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(81) **Designated States** (*unless otherwise indicated, for every kind of national protection available*): AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, 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.

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[Continued on next page]

(54) **Title:** SYSTEM AND METHOD FOR MAGNETIC RESONANCE IMAGING USING HIGHLY ACCELERATED PROJECTION IMAGING

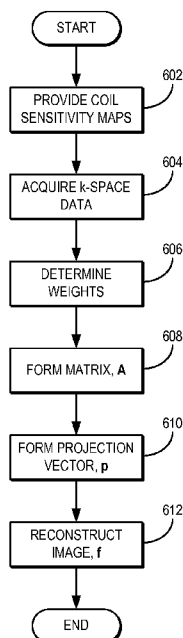


FIG. 6

(57) **Abstract:** A method for highly accelerated projection imaging ("HAPI") is provided. In this method, conventional linear gradients are used to obtain coil sensitivity-weighted projections of the object being imaged. Only a relatively small number of projections, such as sixteen or less, of the object are required to reconstruct a two-dimensional image of the object, unlike conventional projection imaging techniques. The relationship between the voxel values of the imaged object and the coil sensitivity-weighted projections is formulated as a linear system of equations and the reconstructed images are obtained by solving this matrix equation. This method advantageously allows higher acceleration rates compared to echo planar imaging ("EPI") with SENSE or GRAPPA acceleration. Moreover, the method does not require any additional or specialized hardware because hardware in conventional MRI scanners is adequate to implement the method.



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LV, MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK,
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B. FIELDS SEARCHED

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G01R

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

EP0-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 2009/238430 A1 (HAIDER CLIFTON R [US] ET AL) 24 September 2009 (2009-09-24) paragraphs [0008], [0020] - [0022] paragraph [0056] - paragraph [0073]; figures 5-7	1-17
T	----- ERSOZ ALI ET AL: "Highly accelerated projection imaging with coil sensitivity encoding for rapid MRI", MEDICAL PHYSICS, AIP, MELVILLE, NY, US, vol. 40, no. 2, 1 February 2013 (2013-02-01), pages 22305-22305, XP012170986, ISSN: 0094-2405, DOI: 10.1118/1.4789488 ISBN: 978-1-930524-56-9 [retrieved on 2013-02-01] the whole document ----- -/--	1-17

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

☒ See patent family annex.

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

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International application No
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C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
T	ALI ERSOZ ET AL: "Highly Accelerated Projection Imaging (HAPI) with coil sensitivity encoding", PROCEEDINGS OF THE INTERNATIONAL SOCIETY FOR MAGNETIC RESONANCE IN MEDICINE, 21ST ANNUAL MEETING AND EXHIBITION, SALT LAKE CITY, UTAH, USA, 20-26 APRIL 2013, vol. 21, 6 April 2013 (2013-04-06), page 3831, XP055086538, the whole document	1-17
A	----- US 2011/241678 A1 (WEBER HANS [DE] ET AL) 6 October 2011 (2011-10-06) the whole document	1-17
A	----- GERRIT SCHULTZ ET AL: "Radial Imaging With Multipolar Magnetic Encoding Fields", IEEE TRANSACTIONS ON MEDICAL IMAGING, IEEE SERVICE CENTER, PISCATAWAY, NJ, US, vol. 30, no. 12, 1 December 2011 (2011-12-01), pages 2134-2145, XP011380089, ISSN: 0278-0062, DOI: 10.1109/TMI.2011.2164262 the whole document	1-17
A	----- CIRIS P A ET AL: "O-space Imaging: Tailoring Encoding Gradients to Coil Profiles for Highly Accelerated Imaging", PROCEEDINGS OF THE INTERNATIONAL SOCIETY FOR MAGNETIC RESONANCE IN MEDICINE, 17TH SCIENTIFIC MEETING AND EXHIBITION, HONOLULU, HAWAII, USA, 1 January 2009 (2009-01-01), page 4556, XP007911831, the whole document	1-17
A	----- DANIEL GALLICHAN ET AL: "Practical considerations for in vivo MRI with higher dimensional spatial encoding", MAGNETIC RESONANCE MATERIALS IN PHYSICS, BIOLOGY AND MEDICINE, CHAPMAN AND HALL, LONDON, GB, vol. 25, no. 6, 7 April 2012 (2012-04-07), pages 419-431, XP035144972, ISSN: 1352-8661, DOI: 10.1007/S10334-012-0314-Y the whole document ----- -/--	1-17

INTERNATIONAL SEARCH REPORT

International application No
PCT/US2013/043582

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	JUERGEN HENNIG ET AL: "Parallel imaging in non-bijective, curvilinear magnetic field gradients: a concept study", MAGNETIC RESONANCE MATERIALS IN PHYSICS, BIOLOGY AND MEDICINE, CHAPMAN AND HALL, LONDON, GB, vol. 21, no. 1-2, 26 February 2008 (2008-02-26), pages 5-14, XP019596833, ISSN: 1352-8661 the whole document	1-17
A	----- US 2011/098552 A1 (TAKAI HIROSHI [JP]) 28 April 2011 (2011-04-28) the whole document	1-17
A	----- KAI TOBIAS BLOCK ET AL: "Undersampled radial MRI with multiple coils. Iterative image reconstruction using a total variation constraint", MAGNETIC RESONANCE IN MEDICINE, vol. 57, no. 6, 29 May 2007 (2007-05-29), pages 1086-1098, XP055007221, ISSN: 0740-3194, DOI: 10.1002/mrm.21236 the whole document	1-17
A	----- PRUESSMANN K P ET AL: "Advances in sensitivity encoding with arbitrary k-space trajectories", MAGNETIC RESONANCE IN MEDICINE, ACADEMIC PRESS, DULUTH, MN, US, vol. 46, no. 4, 1 January 2001 (2001-01-01), pages 638-651, XP002288249, ISSN: 0740-3194, DOI: 10.1002/MRM.1241 the whole document	1-17
A	----- PRUESSMANN K P ET AL: "SENSE: SENSITIVITY ENCODING FOR FAST MRI", MAGNETIC RESONANCE IN MEDICINE, ACADEMIC PRESS, DULUTH, MN, US, vol. 42, no. 5, 1 November 1999 (1999-11-01), pages 952-962, XP000866655, ISSN: 0740-3194, DOI: 10.1002/(SICI)1522-2594(199911)42:5<952::AID-MRM16>3.0.CO;2-S the whole document	1-17
A	----- US 2008/068016 A1 (GADDIPATI AJEETKUMAR [US] ET AL) 20 March 2008 (2008-03-20) the whole document	1-17
	----- -/--	

INTERNATIONAL SEARCH REPORT

International application No
PCT/US2013/043582

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	TUGAN MUFTULER L ET AL: "An inverse method to design RF coil arrays optimized for SENSE imaging; SENSE optimized MRI RF coil", PHYSICS IN MEDICINE AND BIOLOGY, INSTITUTE OF PHYSICS PUBLISHING, BRISTOL GB, vol. 51, no. 24, 21 December 2006 (2006-12-21), pages 6457-6469, XP020096086, ISSN: 0031-9155, DOI: 10.1088/0031-9155/51/24/012 cited in the application the whole document -----	1-17
A	CHEN ET AL: "An optimization method for designing SENSE imaging RF coil arrays", JOURNAL OF MAGNETIC RESONANCE, ACADEMIC PRESS, ORLANDO, FL, US, vol. 186, no. 2, 8 June 2007 (2007-06-08), pages 273-281, XP022107115, ISSN: 1090-7807, DOI: 10.1016/J.JMR.2007.03.014 cited in the application the whole document -----	1-17
A	US 7 519 412 B2 (MISTRETTA CHARLES A [US]) 14 April 2009 (2009-04-14) cited in the application the whole document -----	1-17

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/US2013/043582

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 2009238430 A1	24-09-2009	NONE	

US 2011241678 A1	06-10-2011	DE 102010003552 A1	06-10-2011
		EP 2378308 A1	19-10-2011
		US 2011241678 A1	06-10-2011

US 2011098552 A1	28-04-2011	JP 2011087783 A	06-05-2011
		US 2011098552 A1	28-04-2011

US 2008068016 A1	20-03-2008	DE 102007045054 A1	27-03-2008
		JP 2008068085 A	27-03-2008
		US 2008068016 A1	20-03-2008

US 7519412 B2	14-04-2009	AT 448531 T	15-11-2009
		EP 1902328 A1	26-03-2008
		EP 1902424 A2	26-03-2008
		HK 1124666 A1	26-04-2013
		JP 5047960 B2	10-10-2012
		JP 5167125 B2	21-03-2013
		JP 2009500114 A	08-01-2009
		JP 2009500116 A	08-01-2009
		US 2007010731 A1	11-01-2007
		US 2007038073 A1	15-02-2007
		WO 2007008528 A2	18-01-2007
		WO 2007008532 A1	18-01-2007
