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(54) Title: DEEP LEARNING TECHNIQUES FOR GENERATING MAGNETIC RESONANCE IMAGES FROM SPATIAL FREQUENCY DATA

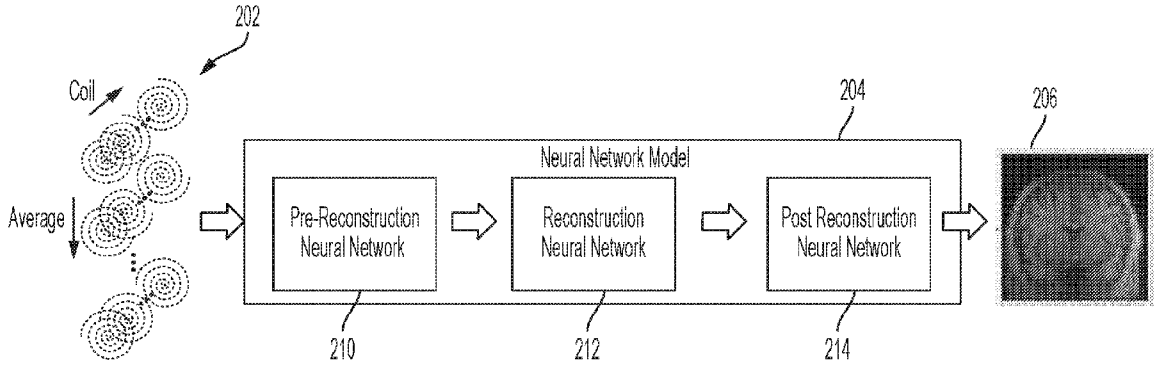

FIG. 2A

(57) Abstract: Techniques for generating magnetic resonance (MR) images of a subject from MR data obtained by a magnetic resonance imaging (MRI) system, the techniques comprising: obtaining input MR spatial frequency data obtained by imaging the subject using the MRI system; generating an MR image of the subject from the input MR spatial frequency data using a neural network model comprising: a pre-reconstruction neural network configured to process the input MR spatial frequency data; a reconstruction neural network configured to generate at least one initial image of the subject from output of the pre-reconstruction neural network; and a post-reconstruction neural network configured to generate the MR image of the subject from the at least one initial image of the subject.

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[Continued on next page]

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— *before the expiration of the time limit for amending the claims and to be republished in the event of receipt of amendments (Rule 48.2(h))*

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INTERNATIONAL SEARCH REPORT

International application No
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A. CLASSIFICATION OF SUBJECT MATTER
INV. G01R33/56 G06K9/40 G06K9/46 G06N3/04 G06T5/00
G01R33/483 G01R33/561 G01R33/565 A61B5/055 G06K9/36
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B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
G06K G06N G01R G06T 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	TAEJOON EO ET AL: "KIKI-net: cross-domain convolutional neural networks for reconstructing undersampled magnetic resonance images", MAGNETIC RESONANCE IN MEDICINE., vol. 80, no. 5, 6 April 2018 (2018-04-06), pages 2188-2201, XP055637216, US ISSN: 0740-3194, DOI: 10.1002/mrm.27201	1-3,5,7, 10,12-18
Y	abstract, sections 1,2,3.1, 3.2, last	8,9,11
A	paragraph of section 4; figures 1,2	4,6

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[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

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"P" document published prior to the international filing date but later than the priority date claimed

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"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

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"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
22 June 2020	02/10/2020

Name and mailing address of the ISA/	Authorized officer
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Form PCT/ISA/210 (second sheet) (April 2005)

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
	-& TAEJOON EO ET AL: "Supporting Information - KIKI-net: cross-domain convolutional neural networks for reconstructing undersampled magnetic resonance images", MAGNETIC RESONANCE IN MEDICINE., vol. 80, no. 5, 6 April 2018 (2018-04-06), pages 2188-2201, XP055640676, US ISSN: 0740-3194, DOI: 10.1002/mrm.27201 section "Supporting information: 1. Network training"	

X	WO 2018/187005 A1 (UNIV MINNESOTA [US])	1-3,5,7,
	11 October 2018 (2018-10-11)	10,12-18
Y	whole document, in particular paragraphs	8,9,11
A	[0019] and [0056]	4,6

Y	ALEXANDER SELVIKV{\AA}G LUNDERVOLD ET AL: "An overview of deep learning in medical imaging focusing on MRI", ARXIV.ORG, CORNELL UNIVERSITY LIBRARY, 201 OLIN LIBRARY CORNELL UNIVERSITY ITHACA, NY 14853, 25 November 2018 (2018-11-25), XP081000303, DOI: 10.1016/J.ZEMEDI.2018.11.002 section "Image Domain Reconstruction"; figure 3	8,9

Y	MICHAEL LUSTIG ET AL: "SPIRiT: Iterative self-consistent parallel imaging reconstruction from arbitrary k-space", MAGNETIC RESONANCE IN MEDICINE, 1 June 2010 (2010-06-01), pages n/a-n/a, XP055007508, ISSN: 0740-3194, DOI: 10.1002/mrm.22428 section 3.1.6; figure 3	11

A	ADRIENNE E. CAMPBELL-WASHBURN ET AL: "Using the robust principal component analysis algorithm to remove RF spike artifacts from MR images : Removal of k-Space Spikes Using RPCA", MAGNETIC RESONANCE IN MEDICINE., vol. 75, no. 6, 20 July 2015 (2015-07-20), pages 2517-2525, XP055707123, US ISSN: 0740-3194, DOI: 10.1002/mrm.25851 the whole document	4

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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.
A	GRAHAM MARK S ET AL: "A supervised learning approach for diffusion MRI quality control with minimal training data", NEUROIMAGE, ELSEVIER, AMSTERDAM, NL, vol. 178, 5 June 2018 (2018-06-05), pages 668-676, XP085428351, ISSN: 1053-8119, DOI: 10.1016/J.NEUROIMAGE.2018.05.077 first paragraph of sub-section "Classifier" on p. 671 first three paragraphs of "Discussion" on pages 672 and 674	4
A	MEHMET AK?AKAYA ET AL: "Utility of respiratory-navigator-rejected k-space lines for improved signal-to-noise ratio in three-dimensional cardiac MR", MAGNETIC RESONANCE IN MEDICINE, vol. 70, no. 5, 11 December 2012 (2012-12-11), pages 1332-1339, XP055088354, ISSN: 0740-3194, DOI: 10.1002/mrm.24566 the whole document	6
X,P	ILKAY OKSUZ ET AL: "Detection and Correction of Cardiac MR Motion Artefacts during Reconstruction from K-space", ARXIV.ORG, CORNELL UNIVERSITY LIBRARY, 201 OLIN LIBRARY CORNELL UNIVERSITY ITHACA, NY 14853, 12 June 2019 (2019-06-12), XP081381200, sections 1, 2 and 3; figure 1	1,6

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INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2020/022306

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:

see additional 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 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.:

1-18

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.

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/US2020/022306

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
WO 2018187005 A1	11-10-2018	NONE	

FURTHER INFORMATION CONTINUED FROM PCT/ISA/ 210

This International Searching Authority found multiple (groups of) inventions in this international application, as follows:

1. claims: 1-18

   A method of image MR image reconstruction with a sequence of three neural networks.

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2. claims: 19-37

   A method of MR image reconstruction , wherein blurring induced by motion during acquisition of MR data is reduced.

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3. claims: 38-49

   A method of MR image reconstruction, wherein errors introduced by the reconstruction model are removed.

   ---

4. claims: 50-61

   A method of reconstruction of multi-coil parallel imaging MR data without the need to determine coil sensitivity profiles.

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5. claims: 62, 63

   A method of reconstruction of multi-coil parallel imaging MR data deployable in systems with different numbers of physical RF coils.
