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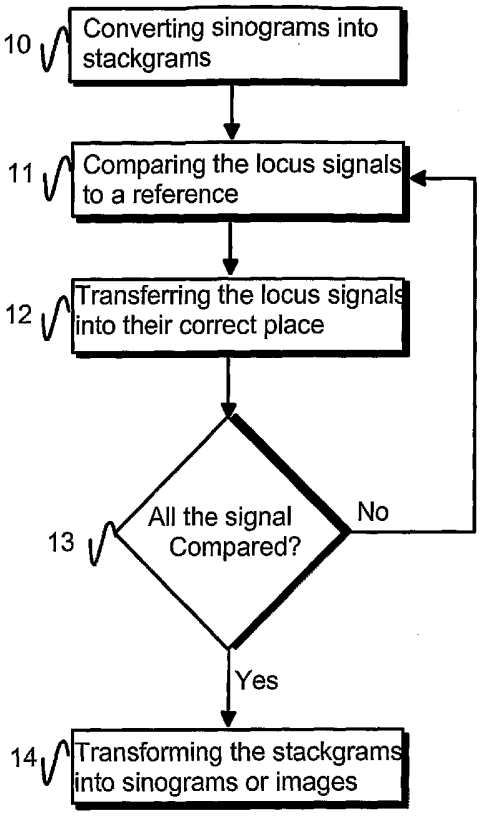
(54) Title: METHOD, SYSTEM AND SOFTWARE PRODUCT FOR MOTION CORRECTION OF TOMOGRAPHIC IMAGES



(57) Abstract: The present invention relates to motion correction of tomographic images so that in filtering the measurement information, information is lost as little as possible. In the method of the invention, the measurement information, sinograms, are transformed to stackgrams (10). The motion correction is made by comparing the locus signals being generated from the sine waves of the stackgram to a reference signal (11). The signal best corresponding to the reference is transferred into its correct place (12). When the comparison has been performed for all the signals (13), the stackgrams are transformed back to sinograms, or are constructed directly to images (14).

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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.

METHOD, SYSTEM AND SOFTWARE PRODUCT FOR MOTION CORRECTION OF TOMOGRAPHIC IMAGES

The invention relates to the motion correction of tomographic images.

BACKGROUND OF THE INVENTION

Tomography is a method which enables one to get information about the inner structure of an article without damaging the article itself. The most common application area of tomography is medicine, in which a patient is scanned e.g. when conducting pharmacological researches. Since the scanning takes a long time, the motion of the patient causes inaccuracy of imaging. In addition, the measurement data, which is called sinograms, typically contains a lot of noise, making it difficult to generate the final image.

A sinogram is not a complete image of an object to be scanned or measured, but its projections at regular intervals, ranging between 0°-180°. Mathematically, a tomography is usually modelled using a radon transformation. A sinogram is reconstructed to form an image using some approximation of a reverse Radon transformation. One such generally known reconstruction method is FBP (filtered backprojection), in which singorams are filtered in the frequency plane e.g. with a ramp filter prior to the backprojection. A Radon transformation and an FBP reconstruction are known per se e.g. from the book "A. Jain, Fundamentals of Digital Image Processing, Englewood Cliffs, NJ, Prentice Hall International, 1989", on pages 434-448.

In tomographic imaging, the determination of the motion of a patient is usually made based on reconstructed images, and the motion correction is directed to a two- or three dimensional series of im-

ages. The reconstruction of images is not a reverse operation in the same manner as a stackgram transformation, instead when reconstructing a sinogram to form an image and projecting the image back into a sinogram, the final result does not completely correspond to the original sinogram. Motion correction cannot be made directly by means of sinograms either, because the geometry of sinograms is based on the measurement data of the cross-sectional plane. One common reconstruction method is filtered back-projection, which is known per se e.g. from the above-mentioned book of A. Jain.

One solution for eliminating the noise caused by the sinogram information is to filter out the noise from the sinogram. This is, however, not simple because direct filtering of a sinogram can distort the sinusoids of the sinogram, and efficient filtering can cause a considerable inaccuracy in the image. The most common method at present is radial filtering which is performed in parallel to the lines of the sinogram. The method is known e.g. from the reference publication "P.J. La Riviere, X. Pan, Nonparametric regression Sinogram Smoothing Using a Roughness-Penalized Poisson Likelihood Objective Function, IEEE Transactions on Medical Imaging, 19(8), 2000, pages 773-786.". It is possible to filter a sinogram also cornerwise perpendicularly to the lines of the sinogram. It is, however, not a commonly used method due to the inaccuracy caused. Further, the filtering methods of sinograms usually are dependant on the target of application.

As the motion of a research object in tomographic imaging is a common problem, several alternative solutions have been developed to address the problem. Patent publication US 6535570 relates to a method for eliminating the motion in traditional tomographic imaging. In the method, the motion is cor-

rected by means of a separate correlation coefficient. Also patent publication US 2002/0163994 discloses a method which uses a separate correction coefficient. Patent publication US 6026142 discloses a method in which the edges of images blurred by noise are retrieved from sinograms. The method in accordance with the invention enables one to search for the edges also from the final constructed tomographic image. Patent publication US 2002/0172321 calculates specific deviation signals for each projection angle.

The problem with the prior-art solutions is the difficulty of filtering as well as losing information in reconstructions. Due to this there is an obvious need for an efficient filtering method.

OBJECTIVE OF THE INVENTION

The objective of the invention is to disclose a new type of method for eliminating the interference caused by motion in tomographic imaging. One specific objective of the invention is to disclose a method in which when filtering, information is lost as little as possible.

SUMMARY OF THE INVENTION

In the method and system in accordance with the invention, a patient or research subject is scanned using tomographic equipment to generate sinograms. The invention is characterised by the fact that the sinograms are transformed to stackgrams when eliminating the inaccuracies caused by the motion of the research subject. The locus signals generated from the sine waves of the stackgrams are compared to a reference signal. The locus signal best corresponding to the reference is transferred into place. Once the comparison has been performed for all the signals, the

stackgrams are transformed back to sinograms for the construction of the final image, or are summed directly to form an image.

The advantage of the method and system of the invention compared to conventional methods and systems is the improvement of the quality of images, which, in turn, enables use of bigger resolutions and obtaining more accurate research results. According to the invention, in filtering images, information is lost considerably less than by conventional methods. Further, the images need not be reconstructed for the motion correction, so necessary information is not lost in unnecessary reconstructions.

LIST OF FIGURES

Fig. 1 represents one functional block diagram of an embodiment in accordance with the invention, and

Fig. 2 represents one system in accordance with the invention.

DETAILED DESCRIPTION OF THE INVENTION

A sinogram is an image matrix whose lines contain projections about the measurement object. The idea of a stackgram is based on the fact that by means of a stackgram it is possible to find out in the sinogram all the sine waves constituting a sinogram, i.e. locus signals. This is achieved by transforming the sinogram to a three-dimensional stackgram consisting of a stack of overlapping back projected projections. The sine waves of a sinogram are in the stackgram parallel to the vertical axis of the stackgram. The stackgram is transformed back to the sinogram by applying a Radon transformation to every layer of the stackgram. In practice, the implementation of stack-

gram transformations means rotating back projected images, i.e. it is a question about an interpolation problem.

A transformation from a sinogram to a stackgram is a completely reverse transformation, so the outcome is congruent with the original one within the limits of the numerical accuracy of a computer. This is possible by means of discrete sinc interpolation.

A stackgram can be applied to motion correction, which enables one to obtain a motion corrected sinogram or an FBP image by multiplying the planes of the stackgram by a 2D Ramp filter and by summing the stackgrams thus obtained to form an image. The motion correction is made prior to the reconstruction of the image. The transformation of a sinogram to a stackgram gives a possibility to perceive and correct the motion of a patient or testee when scanning and to return the motion correction to the sinograms without losing information in the process other than within the limits of the numerical accuracy of a computer. As it is possible in the stackgrams to locate a locus signal or a group of locus signals representing one point or a sharp edge, it is possible to find out character positions by the motion of which the motion of a patient or an object during the research is judged. The extent of motion is not very large in the situations in question because e.g. in brain examinations the patient's head is propped using a head support.

The transformation from a sinogram to a stackgram (Sg, Stackgram) is performed by formula 1, wherein

$$h(x,y,\phi) = Sg = g(x*\cos\phi + y*\sin\phi, \phi) \quad (1)$$

The difference of the transformation compared to the back projection is the absence of an integral operator as the sum of the elements has been substi-

tuted with a third dimension. Correspondingly, the transformation of the stackgrams back to sinograms succeeds by formula 2.

$$g(l,\phi) = S^{-1}h = R_{\phi}h(x,y,\phi) \qquad (2)$$

The aim for a very big image resolution in new emission tomographic devices requires the correction of even the smallest motions. It would be advantageous to make the corrections as near the measurement situation as possible, in other words on the sinogram level. This means that the research is collected e.g. as periods of one second, which are, after the motion correction, summed to form the desired time series sinograms, and are reconstructed to form the images.

Fig. 1 represents the utilisation of tomographic images in motion correction. Fig. 1 represents the inventive part of the method because the scanning of an object and the generation of a sinogram are known per se and generally used. In motion correction, a sinogram, in a three-dimensional measurement, sinograms, are transformed to stackgrams, step 10. After this, the locus signals of stackgrams are compared to the selected locus signal that serves as a reference, step 11. The comparison is performed e.g. inside a 15*15*15 window. The locus signal best corresponding to the reference is transferred into its correct place in the stackgrams, step 12. Once all the locus signals have been compared, the stackgrams are transformed back to sinograms. The final images can be constructed from the motion-corrected sinograms.

The idea is in principle of the same kind as in a three-dimensional case comparing a pack of images pixel by pixel, and making motion correction based on it. If locus signals of stackgrams are used for the comparison, then instead of information of one pixel,

information is obtained more to the tune of projection angles. In addition to this, each locus signal is slightly different, so the comparison of signals is successful, although there would be a lot of noise. At its simplest, the comparison can be performed based on a mean absolute error (MAE number, Mean Absolute Error).

Fig. 2 represents a system as shown in Fig. 2 comprising measurement equipment 20 and a processing system 22, which have been connected to one another via a telecommunication connection 21. The measurement equipment is preferably measurement equipment which is suitable for tomographic imaging and which is used to scan a patient or research subject. The processing system 22 is used to eliminate the measurement accuracy that is caused by the motion of the measurement object. The processing system further comprises means 23 for generating stackgrams based on the sinograms, means 24 for comparing the locus signals of the stackgrams to a reference, means 25 for transferring in place the locus signals best corresponding to the reference, as well as means 26 for transforming the stackgram back to a sinogram. The processing system 22 can be connected to other systems, which are not an object of this invention, such as e.g. to a medical system, for analysing a tomographic image. It must be noted that means 23-26 can also be implemented as software instead of hardware.

The invention is not limited solely to the embodiment examples referred to above, instead many variations are possible within the scope of the inventive idea defined by the claims.

CLAIMS

1. A method for correcting the errors caused by the motion of a tomographic image, the method comprising the following steps:

scanning an object to generate sinograms;

correcting the errors caused by the errors in the measurements;

constructing a tomographic image;

c h a r a c t e r i s e d in that the correction of the errors caused by motion further comprises the steps of:

generating three-dimensional stackgrams based on the sinograms by placing back projected projections on top of each other;

comparing the locus signals generated from the sine waves of the stackgrams to a reference signal; and

transferring the locus signal best corresponding to the reference into its correct place in the stackgrams.

2. The method as defined in claim 1, c h a r a c t e r i s e d in that the construction of tomographic images further comprises the step of: transforming the stackgrams to sinograms.

3. The method as defined in claim 1, c h a r a c t e r i s e d in that a tomographic image is constructed by summing the ramp filtered stackgrams to form images.

4. A system for correcting the errors caused by the motion of a tomographic image, the system comprising:

equipment (20) for generating tomographic images;

a processing system (22) for making motion correction for the images and forming the final image;

a telecommunication connection (21) for connecting the aforementioned equipment (20) and the aforementioned processing system (22);

characterised in that the processing system (22) further comprises:

means (23) for generating stackgrams based on the sinograms;

means (24) for comparing the locus signals being generated from the sine waves of the stackgrams to a reference;

means (25) for transferring in place the locus signals best corresponding to the reference; and

means (26) for generating a tomographic image.

5. The system as defined in claim 4, characterised in that the means (26) for generating a tomographic image are arranged to transform the stackgrams to sinograms.

6. The system as defined in claim 4, characterised in that the means (26) for generating a tomographic image are arranged to generate the image by summing the Ramp filtered stackgrams.

7. A software product for correcting the errors caused by the motion of a tomographic image, the software product being arranged:

to receive measurement information from the equipment to generate tomographic images;

to correct the errors caused by the motion in the measurements;

to construct a tomographic image;

characterised in that the software product is further arranged to:

generate stackgrams from the sinograms;

compare the locus signals being generated from the sine waves of the stackgrams to a reference; and

transferring into place the locus signal best corresponding to the reference.

8. The software product as defined in claim 7, c h a r a c t e r i s e d in that the software product is arranged to generate a tomographic image by first transforming the stackgrams to sinograms.

9. The software programs as defined in claim 7, c h a r a c t e r i s e d in that the software product is arranged to generate a tomographic image by summing the Ramp filtered stackgrams.

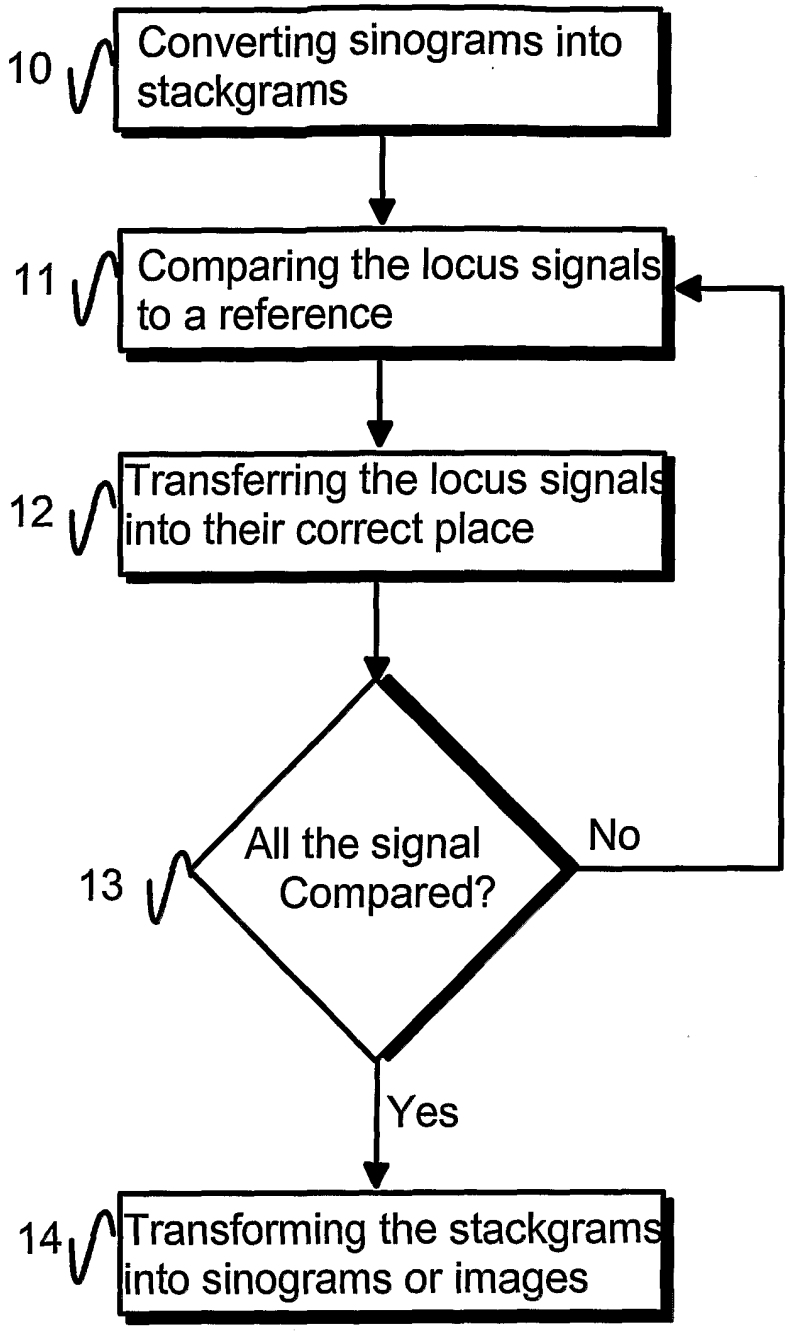
10
Converting sinograms into stackgrams
11
Comparing the locus signals to a reference
12
Transferring the locus signals into their correct place
13
All the signal Compared?
No
Yes
14
Transforming the stackgrams into sinograms or images

Fig. 1

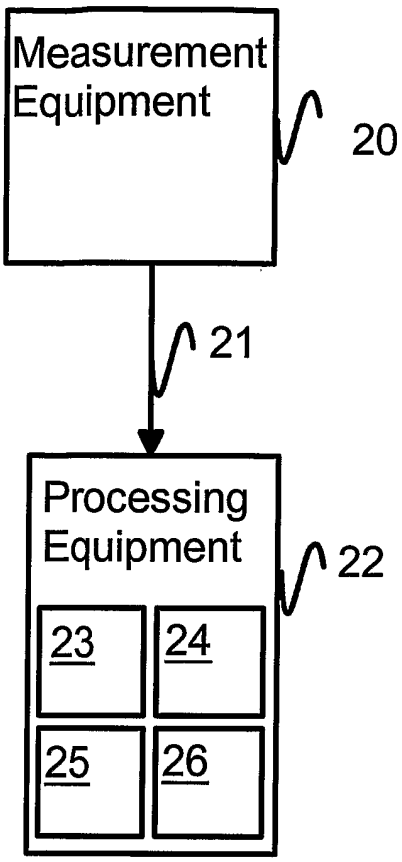
Measurement Equipment
20
21
Processing Equipment
22
23
24
25
26

Fig. 2

INTERNATIONAL SEARCH REPORT

International application No.
PCT/FI 2004/000490

A. CLASSIFICATION OF SUBJECT MATTER

IPC7: G06T 11/00, A61B 6/03
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)

IPC7: G06T, G06F, A61B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

SE,DK,FI,NO classes as above

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

EPO-INTERNAL, WPI DATA, PAJ, INSPEC, COMPENDEX

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	HAPPONEN, A P et al: Sinogram filtering using a stackgram domain. Proceedings of the Second IASTED International Conference, VISUALIZATION, IMAGING AND IMAGE PROCESSING, September 9-12, 2002, Malaga, Spain. ISBN 0-88986-354-3. See pages 339-341 ---	1-9
Y	WO 02085184 A2 (CASE WESTERN RESERVE UNIVERSITY), 31 October 2002 (31.10.2002), page 1, line 7 - line 29; page 2, line 13 - line 24; page 9, line 19 - page 11, line 13, page 13, line 1 - line 32 ---	1-9

[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
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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
"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
23 November 2004	25 -11- 2004
Name and mailing address of the ISA/ Swedish Patent Office Box 5055, S-102 42 STOCKHOLM Facsimile No. +46 8 666 02 86	Authorized officer Jesper Bergstrand /LR Telephone No. +46 8 782 25 00

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International application No.
PCT/FI 2004/000490

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 6028907 A (ADLER, R L ET AL), 22 February 2000 (22.02.2000), column 4, line 10 - column 5, line 12; column 5, line 45 - column 6, line 15; column 7, line 38 - column 9, line 15	1-9
A	US 5744802 A (MUEHLLEHNER, G ET AL), 28 April 1998 (28.04.1998), column 3, line 66 - column 4, line 53; column 6, line 49 - line 61	1-9
A	WO 9705574 A1 (IMPERIAL CANCER RESEARCHTECHNOLOGY LTD), 13 February 1997 (13.02.1997), the whole document	1-9
A	US 5224037 A (JONES, W F ET AL), 29 June 1993 (29.06.1993), column 1, line 16 - line 30; column 1, line 60 - column 2, line 4; column 4, line 37 - line 64	1-9

INTERNATIONAL SEARCH REPORT

Information on patent family members

30/10/2004

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