Title: METHOD OF PROVIDING A DISPLAYABLE PIXEL DATA SET FROM MEASUREMENT DATA PROVIDED BY A DIFFERENTIAL PHASE CONTRAST X-RAY IMAGING SYSTEM

Abstract: A method for providing a displayable pixel data set (11) from measurement data (3) provided by a differential phase-contrast X-ray imaging system (1) and a device (7) adapted to perform such method are proposed. The measurement data (3) comprise three types of measurement information: an absorption representing image data set A, a differential phase-contrast representing image data set D and a coherence representing image data set C. Each of the image data sets A, D and C comprises a 2-dimensional or 3-dimensional set of pixels (5) and the three image data sets are spatially aligned with each other. In the method for providing a displayable pixel data set, a colour value corresponding to a position in a 3-dimensional colour space (9) is attributed to each pixel (13) in the displayable pixel data set (11), wherein each of three coordinates HSI of the position in the 3-dimensional colour space (9) is determined based on data values A, D, C of a corresponding pixel (5) in a respective one of the image data sets A, D, C. For example, the coordinates within the colour space (9) may be indicated by an intensity I, a saturation S and a hue H thereby allowing a very intuitive representation of the complex DPCI measurement data to a human observer.
METHOD OF PROVIDING A DISPLAYABLE PIXEL DATA SET FROM MEASUREMENT DATA PROVIDED BY A DIFFERENTIAL PHASE-CONTRAST X-RAY IMAGING SYSTEM

FIELD OF THE INVENTION

The present invention relates to a method of providing a displayable pixel data set from measurement data provided by a differential phase-contrast X-ray imaging system. Furthermore, the invention relates to a device and a computer program product adapted to perform such method as well as a computer-readable medium comprising the computer program product. Furthermore, the invention relates to a method and a device for displaying measurement data provided by a differential phase-contrast X-ray imaging system.

BACKGROUND OF THE INVENTION

X-ray imaging systems are conventionally used for examining objects of interest, particularly in medical applications. Recently, an improved X-ray imaging method referred to as grating-based differential phase-contrast imaging (DPCI) has been proposed by F. Pfeiffer et al., Phys. Rev. Let. 98(10), 108105, 2007. An example of a differential phase-contrast imaging system is described in WO 2010/109368 A1.

SUMMARY OF THE INVENTION

There may be a need for an improved capability of visualizing internal structures in an object of interest. Particularly, there may be a need for an advantageous visual representation of measurement data provided by a differential phase-contrast X-ray imaging system.

Such needs may be met by the subject-matter of the independent claims. Embodiments of the invention are described in the dependent claims.

According to a first aspect of the present invention, a method of providing a displayable pixel data set from measurement data provided by a differential phase-contrast X-ray imaging (DPCI) system is proposed. Therein, the measurement data comprises three types of data sets each comprising a 2-dimensional or 3-dimensional set of pixels: (1.) an absorption representing image data set A in which each pixel represents a data value indicating an X-ray absorption at the position of the pixel; (2.) a differential phase-contrast representing image data set D in which each pixel represents a data value indicating a differential phase-contrast at
the position of the pixel; and (3.) a coherence representing image data set C in which each pixel represents a data value indicating a degree of coherence or a degree of de-coherence of the X-ray beam relating to the position of the pixel. As DPCI allows for simultaneous acquisition of all three measurement data values for each pixel, the three image data sets A, D, C are spatially aligned with each other. Using such measurement data, the proposed method of providing a displayable pixel data set comprises attributing a colour value corresponding to a position in a 3-dimensional colour space to each pixel in the displayable pixel data set, wherein each of the three coordinates of the position in the 3-dimensional colour space is determined based on data values of a corresponding pixel in a respective one of the image data sets A, D, C. In other words, each coordinate of a point in 3D colour space may be determined by all three values A, D and C, e.g. in the specific case where the 3D colour space is a RGB space, the coordinate could be determined as \( R = R(A,D,C) \), \( G = G(A,D,C) \), \( B = B(A,D,C) \).

One option of a 3-dimensional colour space used in attributing the colour values for each pixel is the hue-saturation-intensity colour system (HSI). In this colour space, a position is defined by a first coordinate indicating a hue, a second coordinate indicating a saturation and a third coordinate indicating an intensity. Using such HSI colour space, the complex information included in the measurement data of the DPCI system may be conveyed to a human observer in an ergonomic way such that the information may be received and understood without dramatically increasing the reading time. However, it may be noted that also other types of 3-dimensional colour spaces such as RGB (red-green-blue) colour space or CMY (cyan-magenta-yellow) colour space may be used.

Using such HSI colour space, the DPCI measurement data may be provided for display in a particularly ergonomic manner when an intensity value is attributed based on the position in the colour space indicated by the data value of the absorption representing image data set A at the corresponding pixel, a hue value is attributed based on the position in the colour space indicated by the data value of the differential phase-contrast representing image data set D at the corresponding pixel and a saturation value is attributed based on the position in the colour space indicated by the data value of the coherence representing image data set C at the corresponding pixel.

An alternative option for attributing the colour values in an ergonomic way may be obtained when an intensity value is attributed based on the position in the colour space indicated by the data value of the differential phase-contrast representing image data set D at the corresponding pixel, the hue value is attributed based on the position in the colour space
indicated by the data value of the absorption representing image data set A at the
corresponding pixel, and the saturation value is attributed based on the position in the colour
space indicated by the data value of the coherence representing image data set C at the
corresponding pixel.

A second aspect of the present invention relates to a method of displaying
measurement data provided by a DPCI X-ray system wherein a displayable pixel data set is
provided using the above-described method and is then displayed on a colour display such as
e.g. a screen of a colour monitor. Using such displaying method, the complex information
included in the measurement data provided by a DPCI X-ray system may be conveyed to a
human reader such as a physician in a way relatively easy to perceive.

A third aspect of the invention relates to a device for providing a displayable
pixel data set from measurement data provided by a DPCI X-ray system, wherein the device is
adapted to perform the method according to the above first aspect of the invention.

A fourth aspect of the invention relates to a device for displaying measurement
data provided by a DPCI X-ray system, wherein the device is adapted to perform the method
of the above second aspect.

A fifth aspect of the invention relates to a computer program product which is
adapted to perform the method according to the above first aspect when executed on a computer.

A sixth aspect of the invention relates to a computer-readable medium having
stored thereon the computer program product according to the fifth aspect of the invention.

It may be seen as a gist of the present invention to provide and possibly display
a displayable pixel data set from the complex measurement data provided by a DPCI X-ray
system by attributing any possible composition of measurement values comprised in the
measurement data to exactly one colour value. In other words, as the DPCI X-ray system
provides three different types of data values for each pixel within a region of interest, a
method is proposed giving rules how these three data values may be represented on a colour
display in a way such that the complete information comprised in the three data values may be
easily and unambiguously perceived by a human viewer. For this purpose, each of the three
data values of one pixel in the measurement data set may be interpreted as indicating a
coordinate in a 3-dimensional colour space. In this way, the attributing of colour values for
each pixel is bijective, i.e. each colour value represents exactly one specific combination of the
three data values comprised in the measurement data for this pixel. As described in more detail
below, one specific 3-dimensional colour space is the HSI colour space in which hue,
saturation and intensity are represented by cylindrical coordinates. Using such HSI colour space, the information comprised in the DPCI measurement data may be represented in a more perceptually relevant manner than in many other representations.

These and other aspects of the invention will become more apparent from and elucidated with reference to the embodiments described hereinafter. Exemplary embodiments of the invention will be described in the following with reference to the appended drawing.

BRIEF DESCRIPTION OF THE DRAWING

Fig. 1 schematically illustrates a method and device according to embodiments of the present invention.

The drawing is only schematically and not to scale.

DETAILED DESCRIPTION OF EMBODIMENTS

Conventional absorption based 2-dimensional X-ray imaging in the medical domain typically provides essentially one type of information, namely the position-dependent X-ray attenuation of an object placed between an X-ray source and an X-ray detector. The linear attenuation coefficients of various biological tissue types may show relatively little variation so that absorption contrast of a transmission X-ray image is usually rather weak. This may hinder in many cases a clear differentiation of diseased and healthy types of tissue, as e.g. the differentiation of breast tumour and surrounding tissue due to inherently low contrast and the presence of image noise.

A new type of X-ray imaging named differential phase-contrast imaging (DPCI) has been proposed. This DPCI may provide three a priori independent types of information which may be obtained simultaneously for each pixel representing a position within the observed 2-dimensional region or 3-dimensional volume: In addition to the conventional absorption contrast which may be provided in the form of line-integrals of the linear attenuation of an X-ray beam crossing the observed region, the DPCI method may further provide gradients of the line-integrals of an X-ray refraction index decrement which may relate to an X-ray wave fronts phase gradient. Accordingly, additional to a conventional absorption or attenuation image, DPCI may provide for a differential phase-contrast image. Furthermore, DPCI may provide a third type of information indicating a quantitative measure of a loss of visibility upon transmission of the X-rays through the object. This may also be understood as a loss of coherence and the information may be referred as coherence image or de-coherence
image. These two additional types of information, i.e. the differential phase-contrast image and the coherence image, may help to enhance edge structures at boundaries between two tissue types that may be only weakly discernable in a conventional attenuation image.

It may be noted that the measurement data may be provided by any type of X-ray examination device using DPCI techniques, such as radiography, mammography or computer tomography systems.

The invention described herein relates to a method of how to process the measurement data provided by the DPCI system including these three types of information in order to be displayed to a human observer in a way easy to perceive. In the following, an embodiment of such method and device will be explained with reference to Fig. 1.

A DPCI X-ray system 1 is used to examine an object of interest 53 interposed between an X-ray source 51 and an X-ray detector 55. Further details of the DPCI X-ray system 1 such as the provision of phase gratings will not be described in this context.

The DPCI X-ray system 1 provides measurement data 3 in which for each location within the object 53 a corresponding pixel 5 comprises information $A_{ij}$ indicating an absorption data value, information $D_{ij}$ indicating a data value representing a local differential phase-contrast and information $C_{ij}$ indicating a data value representing a loss of coherence at the respective position.

While in Fig. 1, the entire measurement data 3 is represented as a single matrix, it could also have been represented as three different matrixes in which a first matrix represents an absorption representing image data set $A$, a second matrix represents a differential phase-contrast representing image data set $D$ and a third matrix represents a coherence representing image data set $C$.

The measurement data 3 is then provided from the DPCI X-ray system 1 to a device 7 for providing a displayable pixel data set from this measurement data. This device 7 is adapted for performing a method in which each of the pixels 5 of the observed region 53 is given a specific colour value depending on the data values $A_{ij}$, $D_{ij}$, $C_{ij}$ in the respective pixel 5. For this purpose, the device 7 may be a computing device comprising input and output ports and further comprising a processor for manipulating incoming data and memory for temporarily storing data. In the device 7, a model of a 3-dimensional colour space 9 is implemented. In the embodiment shown, the 3-dimensional colour space 9 is a HSI colour space. Therein, a specific colour value may be represented by its cylindrical coordinates wherein an angle around the central axis corresponds to the “hue” $H$, a distance from the
central axis corresponds to a “saturation” $S$ and a distance along the central axis corresponds to an “intensity” $I$ of the colour value.

Having these three coordinates $H$, $S$, $I$ of the colour space $9$ on the one hand and having three data values $A_{ij}$, $D_{ij}$, $C_{ij}$ for each pixel $5$ of the measurement data $3$ on the other hand, the system $7$ may attribute a specific colour value to each pixel $5$ and may thereby provide a displayable pixel data set $11$ in which each pixel $13$ comprises a colour value $15$ indicated by its coordinates in the colour space $9$.

This displayable pixel data set $11$ may then be transmitted to a colour display $17$ e.g. in the form of a screen of a colour monitor.

In the exemplary embodiment shown in Fig. $1$, a specific manner of attributing coordinates of a colour value $15$ depending on the provided measurement data is depicted. In this example, the intensity $I$ is given by the absorption data value $A_{ij}$, i.e. $I = f(A_{ij})$, which is very intuitive as it corresponds to conventional X-ray image representations. The hue $H$ is given by the differential phase-contrast data value $D_{ij}$, i.e. $H = f(D_{ij})$, which may be appropriate because the hue $H$ as well as the phase-contrast are by nature cyclic values which wrap around periodically. The saturation $S$ may be given by the coherence data value $C_{ij}$, i.e. $S = f(C_{ij})$, which may be very intuitive because areas of low coherence will stay grey as in conventional X-ray representations and strong colour will be overlaid only in areas of meaningful coherence, i.e. in areas, in which the measurement values provided by the DPCI X-ray system may be regarded as very reliable.

In an alternative way of attributing colour values $15$ to the pixels $13$ of the displayable pixel data set $11$, the intensity $I$ is given by the differential phase-contrast data value $D_{ij}$, i.e. $I = f(D_{ij})$, which may be intuitive because the differential phase-contrast image $D$ may be perceived by the human visual system as a structure or a “fabric”. The hue $H$ is then given by the absorption data value $A_{ij}$, i.e. $H = f(A_{ij})$, which is capable of colour-code image areas of different tissue types, discriminated by their respective absorption value. The saturation $S$ is again given by the coherence data value $C_{ij}$, i.e. $S = f(C_{ij})$, as described above with respect to the previous embodiment of attributing colour values. Herein, it may be advantageous to scale the hue values $H$ in such a way that the entire dynamic range of the attenuation of the object may fit within the hue space before the colours repeat themselves, as the attenuation is not cyclic.

It may be noted that the described methods may be performed by a computer, i.e. the device $7$ may be a computing device. Accordingly, an embodiment of the present
invention relates to a computer program product or a computer program element which is characterized by being adapted to perform or control respective method steps of the described method according to embodiments of the invention when executed on a computer. The computer program product might therefore be stored on a computer unit which may be adapted to perform or induce a performing of the method steps. Moreover, it may be adapted to operate components of the above-described device. The computing device may be adapted to operate automatically and/or to execute the orders of a user. The computer program product will be loaded into a working memory of a data processor. The data processor may thus be equipped to carry out the method according to embodiments of the invention. This embodiment of the invention covers both, a computer program product that right from the beginning uses the invention as well as a computer program product that by means of an update turns an existing program into a program that uses the invention. A computer-readable medium having stored thereon such computer program product may be provided for example as a CD-ROM. Alternatively, the computer program may also be provided over a network like the WorldWideWeb and can be downloaded into the working memory of the data processor. Accordingly, the computer-readable medium according to an embodiment may also be a medium for making the computer program product available for downloading.

It has to be noted that embodiments of the present invention are described herein with reference to different subject-matters. In particular, some embodiments are described with reference to method type claims whereas other embodiments are described with reference to device type claims. However, a person skilled in the art will gather from the above and the following description that, unless other notified, in addition to any combination of features belonging to one type of subject-matter also any combination between features relating to different subject-matters is considered to be disclosed with this application.

However, all features can be combined providing synergetic effects that are more than the simple summation of the features.

In the claims and the specification, the word “comprising” does not exclude other elements or steps, and the indefinite article “a” does not exclude a plurality. It should also be noted that reference signs in the claims should not be construed as limiting the scope of the claims.
LIST OF REFERENCE SIGNS:

5
1 Differential phase-contrast imaging X-ray system
3 Measurement data
5 Pixel
7 Device for providing displayable pixel data
9 3-dimensional colour space
11 Displayable pixel data set
13 Pixel
15 Colour value
17 Colour display
CLAIMS:

5

1. Method of providing a displayable pixel data set (11) from measurement data (3) provided by a differential phase contrast X-ray imaging system (1), the measurement data comprising:
an absorption representing image data set A,
a differential phase contrast representing image data set D, and
a coherence representing image data set C,
wherein each of the image data sets A, D and C comprise a 2-dimensional or 3-dimensional set of pixels (5) and the three image data sets are spatially aligned with each other, the method comprising:

10 attributing a color value corresponding to a position in a 3-dimensional color space (9) to each pixel (13) in the displayable pixel data set,
wherein each of three coordinates of the position in the 3-dimensional color space is determined based on data values of a corresponding pixel in a respective one of the image data sets A, D, C.

20 2. Method of claim 1, wherein the color space is defined such that the position in the color space is defined by a first coordinate H indicating a hue, a second coordinate S indicating a saturation and a third coordinate I indicating an intensity.

25 3. Method of claim 2, wherein for each pixel an intensity value $I = f(A)$ is attributed based on the position in the color space indicated by the data value of the absorption representing image data set A at the corresponding pixel, a hue value $H = f(D)$ is attributed based on the position in the color space indicated by the data value of the differential phase contrast representing image data set D at the corresponding pixel, and

30 a saturation value $S = f(C)$ is attributed based on the position in the color space indicated by the data value of the coherence representing image data set C at the corresponding pixel.
4. Method of claim 2, wherein for each pixel an intensity value $I = f(D)$ is attributed based on the position in the color space indicated by the data value of the differential phase contrast representing image data set $D$ at the corresponding pixel,

a hue value $H = f(A)$ is attributed based on the position in the color space indicated by the data value of the absorption representing image data set $A$ at the corresponding pixel, and

a saturation value $S = f(C)$ is attributed based on the position in the color space indicated by the data value of the coherence representing image data set $C$ at the corresponding pixel.

5. Method of one of claims 1 to 4, wherein the attribution of a color value is determined, based on data values of a corresponding pixel in a respective one of the image data sets $A$, $D$, $C$, in a bijective manner.

6. Method of displaying measurement data provided by a differential phase contrast X-ray imaging system, the method comprising:

providing a displayable pixel data set using a method according to one of claims 1 to 5, and displaying the displayable pixel data set on a color display (17).

7. Device (7) for providing a displayable pixel data set from measurement data provided by a differential phase contrast X-ray imaging system, wherein the device is adapted to perform the method according to one of claims 1 to 5.

8. Device (7, 17) for displaying measurement data provided by a differential phase contrast X-ray imaging system, wherein the device is adapted to perform the method according to claim 6.

9. Computer program product which is adapted to perform the method according to one of claims 1 to 5 when executed on a computer.

10. Computer readable medium having stored thereon a computer program product according to claim 9.
INTERNATIONAL SEARCH REPORT

A. CLASSIFICATION OF SUBJECT MATTER

INV. 606111/00
ADD.

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)

GO6T

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 practical, search terms used)

EPO-Internal, COMPENDEX, INSPEC, IBM-TDB, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

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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 document 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 document 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
- "X" 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
- "Y" 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
- "**" document of particular relevance; the claimed invention cannot be considered novel or 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

16 January 2012

Date of mailing of the international search report

25/01/2012

Name and mailing address of the ISA/
European Patent Office, P.O. Box 564, European Patent Office, P.O. Box 564, 22801 H 1234, The Hague, The Netherlands, The Hague, The Netherlands, Netherlands

Authorized officer

Katariotis, Antonios
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