the first distance and/or the second distance.

21. A non-transitory machine readable medium having information recorded thereon for surgical procedure assistance, wherein the information, when read by a machine, causes the machine to perform the steps of:

receiving a first image of a patient captured prior to a surgical procedure;

generating a treatment plan based on the first image, wherein the treatment plan includes information related to one or more surgical instruments;

receiving a second image of the patient captured after the surgical procedure has been initiated;

dynamically adjusting the treatment plan based on a pose of any of the one or more surgical instruments identified from the second image;

receiving a third image of the patient captured after a lesion is treated by at least one of the one or more surgical instruments based on the adjusted treatment plan;

determining whether a further treatment to the lesion is needed based on the third image; and

upon determining a further treatment is needed, dynamically generating an updated treatment plan based on the third image.

22. The medium of claim 21, wherein the step of determining comprises:

automatically quantifying an actual treatment zone in relationship to the lesion.

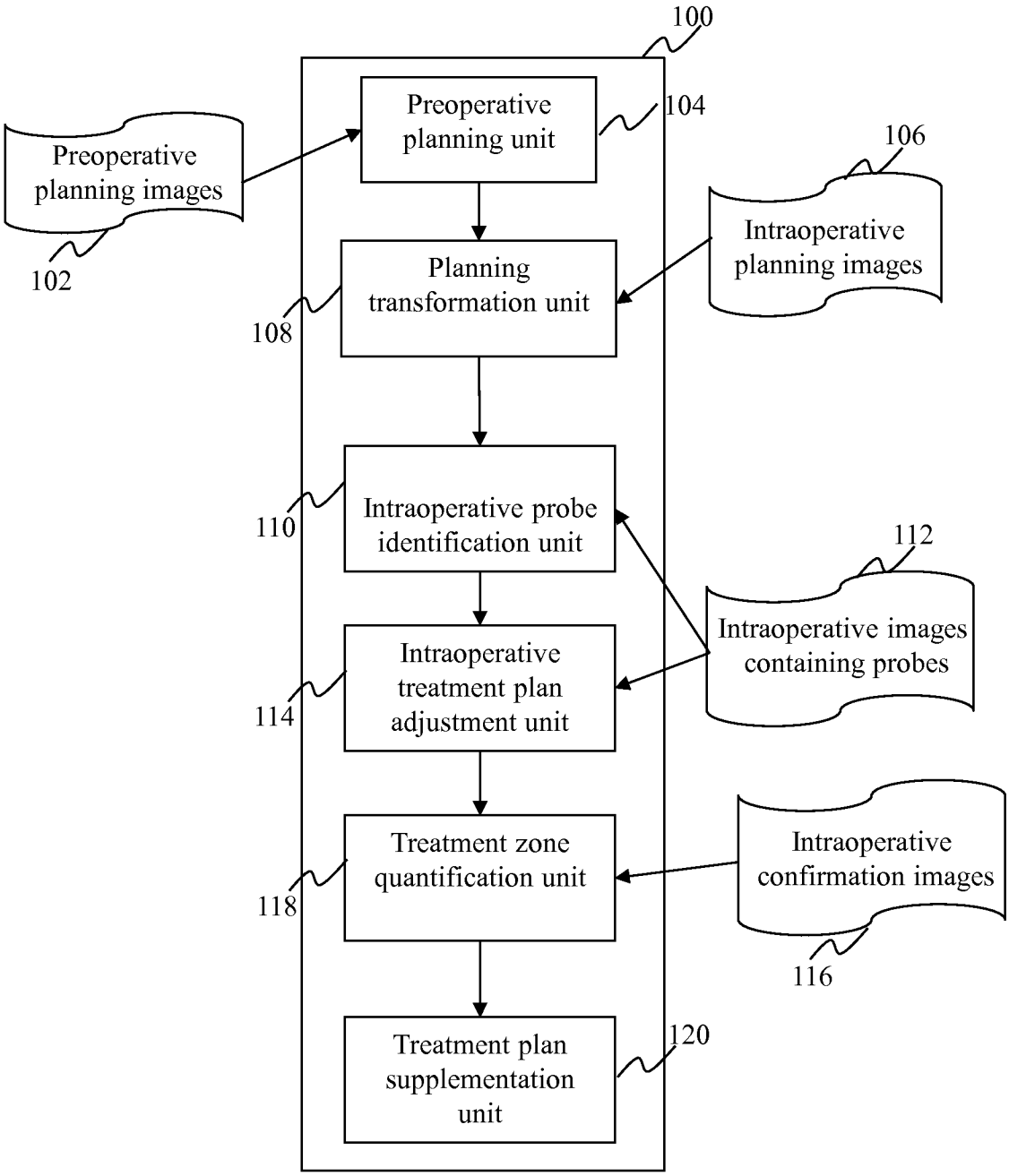

100
Preoperative planning unit
104
Preoperative planning images
102
106
Intraoperative planning images
Planning transformation unit
108
Intraoperative probe identification unit
110
112
Intraoperative images containing probes
Intraoperative treatment plan adjustment unit
114
Treatment zone quantification unit
118
Intraoperative confirmation images
116
Treatment plan supplementation unit
120

Fig. 1

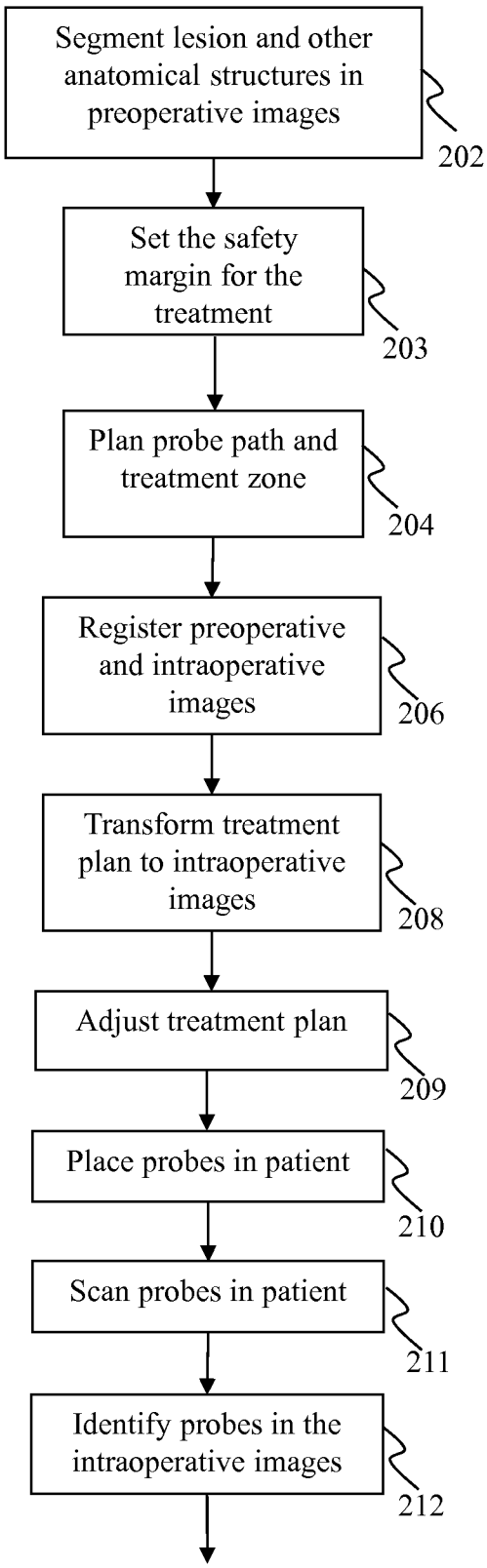

Segment lesion and other anatomical structures in preoperative images
202
Set the safety margin for the treatment
203
Plan probe path and treatment zone
204
Register preoperative and intraoperative images
206
Transform treatment plan to intraoperative images
208
Adjust treatment plan
209
Place probes in patient
210
Scan probes in patient
211
Identify probes in the intraoperative images
212

Fig. 2A

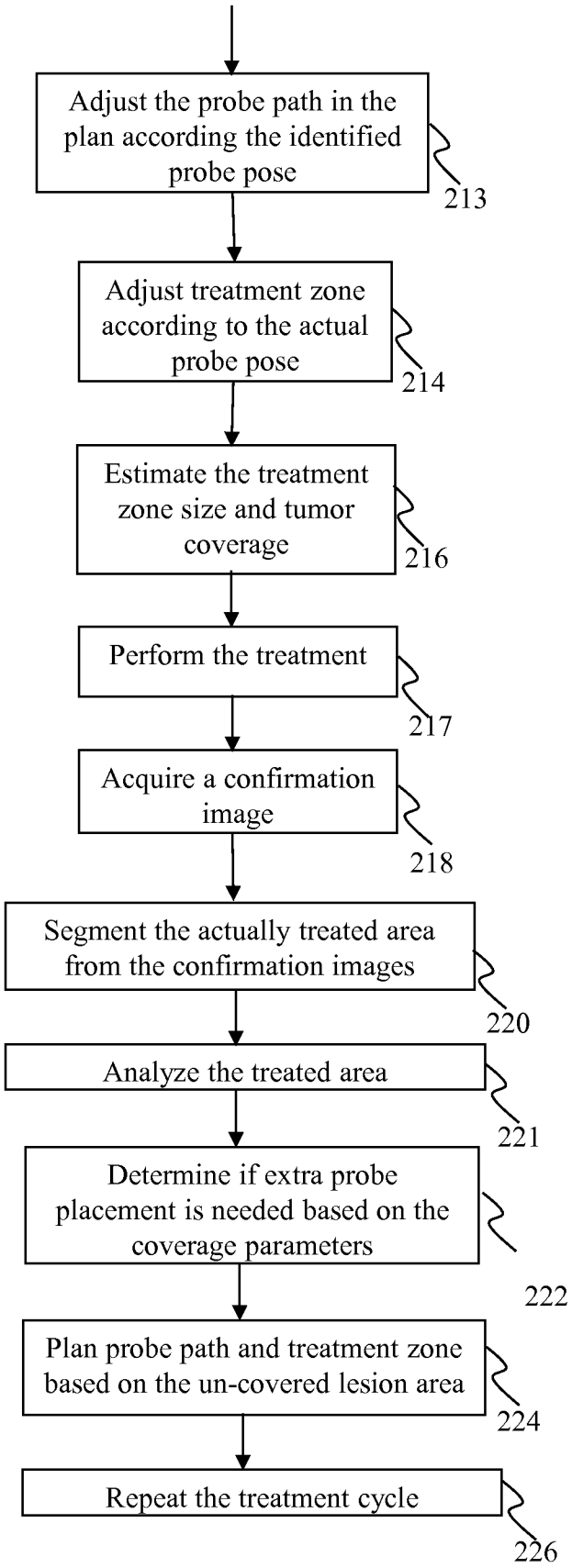

Adjust the probe path in the plan according the identified probe pose
213
Adjust treatment zone according to the actual probe pose
214
Estimate the treatment zone size and tumor coverage
216
Perform the treatment
217
Acquire a confirmation image
218
Segment the actually treated area from the confirmation images
220
Analyze the treated area
221
Determine if extra probe placement is needed based on the coverage parameters
222
Plan probe path and treatment zone based on the un-covered lesion area
224
Repeat the treatment cycle
226

Fig. 2B

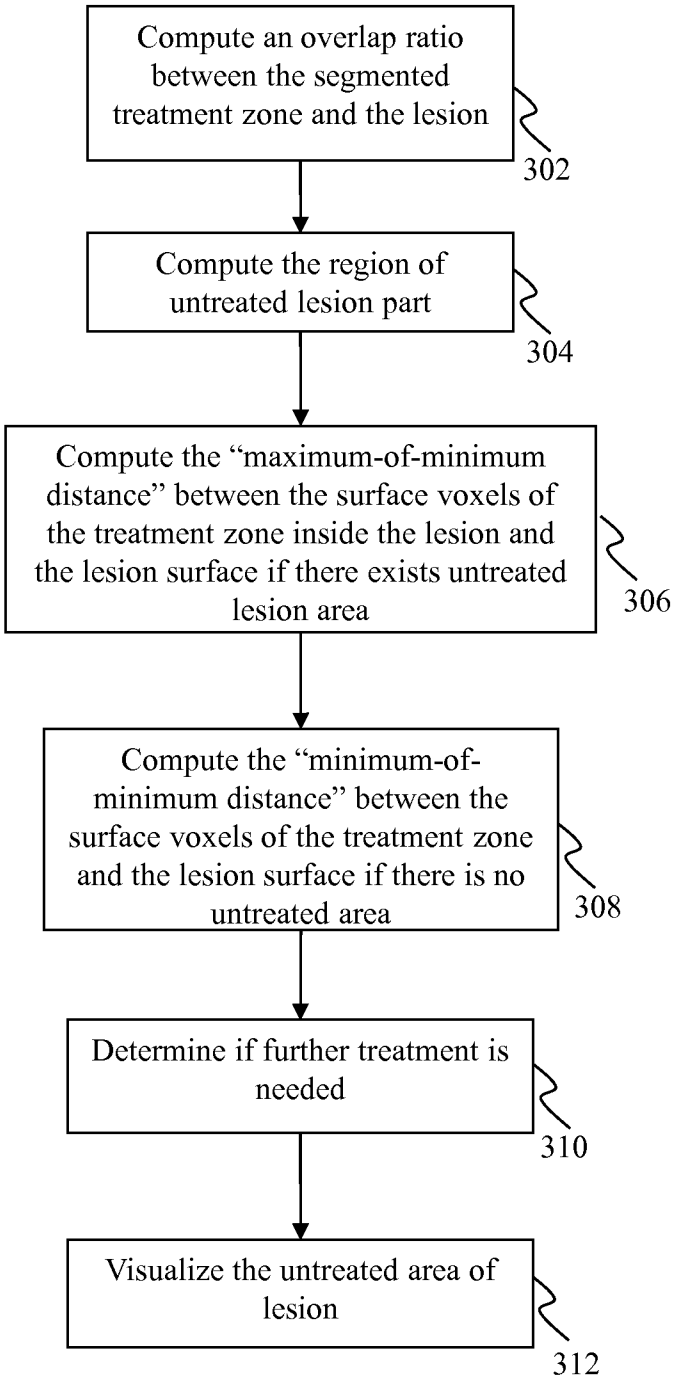

Compute an overlap ratio between the segmented treatment zone and the lesion
302
Compute the region of untreated lesion part
304
Compute the "maximum-of-minimum distance" between the surface voxels of the treatment zone inside the lesion and the lesion surface if there exists untreated lesion area
306
Compute the "minimum-of-minimum distance" between the surface voxels of the treatment zone and the lesion surface if there is no untreated area
308
Determine if further treatment is needed
310
Visualize the untreated area of lesion
312

Fig. 3

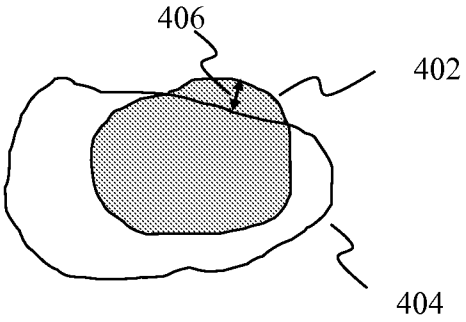


Fig. 4A

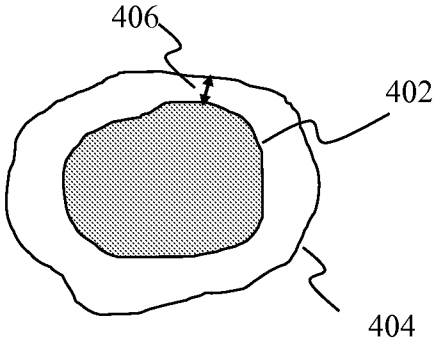


Fig. 4B

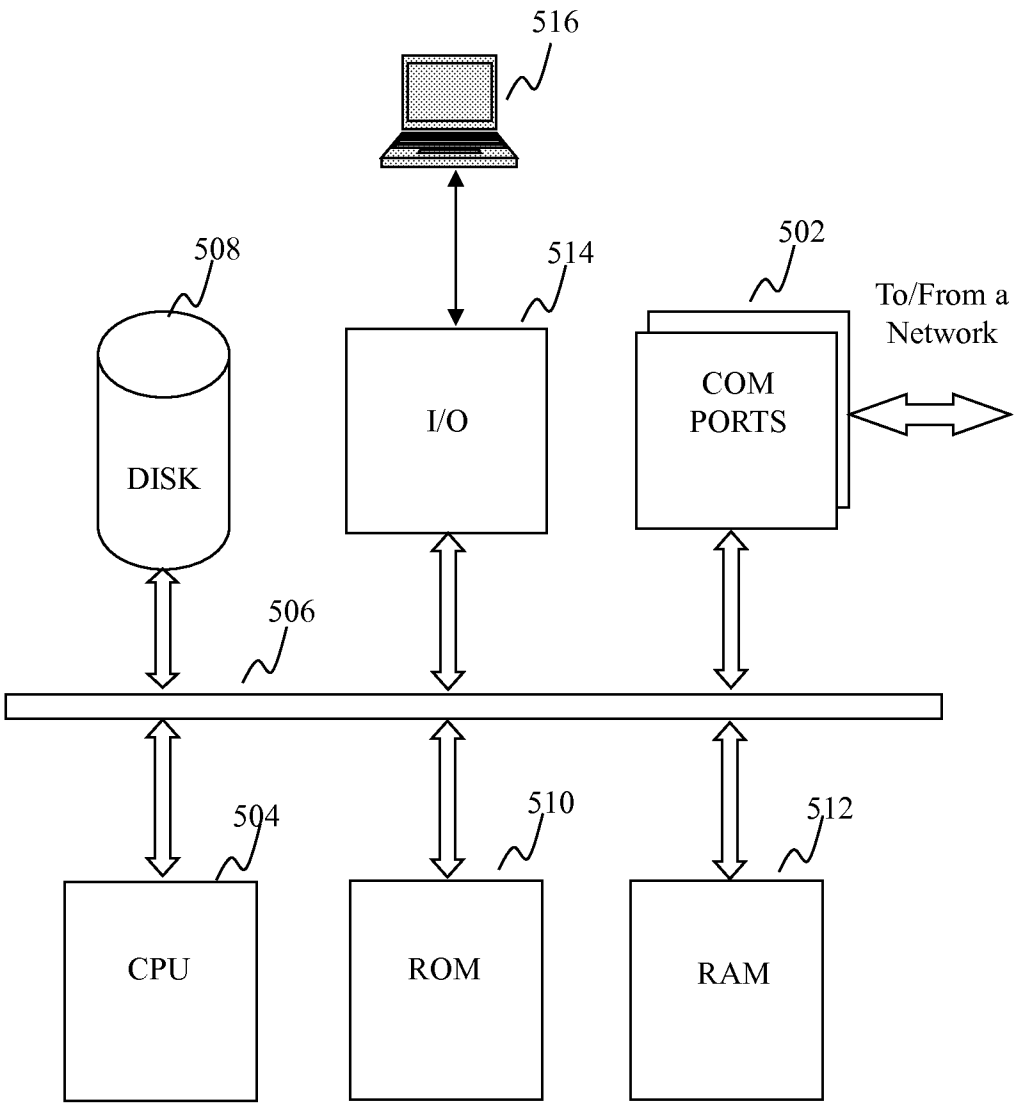

500
516
508
514
502
To/From a Network
DISK
I/O
COM PORTS
506
504
510
512
CPU
ROM
RAM

Fig. 5

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US 15/30092

A. CLASSIFICATION OF SUBJECT MATTER
IPC(8) - A61B 5/00 (2015.01)
CPC - A61B 5/0002
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)
IPC(8): A61B 5/00 (2015.01); CPC: A61B 5/0002

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
USPC: 600/300, 600/301
IPC(8): A61B 5/00 (2015.01); CPC: A61B5/0002, G06F19/3418, G06F19/322, G06F19/3406, G06Q50/22

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
PatBase, ProQuest Dialog, Google Web, Google Patents (Search terms: image, video, guide, surgical, catheter, stent, Seldinger, medical, angioplasty, instrument, lesion, dynamically adjust, segmentation, partition, treatment, region, area, zone, overlap, voxel, ratio, fraction, overlap, surface, border, boundary, distance, safety margin, etc.)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X — Y	US 8,706,186 B2 (Fichtinger et al.) 22 April 2014 (22.04.2014), col. 3, ln. 59, col. 5, ln. 22-23 and 43-44, col. 12, ln. 32-34, col. 15, ln. 54-60, col. 16, ln. 23-32, col. 21, ln. 7-8, 36-55, and 59-60, col. 22, ln. 36-39 and 46-47, col. 23, ln. 12 to col. 24, ln. 30, and col. 28, ln. 52-54, and Figs. 15-16, and claims 1, 12, 20, and 22.	1, 7-9, 11, 17-19 --- 2-6, 10, 12-16, 20-22
Y	US 6,138,045 A (Kupinski et al.) 24 October 2000 (24.10.2000), col. 5, ln. 1-8 and 11-26, col. 10, ln. 8-14 and 36-46, and col. 12, ln. 9-18 and 42-57.	2-5, 10, 12-15, 20-22
Y	US 7,672,705 B2 (Lachaine et al.) 02 March 2010 (02.03.2010), col. 3, ln. 46-49 and 54-57, and col. 4, ln. 6-10 and 59-62.	6, 16
Y	US 7,574,029 B2 (Peterson et al.) 11 August 2009 (11.08.2009), col. 3, ln. 36-40, col. 6, ln. 48-51 and 63-66, and col. 7, ln. 27-32.	4, 10, 14, 20
A	US 2010/0063496 A1 (Trovato et al.) 11 March 2010 (11.03.2010) (entire document).	1-22

☐ Further documents are listed in the continuation of Box C. ☐

* 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
18 July 2015 (18.07.2015)	12 AUG 2015
Name and mailing address of the ISA/US Mail Stop PCT, Attn: ISA/US, Commissioner for Patents P.O. Box 1450, Alexandria, Virginia 22313-1450 Facsimile No. 571-273-8300	Authorized officer: Lee W. Young PCT Helpdesk: 571-272-4300 PCT OSP: 571-272-7774

Form PCT/ISA/210 (second sheet) (January 2015)