

(19) World Intellectual Property Organization
International Bureau



(43) International Publication Date
17 March 2005 (17.03.2005)

PCT

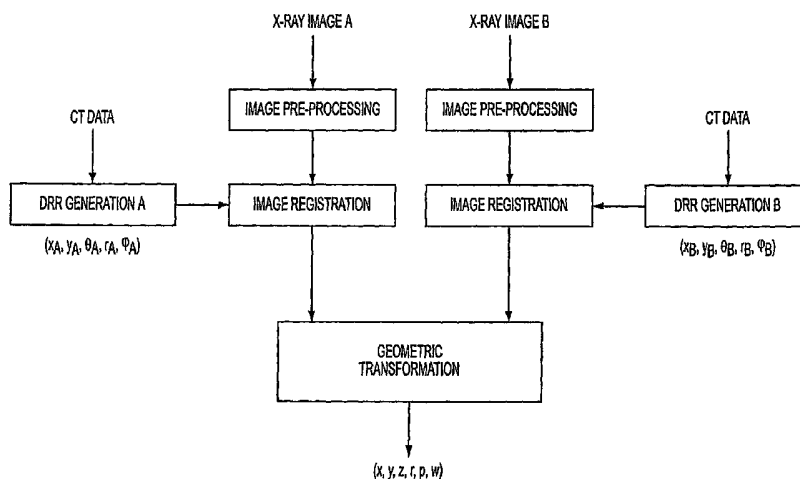
(10) International Publication Number
WO 2005/024721 A3

- (51) International Patent Classification⁷: **A61B 5/05**, 95117 (US). **FU, Dongshan** [CN/US]; 2180 Agnew Road, Santa Clara, CA 95054 (US). **QURESHI, Shehrzad** [—/US]; 425 Alma Street, #110, Palo Alto, CA 94301 (US).
A61N 5/10
- (21) International Application Number: PCT/US2004/027158
- (22) International Filing Date: 20 August 2004 (20.08.2004)
- (25) Filing Language: English
- (26) Publication Language: English
- (30) Priority Data:

| | | |
|------------|-----------------------------|----|
| 10/652,786 | 29 August 2003 (29.08.2003) | US |
| 10/652,717 | 29 August 2003 (29.08.2003) | US |
| 10/652,785 | 29 August 2003 (29.08.2003) | US |
- (71) Applicant: **ACCURAY, INC.** [US/US]; 1310 Chesapeake Terrace, Sunnyvale, CA 94089 (US).
- (72) Inventors; and
- (75) Inventors/Applicants (for US only): **KUDUVALLI, Gopinath** [CA/US]; 3988 Williams Road, San Jose, CA
- (74) Agent: **VINCENT, Lester, J.**; Blakely, Sokoloff, Taylor & Zafman, LLP, 12400 Wilshire Boulevard, 7th Floor, Los Angeles, CA 90025 (US).
- (81) Designated States (unless otherwise indicated, for every kind of national protection available): AE, AG, AL, AM, AT, AU, AZ, BA, BB, BG, BR, BW, BY, BZ, CA, CH, CN, CO, CR, CU, CZ, DE, DK, DM, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MA, MD, MG, MK, MN, MW, MX, MZ, NA, NI, NO, NZ, OM, PG, PH, PL, PT, RO, RU, SC, SD, SE, SG, SK, SL, SY, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, YU, ZA, ZM, ZW.
- (84) Designated States (unless otherwise indicated, for every kind of regional protection available): ARIPO (BW, GH, GM, KE, LS, MW, MZ, NA, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM),

[Continued on next page]

(54) Title: 2D/3D IMAGE REGISTRATION IN IMAGE-GUIDED RADIOSURGERY



(57) Abstract: An image-guided radiosurgery method and system are presented that use 2D/3D image registration to keep the radiosurgical beams properly focused onto a treatment target. A pre-treatment 3D scan of the target is generated at or near treatment planning time (CT DATA). A set of 2D DRRs are generated (DRR GENERATION A and DRR GENERATION B), based on the pretreatment 3D scan (CT DATA). At least one 2D x-ray image of the target is generated in near real time during treatment (X-RAY IMAGE A). The DRRs are registered with the x-ray images, by computing a set of 3D transformation parameters that represent the change in target position between the 3D scan and the x-ray images (IMAGE REGISTRATION). The relative position of the radiosurgical beams and the target is continuously adjusted in near real time in accordance with the 3D transformation parameters (GEOMETRIC TRANSFORMATION). A hierarchical and iterative 2D/3D registration algorithm is used, in which the transformation parameters that are in-plane with respect to the image plane of the x-ray images are computed separately from the out-of-plane transformation parameters.

WO 2005/024721 A3



European (AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HU, IE, IT, LU, MC, NL, PL, PT, RO, SE, SI, SK, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

(88) Date of publication of the international search report:
17 November 2005

Published:

- *with international search report*
- *before the expiration of the time limit for amending the claims and to be republished in the event of receipt of amendments*

For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.

INTERNATIONAL SEARCH REPORT

International application No.

PCT/US04/27158

| <p>A. CLASSIFICATION OF SUBJECT MATTER IPC(7) : A61B 5/05;A61N 5/10 US CL : 378,4,62,63,65,205;382/132;600/427,429 According to International Patent Classification (IPC) or to both national classification and IPC</p> | | | | | | | | | | | | | | | | | | | | | | |
|--|--|--|---|---|--|---|--|--|--|--|---|---|----|---|--|----------|---|--|---|---|---|------|
| <p>B. FIELDS SEARCHED Minimum documentation searched (classification system followed by classification symbols) U.S. : 378,4,62,63,65,205;382/132;600/427,429 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)</p> | | | | | | | | | | | | | | | | | | | | | | |
| <p>C. DOCUMENTS CONSIDERED TO BE RELEVANT</p> <table border="1"> <thead> <tr> <th>Category *</th> <th>Citation of document, with indication, where appropriate, of the relevant passages</th> <th>Relevant to claim No.</th> </tr> </thead> <tbody> <tr> <td>X --- Y</td> <td>US 5,901,199 A (MURPHY et al) 04 May 1999 (04.05.1999), column 4, line 20 -- column 6, line 14, column 9, lines 18-19, and figures 1 and 3.</td> <td>1-3, 9, 10, 22, 85, and 87-90 ----- 8</td> </tr> <tr> <td>Y --- P</td> <td>US 2004/0092815 A1 (SCHWEIKARD et al) 13 May 2004 (13.05.2004), abstract, paragraphs 24, 27, 36, 38, 39, 44, and 45, and figure 1.</td> <td>51, 53-55, and 64</td> </tr> <tr> <td>Y</td> <td>US 5,117,829 A (MILLER et al) 02 June 1992 (02.06.1992), column 3, lines 50-66.</td> <td>51</td> </tr> <tr> <td>Y</td> <td>PENNEY et al., "A Comparison of Similarity Measures for Use in 2-D--3-D Medical Image Registration", IEEE Transactions on Medical Imaging, August 1998, Vol 17. No. 4, pages 586-595, especially page 592.</td> <td>8 and 51</td> </tr> <tr> <td>A</td> <td>US 2004/0267113 A1 (THOMSON, EUAN) 30 December 2004 (30.12.2004), abstract and figure 1.</td> <td>3</td> </tr> <tr> <td>A</td> <td>US 6,470,207 B1 (SIMON et al) 22 October 2002 (22.10.2002), abstract, and column 4, lines 1-12.</td> <td>1-90</td> </tr> </tbody> </table> | | Category * | Citation of document, with indication, where appropriate, of the relevant passages | Relevant to claim No. | X --- Y | US 5,901,199 A (MURPHY et al) 04 May 1999 (04.05.1999), column 4, line 20 -- column 6, line 14, column 9, lines 18-19, and figures 1 and 3. | 1-3, 9, 10, 22, 85, and 87-90 ----- 8 | Y --- P | US 2004/0092815 A1 (SCHWEIKARD et al) 13 May 2004 (13.05.2004), abstract, paragraphs 24, 27, 36, 38, 39, 44, and 45, and figure 1. | 51, 53-55, and 64 | Y | US 5,117,829 A (MILLER et al) 02 June 1992 (02.06.1992), column 3, lines 50-66. | 51 | Y | PENNEY et al., "A Comparison of Similarity Measures for Use in 2-D--3-D Medical Image Registration", IEEE Transactions on Medical Imaging, August 1998, Vol 17. No. 4, pages 586-595, especially page 592. | 8 and 51 | A | US 2004/0267113 A1 (THOMSON, EUAN) 30 December 2004 (30.12.2004), abstract and figure 1. | 3 | A | US 6,470,207 B1 (SIMON et al) 22 October 2002 (22.10.2002), abstract, and column 4, lines 1-12. | 1-90 |
| Category * | Citation of document, with indication, where appropriate, of the relevant passages | Relevant to claim No. | | | | | | | | | | | | | | | | | | | | |
| X --- Y | US 5,901,199 A (MURPHY et al) 04 May 1999 (04.05.1999), column 4, line 20 -- column 6, line 14, column 9, lines 18-19, and figures 1 and 3. | 1-3, 9, 10, 22, 85, and 87-90 ----- 8 | | | | | | | | | | | | | | | | | | | | |
| Y --- P | US 2004/0092815 A1 (SCHWEIKARD et al) 13 May 2004 (13.05.2004), abstract, paragraphs 24, 27, 36, 38, 39, 44, and 45, and figure 1. | 51, 53-55, and 64 | | | | | | | | | | | | | | | | | | | | |
| Y | US 5,117,829 A (MILLER et al) 02 June 1992 (02.06.1992), column 3, lines 50-66. | 51 | | | | | | | | | | | | | | | | | | | | |
| Y | PENNEY et al., "A Comparison of Similarity Measures for Use in 2-D--3-D Medical Image Registration", IEEE Transactions on Medical Imaging, August 1998, Vol 17. No. 4, pages 586-595, especially page 592. | 8 and 51 | | | | | | | | | | | | | | | | | | | | |
| A | US 2004/0267113 A1 (THOMSON, EUAN) 30 December 2004 (30.12.2004), abstract and figure 1. | 3 | | | | | | | | | | | | | | | | | | | | |
| A | US 6,470,207 B1 (SIMON et al) 22 October 2002 (22.10.2002), abstract, and column 4, lines 1-12. | 1-90 | | | | | | | | | | | | | | | | | | | | |
| <p><input type="checkbox"/> Further documents are listed in the continuation of Box C. <input type="checkbox"/> See patent family annex.</p> | | | | | | | | | | | | | | | | | | | | | | |
| <p>* Special categories of cited documents:</p> <table border="0"> <tr> <td>"A" document defining the general state of the art which is not considered to be of particular relevance</td> <td>"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</td> </tr> <tr> <td>"E" earlier application or patent published on or after the international filing date</td> <td>"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</td> </tr> <tr> <td>"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)</td> <td>"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</td> </tr> <tr> <td>"O" document referring to an oral disclosure, use, exhibition or other means</td> <td>"&" document member of the same patent family</td> </tr> <tr> <td>"P" document published prior to the international filing date but later than the priority date claimed</td> <td></td> </tr> </table> | | "A" document defining the general state of the art which is not considered to be of particular relevance | "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 | "E" earlier application or patent published on or after the international filing date | "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 | "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) | "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 | "O" document referring to an oral disclosure, use, exhibition or other means | "&" document member of the same patent family | "P" document published prior to the international filing date but later than the priority date claimed | | | | | | | | | | | | |
| "A" document defining the general state of the art which is not considered to be of particular relevance | "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 | | | | | | | | | | | | | | | | | | | | | |
| "E" earlier application or patent published on or after the international filing date | "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 | | | | | | | | | | | | | | | | | | | | | |
| "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) | "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 | | | | | | | | | | | | | | | | | | | | | |
| "O" document referring to an oral disclosure, use, exhibition or other means | "&" document member of the same patent family | | | | | | | | | | | | | | | | | | | | | |
| "P" document published prior to the international filing date but later than the priority date claimed | | | | | | | | | | | | | | | | | | | | | | |
| <p>Date of the actual completion of the international search 29 April 2005 (29.04.2005)</p> | <p>Date of mailing of the international search report 06 SEP 2005</p> | | | | | | | | | | | | | | | | | | | | | |
| <p>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. (703) 305-3230</p> | <p>Authorized officer <i>for Michelle R. Kao</i> Chih-Cheng Glen Kao Telephone No. (571) 272-2800</p> | | | | | | | | | | | | | | | | | | | | | |

INTERNATIONAL SEARCH REPORT

International application No.

PCT/US04/27158

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. Claims Nos.:
because they relate to subject matter not required to be searched by this Authority, namely:

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:
Please See Continuation Sheet

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 fee, this Authority did not invite payment of any additional fee.
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.
 No protest accompanied the payment of additional search fees.

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US04/27158

BOX III. OBSERVATIONS WHERE UNITY OF INVENTION IS LACKING

This application contains the following inventions or groups of inventions which are not so linked as to form a single general inventive concept under PCT Rule 13.1. In order for all inventions to be examined, the appropriate additional examination fees must be paid.

Group I, claim(s) 1-30 and 85-90, drawn to a method, system, and apparatus including adjusting the relative position of a radiation beam generator and a target by an amount prescribed by 3D transformation parameters.

Group II, claim(s) 31-67, drawn to a method and system including determining a set-of in-plane transformation parameters (x , y , θ) and out-of-plane rotational parameters (r , ϕ), said parameters representing the difference in position of a target as shown in an x-ray image as compared to the position of the target as shown by a reconstructed image, wherein r and ϕ represent the rotations of said target about first and second mutually orthogonal axes, said rotations being out-of-plane with respect to an image plane, said out-of-plane rotations representing the projection of said target onto said image plane; and wherein x and y represent the amount of translation of said target within said image plane in the directions of said x - and y - axes, respectively, and θ represents the amount of rotation of said target within said image plane about an axis perpendicular to both said x - and said y - axes.

Group III, claim(s) 68-84, drawn to a method and system including forming a difference image by subtracting pixel values of a second image from pixel values of a first image, and summing asymptotic functions of gradients of said difference image over all the pixels within a neighborhood R , wherein said neighborhood R is defined so that said gradients of said different image can be considered in at least four directions.

The inventions listed as Groups I, II, and III do not relate to a single general inventive concept under PCT Rule 13.1 because, under PCT Rule 13.2, they lack the same or corresponding special technical features for the following reasons:

Regarding Group I, the rest of the Groups lack the same or corresponding adjusting of a relative position of a radiation beam generator and a target by an amount prescribed by 3D transformation parameters.

Regarding Group II, the rest of the Groups lack the same or corresponding determining of a set-of in-plane transformation parameters (x , y , θ) and out-of-plane rotational parameters (r , ϕ), said parameters representing the difference in position of a target as shown in an x-ray image as compared to the position of the target as shown by a reconstructed image, wherein r and ϕ represent the rotations of said target about first and second mutually orthogonal axes, said rotations being out-of-plane with respect to an image plane, said out-of-plane rotations representing the projection of said target onto said image plane; and wherein x and y represent the amount of translation of said target within said image plane in the directions of said x - and y - axes, respectively, and θ represents the amount of rotation of said target within said image plane about an axis perpendicular to both said x - and said y - axes.

Regarding Group III, the rest of the Groups lack the same or corresponding forming of a difference image by subtracting pixel values of a second image from pixel values of a first image, and summing of asymptotic functions of gradients of said difference image over all the pixels within a neighborhood R , wherein said neighborhood R is defined so that said gradients of said different image can be considered in at least four directions.