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(74) Agents: SCHOUTEN, Marcus M. et al.; Prof. Holstlaan 6, NL-5656 AA Eindhoven (NL).

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(71) Applicant (for DE only): PHILIPS INTELLECTUAL PROPERTY & STANDARDS GMBH [DE/DE]; Lübeckertordamm 5, 20099 Hamburg (DE).

(71) Applicant (for all designated States except DE, US): KONINKLIJKE PHILIPS ELECTRONICS N.V. [NL/NL]; Groenewoudseweg 1, NL-5621 BA Eindhoven (NL).

(72) Inventors; and

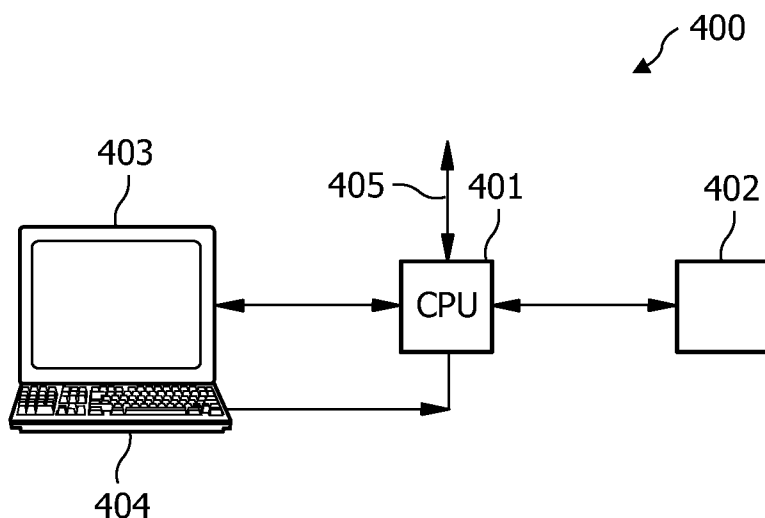
(75) Inventors/Applicants (for US only): BREDNO, Jörg [DE/NL]; c/o Prof. Holstlaan 6, NL-5656 AA Eindhoven (NL). WEESE, Jürgen [DE/NL]; c/o Prof. Holstlaan 6, NL-5656 AA Eindhoven (NL). GROTH, Alexandra [DE/NL]; c/o Prof. Holstlaan 6, NL-5656 AA Eindhoven (NL).

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(54) Title: MOTION-COMPENSATED CORONARY FLOW FROM PROJECTION IMAGING



(57) Abstract: Diagnostic angiograms only provide the projected lumen of a coronary, which is only an indirect measure of blood flow and pressure decline. According to an exemplary embodiment of the present invention, a motion compensated determination of a flow dynamics and a pressure decline for stenosis grading is provided, in which the motion compensation is performed on the basis of a tracking of a first position of a first marker and a second position of a second marker in the projection data set. This may provide for a robust and precise flow dynamics and pressure decline determination.

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Motion-compensated coronary flow from projection imaging

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Field of the invention

The invention relates to the field of medical imaging. In particular, the invention relates to an examination apparatus for motion compensated determination of flow dynamics from an image sequence of an object of interest, to a method of motion compensated determination of flow dynamics, an image processing device, a computer-readable medium and a program element.

Technological background

Stenosis grading from contrasted x-ray angiograms is of major interest for minimally invasive treatment of diseased coronaries in the cardiac cathlab. Obstructed volume flow and increased pressure decline at a coronary lesion are the major cause of coronary heart disease. For a well founded treatment decision, it is important in daily clinical routine to assess the severity of such stenoses. Currently, subjective visual inspection of coronary angiograms or the determination of the pressure decline using an intravascular pressure gauge are used to assess this severity. Coronaries move with heart beat and respiration of a patient such that a separation between the movement of the vessels themselves and the flow of blood inside the vessels is required for a clinically valid assessment.

Summary of the invention

It would be desirable to have a motion compensated determination of coronary flow.

It should be noted that the following described exemplary embodiments of the invention apply also for the method, the computer-readable medium, the image processing device and the program element.

According to an exemplary embodiment of the present invention, an examination apparatus for motion compensated determination of flow dynamics from

an image sequence of an object of interest is provided, the examination apparatus comprising an analysis unit adapted for performing a determination of a first volume flow in a region of the object of interest, wherein the determination comprises a motion compensation performed on the basis of a tracking of a first position of a first marker in
5 the image sequence, wherein a motion of the marker corresponds to a motion of the object of interest.

Therefore, the examination apparatus may be adapted to determine a motion and therefore, e.g., a volume flow, fluid characteristics or transient properties in a region, which may, for example, be a coronary artery. In order to determine the flow
10 dynamics, the position of a first marker, which is present in the region of the object of interest, is detected in the image sequence. This marker is adapted for marking the region of interest (i.e. a vessel segment of interest).

It should be noted, however, that further markers may be present. For example, a second marker may be provided which position in the image sequence is
15 tracked as well. Thus, not only a linear motion may be determined and compensated for, but also a rotation of the structure comprising the two markers. If, for example, a third marker is tracked as well, a three-dimensional movement of the structure (such as a bending or deformation) may be determined and compensated for.

It should be noted, that the terms “motion compensation” or “motion
20 compensated determination” also refer to “deformation compensation” or “deformation compensated determination”.

According to another exemplary embodiment of the present invention, the examination apparatus further comprises an acquisition unit adapted for acquiring the image sequence in one of a dedicated flow run and a standard acquisition run.

25 Therefore, according to this exemplary embodiment of the present invention, the motion compensated flow determination may be performed on either a data set which is acquired particularly for such determination process, or on the basis of a standard data set which is acquired during a normal examination process.

According to another exemplary embodiment of the present invention,
30 the image sequence or data set is acquired according to the following scheme:
acquisition of first image data without contrast agent, application of a small diluted

amount of contrast agent, and subsequent acquisition of second image data corresponding to an in- and outflow of the contrast agent during a multitude of cardiac cycles.

Thus, the diluted contrast agent that does not obscure the markers is
5 observed during in- and outflow through the object of interest directly after and together with the first “empty” heartbeat in one acquisition with no stop and restart of the imager in between.

According to another exemplary embodiment of the present invention, the image sequence is an angiogram data set.

10 Therefore, a flow determination for coronary stenosis grading may be provided on the basis of angiogram data.

According to another exemplary embodiment of the present invention, the motion compensation comprises the use of heartbeat data or respiration (or exhalation) data.

15 Thus, motion compensation may not only be performed on the basis of the first and second marker positions, but may also be performed on the basis of electrocardiogram data (if the heart of a patient is imaged) or on the basis of breathing data (in case, for example, the lung of a patient is imaged).

The method may also be applied to vessels in the lung. However, a main
20 field of application of the invention is the compensation of respiration motion where the heart beats itself but is also deformed and shifted around by respiration. The application of the invention may thus include a compensation of heart beat motion, a compensation of respiration motion, a compensation of voluntary and non voluntary patient motion and any combination thereof.

25 According to another exemplary embodiment of the present invention, the analysis unit is further adapted for determining a time intensity curve of contrast agent concentration on the basis of at least the first position of the first marker and a second position of a second marker, and performing a model-based flow analysis adapted to determine at least one of a total volume flow and a pressure decline, even in
30 the presence of strong pulsation effects.

Therefore, by collecting time intensity curves of contrast agent concentration from at least two well-defined points in a moving coronary, a model-based flow analysis adapted for total volume flow determination, pressure decline and further relevant parameters in a vessel may be possible, even in the presence of strong pulsation effects.

According to another exemplary embodiment of the present invention, the model-based flow analysis includes varying flow speeds over the cardiac cycle and compensates for such pulsatility when electrocardiogram data is available as input.

According to another exemplary embodiment of the present invention, the object of interest is a coronary artery, wherein the region of the object of interest is a first vessel segment of the coronary artery.

Furthermore, the first and second markers may be adapted as distance markers of one of a guide wire, a semi-transparent guide wire, a stenting device and a ballooning device.

Therefore, according to this exemplary embodiment of the present invention, an interventional device with at least two detectable markers is present in the coronary and may allow for a marking of the vessel segment of interest.

According to another exemplary embodiment of the present invention, the analysis unit is further adapted for compensating a variability of the first volume flow over the cardiac cycle by one of a defined time of contrast agent injection or by an inclusion and compensation of the variability in a subsequent analysis.

According to another exemplary embodiment of the present invention, the subsequent analysis is a videodensitometric analysis.

According to still another exemplary embodiment of the present invention, the determination is further adapted for determining a second volume flow in a second vessel segment of the coronary artery and for determining a pressure decline in the first vessel segment on the basis of the second volume flow.

Therefore, according to this embodiment, not only a flow dynamics or a volume flow in the first vessel segment may be determined, but also a pressure change. This may provide for an improved stenosis grading.

According to another exemplary embodiment of the present invention, the examination apparatus is adapted as one of three-dimensional computed tomography apparatus and a three-dimensional rotational x-ray apparatus.

According to another exemplary embodiment of the present invention, the examination apparatus is configured as one of the group consisting of a material testing apparatus (such as, for example, an apparatus adapted for an assessment of fluid dynamics in moving components such as combustion engines) and a medical application apparatus in order to image a sequence showing flow phenomena in moving tubes or containers. A field of application of the invention may be medical imaging.

According to another exemplary embodiment of the present invention, a method of motion compensated determination of flow dynamics from an image sequence of an object of interest with an examination apparatus may be provided, the method comprising the step of determining a flow dynamics in a region of the object of interest, wherein the determination comprises a motion compensation performed on the basis of a tracking of a first position of a first marker in the image sequence, wherein a motion of the marker corresponds a motion of the object of interest.

This may provide for a robust and precise flow dynamics analysis.

According to another exemplary embodiment of the present invention, an image processing device for motion compensated determination of a flow dynamics may be provided, the image processing device comprising a memory for storing an image sequence of the object of interest and an analysis unit adapted for carrying out the above-mentioned method steps.

According to another exemplary embodiment of the present invention, a computer-readable medium may be provided, in which a computer program of motion compensated determination of a flow dynamics from an image sequence of an object of interest is stored which, when being executed by a processor, causes the processor to carry out the above-mentioned method steps.

Furthermore, according to another exemplary embodiment of the present invention, a program element of motion compensated determination of a flow dynamics may be provided, which, when being executed by a processor, causes the processor to carry out the above-mentioned method steps.

It should be noted that the method of examination of the object of interest (comprising the motion compensated determination of the flow dynamics) may be embodied as the computer program, i.e. by software, or may be embodied using one or more special electronic optimisation circuits, i.e. in hardware, or the method may be embodied in hybrid form, i.e. by means of software components and hardware components.

The program element according to an exemplary embodiment of the invention is preferably be loaded into working memories of a data processor. The data processor may thus be equipped to carry out exemplary embodiments of the methods of the present invention. The computer program may be written in any suitable programming language, such as, for example, C++ and may be stored on a computer-readable medium, such as a CD-ROM. Also, the computer program may be available from a network, such as the World Wide Web, from which it may be downloaded into image processing units or processors, or any suitable computers.

It may be seen as the gist of an exemplary embodiment of the present invention that a determination of a flow and of a pressure decline in a coronary artery from dynamic coronary angiograms is performed, wherein the angiograms are either acquired in a dedicated flow run or as standard diagnostic acquisition. Determination of the flow and the pressure decline is performed by using an interventional device with at least two detectable markers adapted for marking the vessel segment of interest. In this exemplary embodiment, preferably the markers are taken from a device which is already present in a coronary of interest during a minimally invasive treatment under x-ray control. This may provide for a robust and precise flow and pressure decline determination.

These and other aspects of the present invention will become apparent from and elucidated with reference to the embodiments described hereinafter.

Brief description of the drawings

Exemplary embodiments of the present invention will be described in the following, with reference to the following drawings.

Fig. 1 shows a simplified schematic representation of an examination apparatus according to an exemplary embodiment of the present invention.

Fig. 2 shows a flow-chart of an exemplary method according to the present invention.

5 Fig. 3 shows an exemplary embodiment of an image processing device according to the present invention, for executing an exemplary embodiment of a method in accordance with the present invention.

10 Detailed description of exemplary embodiments

The illustration in the drawings is schematic. In different drawings, similar or identical elements are provided with the same reference numerals.

Fig. 1 shows a simplified schematic representation of an examination apparatus according to an exemplary embodiment of the present invention.

15 The invention may be applied in the field of two-dimensional imaging like fluoroscopic x-ray, x-ray angiograms, ultrasound, or video-imaging. In such a case, the examination may be performed with conventional x-ray systems. Furthermore, the invention may be applied in the field of three-dimensional imaging, such as three-dimensional rotational x-ray imaging or three-dimensional rotational angiography
20 imaging.

The invention may be particularly used when a motion compensated coronary flow has to be determined from projection imaging but may as well be used when a change of pressure has to be detected in a vessel.

The apparatus depicted in Fig. 1 is a C-arm x-ray examination apparatus,
25 comprising a C-arm 10 attached to a ceiling (not depicted in Fig. 1) by means of an attachment 11. The C-arm 10 holds the x-ray source 12 and the detector unit 13. The control unit 16 is adapted for controlling the acquisition process.

The image data generated by the detector unit 13 is transmitted to image processing unit 17 which is controlled by a computer.

30 Furthermore, an electrocardiogram (ECG) unit 18 may be provided for recording the heartbeat of the patient's heart. The corresponding ECG data is then

transmitted to the image processing unit 17. Furthermore, exhalation data may be recorded and transmitted to the image processing unit 17.

The image processing unit 17 is adapted to carry out the above-mentioned method steps.

5 Furthermore, the system may comprise a monitor 19 adapted for visualising the acquired images. Monitor 19 shows a vessel comprising two markers 20, 21 in one vessel arm.

 The invention relates mainly to sequences of 2D image data but may also be applied to sequences of 3D image data as created by computed tomography, or
10 magnetic resonance imagers.

 Fig. 2 shows a flow-chart of an exemplary method according to the present invention.

 Interventional assessment of coronary blood flow is of major interest for coronary stenosis grading and outcome control, i.e. for interventions due to coronary
15 heart disease. However, diagnostic angiograms only provide the projected lumen of a coronary, which is only an indirect measure of blood flow and pressure decline.

 It is desired to assess the flow resistance and residual flow volume of a coronary stenosis objectively from angiogram sequences without relying on an observer's visual impression of the projected vessel lumen or the use of additional
20 interventional devices. Image analysis to determine blood flow from projections based on videodensitometric methods is described in Shpilfoygel SD, Close RA, Valentino DJ, Duckwiler GR, "X-ray videodensitometric methods for blood flow and velocity measurement: A critical review of literature", Medical Physics 27(9), pp 2008-2023, 2000, but has so far not been successfully transferred to a useful clinical system
25 applicable to coronaries.

 The application of videodensitometric methods that allow to objectively assess blood flow through coronaries from projection angiograms may require to compensate for the following sources of deviation: Cardiac contraction leading to a complex deformation of coronaries, respiration motion leading to a motion of the heart
30 in the rib cage, foreshortening artifacts of the non-planar vessel geometry, and

variabilities of the flow volume due to radius and driving pressure changes over the cardiac cycle.

Furthermore, the robustness and precision of algorithms for videodensitometric flow analysis may be limited. The method according to the invention addresses all above difficulties and may therefore enable videodensitometric blood flow assessment for coronaries during Cathlab interventions.

According to a first embodiment, a dedicated flow acquisition protocol is acquired.

In step 1, a guidewire with distance markers is located over a vessel segment of interest. In step 2, a diagnostic angiogram with diluted contrast agent is acquired during breath-hold of the patient. Then, in step 3, the markers on the guidewire are extracted and define fixed positions in the moving coronary with a well-defined distance in the vessel segment of interest. Time-intensity-curves for the concentration of contrast agent at these positions are then extracted for videodensitometric analyses (step 4). A model-based flow analysis may include varying flow speeds over the cardiac cycle and compensate for such pulsatility when ECG is available as input.

Extensions of this basic method may include the application of available methods to compensate for cardiac and respiration motion for the markers to determine their position even when they are obscured by contrast agent.

Such cardiac motion compensation is described in WO2005039253 A1, Konink Philips Electronics NV, Philips Intellectual Property GMBH, „Angiographic image providing device for operating vascular system, generates angiogram image related to matching between heartbeat phase with given heartbeat phase based on function describing position of heart“, Bredno J, Eck K, Rongen P.

This may allow to apply the same method to standard angiograms in which the vessels are fully opacified and even if the patient did not hold his breath during the acquisition.

For both embodiments, variabilities of the volume flow over the cardiac cycle are compensated either by a defined time of contrast agent injection or by

inclusion and compensation of this effect in the subsequent videodensitometric analyses.

As a first step for flow and stenosis assessment, it may be necessary to identify at least two points that remain fixed in a coronary during heartbeat and respiration motion. These markers may be, for example, located up- and downstream of a suspicious vessel segment, respectively. The tracking of markers as e.g. provided by an interventional device (as described in Florent R, Nosjean L, Lelong P, "Medical viewing system and method for enhancing structures in noisy images", WO 03/043516 A2, 2003) or the guidewire segmentation (as described in Baert S, Niessen WJ, Meijering EHW, Frangi AF, Viergever AF, "Guide wire tracking during endovascular interventions," in Delp SL, DiGioia AM, Jaramaz B(eds.): MICCAI 2000, Proc. LNCS 1935, pp. 727–734, 2000) may be able to provide such marker positions as long as no or only little contrast agent is present in the vessels. This, however, may contradict current clinical protocols that aim for strongly opacified vessels.

In contrast, tracking of the coronaries based on image analysis of contrasted vessels (as described in, e.g., Hoffmann KR, Sen A, Lan L, Kok-Gee C, Esthappan-J, Mazzucco M, "A system for determination of 3D vessel tree centerlines from biplane images", International Journal of Cardiac Imaging, 16(5), pp. 315-330, 2000) requires intense manual interaction and is plagued by the problem that the exact position along a vessel centerline is not available.

In consequence, a modified and dedicated flow protocol according to a first embodiment of the invention is provided. In this embodiment, a guidewire or any other interventional device with distance markers is used and navigated over a coronary segment of interest. A dedicated flow sequence is acquired. In this sequence, the patient is asked to hold his breath. Then, one cardiac cycle is imaged without contrast agent and subsequently, a small and diluted amount of contrast agent is injected. In- and outflow of this contrast agent in few cardiac cycles is imaged. The following processing is applied to such acquisitions:

The position of at least one marker upstream and one marker downstream of a suspicious vessel segment is extracted using e.g. template tracking or other well-

known approaches from computer vision. The position of the markers is stored in $x1(t)$ and $x2(t)$, respectively.

Then, a synchronous analysis of the ECG provides the phase $\Phi_{ECG}(t)$ of the cardiac cycle for all frames in the angiogram sequence.

5 Furthermore, with the position of the two points known in all frames, the local x-ray attenuation $TIC1(t)$ and $TIC2(t)$ is extracted from the angiograms. The distance between these two points is unambiguously known even in the presence of strong bends and foreshortening because these points are located on the guidewire or interventional device.

10 Then, the local contrast agent concentration in the vessel is determined by comparison of the actual greylevel with the greylevel at the respective position during the first non-contrasted heart cycle.

Finally, the distance L between the two control points in the coronary is known from the geometric design of the markers. This secured distance together with
15 the background-corrected $TIC1^*(t)$ and $TIC2^*(t)$ (which contain modified data in comparison to the $TIC1(t)$ and $TIC2(t)$ mentioned above) allows to apply suitable algorithms for videodensitometric blood flow assessment and, therefore, determine the amount of blood flowing through the vessel segment of interest.

In a further exemplary embodiment of the invention, a model-based
20 method for videodensitometry is applied. In this flow model, the transport of contrast agent through a vessel segment of known length and radius is simulated. With $TIC1(t)$ as the observed input into this vessel segment, the model then predicts $TIC2'(t)$ for various flow volumes, velocity profiles in the cross-section of a vessel, diffusion constants between contrast agent and blood, and a driving pressure changing over time.
25 An optimization over these parameters tunes the model such that the prediction $TIC2'(t)$ and the observed $TIC2(t)$ are as similar as possible.

Then, all relevant flow information, especially the volume flow, can be read from the tuned model parameters. For coronary flow, it is necessary to work with a variable driving pressure $p(t)$ and it could be beneficial to introduce a variable vessel
30 radius $r(t)$ that both change over the cardiac cycle. In consequence, the model has to additionally optimize two functions $p(\Phi_{ECG})$ and $r(\Phi_{ECG})$ that are synthesized from few

scalar parameters, e.g. their maximal and minimal value and the moments of respective transition in the cardiac cycle. Physiologic a-priori knowledge on expected courses of $p(\phi_{\text{ECG}})$ and $r(\phi_{\text{ECG}})$ can be used as initialization such that only a match to inter-patient variabilities is required. The maximal and minimal radius of the coronary (that is
5 partially embedded in the myocardium, therefore subject to varying external pressure) can further be estimated from angiograms acquired at respective ϕ_{ECG} .

If the volume flow is also determined in one healthy coronary segment, it may further be possible to quantify the additional pressure decline cause by a stenosis.

As extension and further embodiments, methods are provided that allow
10 to apply the flow analysis even to standard diagnostic angiograms.

The guidewire with distance markers may be replaced by an interventional device or a semi-opaque guidewire. The extraction of markers on interventional devices is described in Florent R, Nosjean L, Lelong P, "Medical viewing system and method for enhancing structures in noisy images", WO 03/043516 A2, 2003
15 and guidewire tracking with end point localization is described in Baert S, Niessen WJ, Meijering EHW, Frangi AF, Viergever AF, "Guide wire tracking during endovascular interventions," in Delp SL, DiGioia AM, Jaramaz B(eds.): MICCAI 2000, Proc. LNCS 1935, pp. 727–734, 2000) for standard guidewires.

A further extension may allow to determine at least two fixed positions in
20 a coronary in a complete contrasted angiogram acquisition even if the markers are partially obscured by a contrast agent injection that aims at the imaging of a fully opaque intravascular lumen:

Firstly, the frames of the angiogram are first classified based on the information if contrast agent is contained in the vessel of interest or not. A respective
25 method has been described in Aach T, Condurache A, Eck K, Bredno J, "Statistical-model based identification of complete vessel-tree frames in coronary angiograms," in Bouman CA and Miller EL (eds.), Electronic Imaging 2004:Computational Imaging, Proc. SPIE 5299, pp 283-294, 2004.

Secondly, template tracking or other well-known methods (as disclosed
30 in Baert S, Niessen WJ, Meijering EHW, Frangi AF, Viergever AF, "Guide wire tracking during endovascular interventions," in Delp SL, DiGioia AM, Jaramaz B(eds.):

MICCAI 2000, Proc. LNCS 1935, pp. 727–734, 2000, and in Florent R, Nosjean L, Lelong P, “Medical viewing system and method for enhancing structures in noisy images”, WO 03/043516 A2, 2003) may provide the positions $x_1(t)$ and $x_2(t)$ of two points in a coronary in all frames that have been classified to contain no or few contrast agent.

Thirdly, respiration motion compensation may provide the global motion of the heart in the rib cage. For example, the depth $\phi_{\text{Resp}}(t)$ of respiration intake from projection angiograms can be used to determine a compensating shift $\Delta(\Phi_{\text{Resp},1}, \Phi_{\text{Resp},2})$ between frames acquired with different depth of respiration intake such that imaged coronaries are registered onto each other. This compensation is also applicable when the coronaries are currently not visible in an angiogram frame.

Using this compensation, the respiration-compensated positions $x_1'(t)$ and $x_2'(t)$ are computed from $x_1(t)$, $x_2(t)$, and $\Phi_{\text{Resp}}(t)$ to depend only on the heart beat and no longer on respiration.

Above information is then combined to create the curves $x_1(\Phi_{\text{ECG}}, \Phi_{\text{Resp}})$ and $x_2(\Phi_{\text{ECG}}, \Phi_{\text{Resp}})$ that determine the position of two fixed points in a coronary at arbitrary phases in the cardiac cycle and for varying depth of respiration intake.

The positions $x_1(t)$ and $x_2(t)$ can now be computed for all frames in which the markers are not visible due to contrast agent in the vessel. A local adaptive matching to the centerline of the coronary can correct for small deviations that result from this prediction.

When $x_1(t)$ and $x_2(t)$ have been extracted over the full angiogram duration, the videodensitometric analysis described for the first embodiment can be applied with no further modification.

According to an aspect of the invention, coronary motion compensation is provided from the position of the visible markers for a dedicated flow acquisition in which only diluted contrast agent is used. For standard angiograms with fully opaque vessels, further already presented motion compensation methods for heartbeat and respiration are applied. Following the coronary motion compensation, it is possible to collect time-intensity curves (TICs) of contrast agent concentration from at least two

well-defined points in a moving coronary. This information is sufficient for a model-based flow analysis that is specially adapted to determine the total volume flow, the pressure decline, and further relevant parameters in a vessel even in the presence of strong pulsation effects.

5 Fig. 3 depicts an exemplary embodiment of a data processing device 400 according to the present invention for executing an exemplary embodiment of a method in accordance with the present invention. The data processing device 400 depicted in Fig. 3 comprises a central processing unit (CPU) or image processor 401 connected to a memory 402 for storing an image depicting an object of interest, such as a coronary
10 artery or other moving objects that hold a fluid.

 The data processor 401 may be connected to a plurality of input/output network or diagnosis devices, such as a x-ray imager. The data processor 401 may furthermore be connected to a display device 403, for example, a computer monitor, for displaying information or an image computed or adapted in the data processor 401. An
15 operator or user may interact with the data processor 401 via a keyboard 404 and/or other output devices, which are not depicted in Fig. 3.

 Furthermore, via the bus system 405, it may also be possible to connect the image processing and control processor 401 to, for example, a motion monitor, which monitors a motion of the object of interest. In case, for example, a lung of a
20 patient is imaged, the motion sensor may be an exhalation sensor. In case the heart is imaged, the motion sensor may be an electrocardiogram unit.

 The proposed model for coronary blood flow analysis may be implemented on a workstation available in a coronary Cathlab, such as a workstation dedicated to provide additional functionalities for imaging, diagnosis, treatment
25 decision and outcome control.

 All processing functions may, according to the invention, be integrated into a common Cathlab workstation. The interventionalist may use a method to select a coronary for further diagnosis and treatment, which is to navigate a guidewire and possible interventional devices into this vessel. Following a diagnostic contrasted
30 angiogram or a dedicated flow acquisition, the algorithm for blood flow assessment may start automatically and provide the flow volume in this vessel of interest.

It should be noted that the term “comprising” does not exclude other elements or steps and the “a” or “an” does not exclude a plurality. Also elements described in association with different embodiments may be combined.

5 It should also be noted that reference signs in the claims shall not be construed as limiting the scope of the claims.

CLAIMS:

5

1. Examination apparatus (100) for motion compensated determination of a flow dynamics from an image sequence of an object of interest (15, 107), the examination apparatus (100) comprising:

an analysis unit (118) adapted for performing a determination of a first flow
10 dynamics in a region of the object of interest (15, 107);
wherein the determination comprises a motion compensation performed on the basis of a tracking of a first position of a first marker in the image sequence;
wherein a motion of the markers corresponds a motion of the object of interest.

15

2. The examination apparatus (100) of claim 1,
further comprising an acquisition unit (108) adapted for acquiring the image sequence in one of a dedicated flow run and a standard acquisition run.

20

3. The examination apparatus (100) of claim 2,
wherein the image sequence is acquired according to the following scheme:
acquisition of first data during a cardiac cycle;
application of a small and diluted amount of contrast agent; and
subsequent acquisition of second data corresponding to an inflow and
25 outflow of the contrast agent during a multitude of cardiac cycles.

4. The examination apparatus (100) of claim 1,
wherein the image sequence is an angiogram data set.

30

5. The examination apparatus (100) of claim 1,

wherein the motion compensation comprises the use of heartbeat data, respiration data, voluntary and involuntary patient motion data.

6. The examination apparatus (100) of claim 1,
5 wherein the analysis unit (118) is further adapted for:
determining a time intensity curve of a contrast agent concentration on the basis of at least the first position of the first marker and a second position of a second marker; and
performing a model-based flow analysis adapted to determine at least one of a
10 total volume flow and a pressure decline, even in the presence of strong pulsation effects.
7. The examination apparatus (100) of claim 6,
wherein the model-based flow analysis includes varying flow speeds over
15 the cardiac cycle and compensates for such pulsatility when electrocardiogram data is available as input.
8. The examination apparatus (100) of claim 1,
wherein the object of interest (15, 107) is a coronary artery; and
20 wherein the region of the object of interest (15, 107) is a first vessel segment of the coronary artery.
9. The examination apparatus (100) of claim 1,
wherein the first and second markers are adapted as distance markers of one of a
25 guide wire, a semi-transparent guide wire, a stenting device, and a ballooning device.
10. The examination apparatus (100) of claim 1,
wherein the analysis unit (118) is further adapted for:

compensating a variability of the first volume flow over the cardiac cycle by one of a defined time of contrast agent injection or by an inclusion and compensation of the variability in a subsequent analysis.

- 5 11. The examination apparatus (100) of claim 10,
 wherein the subsequent analysis is a videodensitometric analysis.
12. The examination apparatus (100) of claim 1,
 wherein the analysis unit (118) is further adapted for:
10 determining a second volume flow in a second vessel segment of the coronary
 artery; and
 determining a pressure decline in the first vessel segment on the basis of the
 second volume flow.
- 15 13. The examination apparatus (100) of claim 1,
 wherein the examination apparatus (100) is adapted as one of a Cathlab imager
 in fixed imaging geometry, a 3D computed tomography apparatus, and a 3D rotational
 X-ray apparatus.
- 20 14. The examination apparatus (100) of claim 1, configured as one of
 the group consisting of a material testing apparatus and a medical application
 apparatus.
15. A method of motion compensated determination of a flow dynamics
 from an image sequence of an object of interest (15, 107) with an examination
25 apparatus, method comprising the step of:
 determining of a first flow dynamics in a region of the object of interest (15,
 107);
 wherein the determination comprises a motion compensation performed
 on the basis of a tracking of a first position of a first marker in the image sequence;

wherein a motion of the markers corresponds to a motion of the object of interest.

16. An image processing device for motion compensated determination of a flow dynamics from an image sequence of an object of interest (15, 107), the image processing device comprising:
- 5 a memory for storing an image sequence of the object of interest (15, 107);
- an analysis unit (118) adapted for:
- 10 determining of a first flow dynamics in a region of the object of interest (15, 107);
- wherein the determination comprises a motion compensation performed on the basis of a tracking of a first position of a first marker in the image sequence;
- wherein a motion of the markers corresponds to a motion of the object of interest.
- 15

17. A computer-readable medium (402), in which a computer program of motion compensated determination of a flow dynamics from an image sequence of an object of interest (15, 107) is stored which, when being executed by a processor (401),
- 20 is adapted to carry out the step of:
- determining of a first flow dynamics in a region of the object of interest (15, 107);
- wherein the determination comprises a motion compensation performed on the basis of a tracking of a first position of a first marker in the image sequence;
- 25 wherein a motion of the markers corresponds to a motion of the object of interest..

18. A program element of motion compensated determination of a flow dynamics from an image sequence of an object of interest (15, 107), which, when being
- 30 executed by a processor (401), is adapted to carry out the step of:

determining of a first flow dynamics in a region of the object of interest
(15, 107);

wherein the determination comprises a motion compensation performed
on the basis of a tracking of a first position of a first marker in the image sequence;

5 wherein a motion of the markers corresponds to a motion of the object of
interest.

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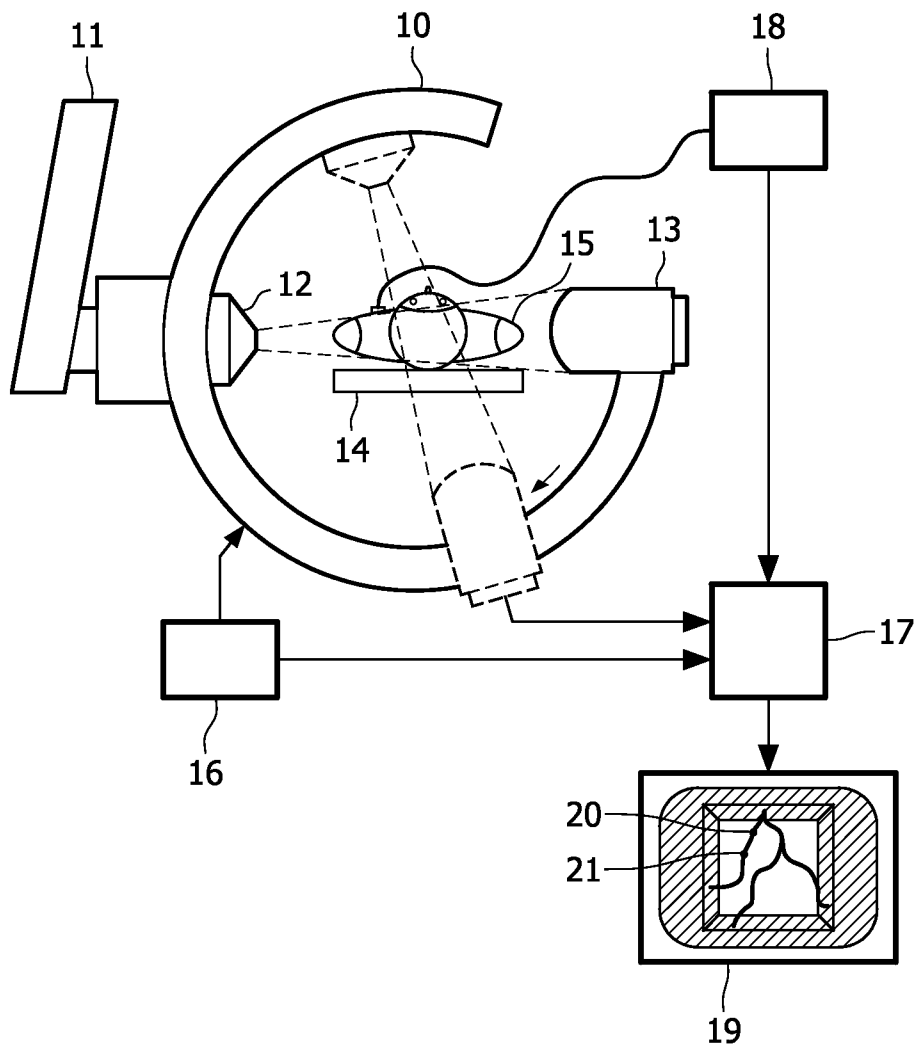


FIG. 1

2/2

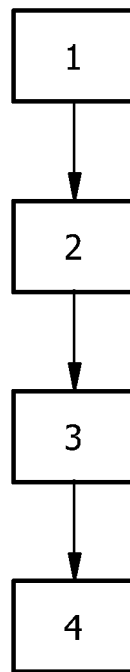


FIG. 2

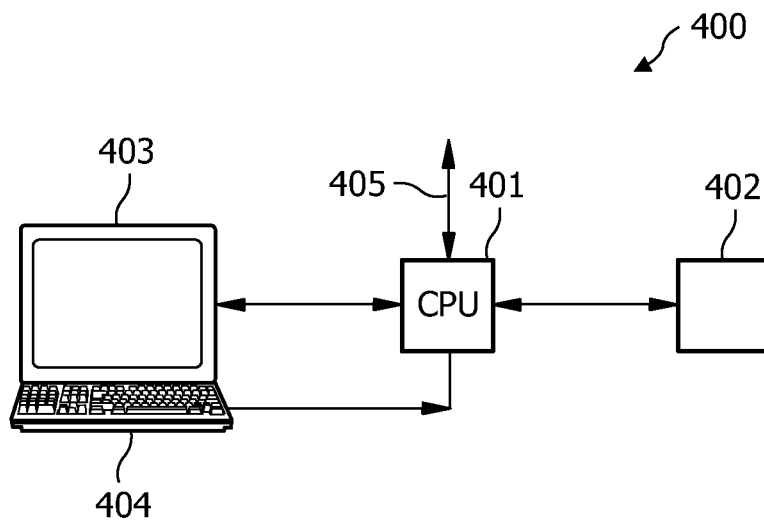


FIG. 3

INTERNATIONAL SEARCH REPORT

International application No

PCT/IB2007/051811

A. CLASSIFICATION OF SUBJECT MATTER

INV. A61B6/00

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)

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 practical, search terms used)

EPO-Internal

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	WO 03/046797 A (KONINKL PHILIPS ELECTRONICS NV [NL]; PHILIPS MED SYST INC [US]) 5 June 2003 (2003-06-05)	1-6, 8, 12-17
Y	abstract; figures 1-3 page 3, line 13 - page 4, line 12 page 6, line 8 - page 7, line 16 page 8, lines 8-23 page 10, lines 7-21	7, 9, 11
Y	WO 02/02173 A1 (CEDARS SINAI MEDICAL CENTER [US]) 10 January 2002 (2002-01-10) abstract page 2, lines 5-11 page 4, line 24 - page 6, line 2 page 8, lines 12-28 page 9, lines 3-18	9, 11



Further documents are listed in the continuation of Box C.



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 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

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

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

27 September 2007

Date of mailing of the international search report

05/10/2007

Name and mailing address of the ISA/

European Patent Office, P.B. 5818 Patentlaan 2
NL - 2280 HV Rijswijk
Tel. (+31-70) 340-2040, Tx. 31 651 epo nl,
Fax: (+31-70) 340-3016

Authorized officer

Lahorte, Philippe

INTERNATIONAL SEARCH REPORT

International application No

PCT/IB2007/051811

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	<p>STUKE I ET AL: "Cardio dynamic subtraction angtography (CDSA)" SECOND JOINT EMBS-BMES CONFERENCE 2002. CONFERENCE PROCEEDINGS. 24TH. ANNUAL INTERNATIONAL CONFERENCE OF THE ENGINEERING IN MEDICINE AND BIOLOGY SOCIETY. ANNUAL FALL MEETING OF THE BIOMEDICAL ENGINEERINGSOCIETY. HOUSTON, TX, OCT. 23 - 26, 2002, ANNUA, vol. VOL. 1 OF 3. CONF. 24, 23 October 2002 (2002-10-23), pages 915-916, XP010619884 ISBN: 0-7803-7612-9 the whole document</p>	7
Y	<p>----- SHPILFOYGEL SIMON D ET AL: "X-ray videodensitometric methods for blood flow and velocity measurement: A critical review of literature" MEDICAL PHYSICS, AIP, MELVILLE, NY, US, vol. 27, no. 9, September 2000 (2000-09), pages 2008-2023, XP012011255 ISSN: 0094-2405 abstract; figure 3 paragraphs [000I], [00II]</p>	11
X	<p>----- US 2006/058674 A1 (OLSTAD BJORN [NO]) 16 March 2006 (2006-03-16) abstract; figures 1,2 paragraphs [0013], [0023], [0025], [0035], [0041]</p>	1,2,5,8, 14-17
A	<p>----- WO 96/31156 A (ANDERSSON MATS [SE]; KNUTSSON HANS [SE]; KRONANDER TORBJOERN [SE]) 10 October 1996 (1996-10-10) abstract; figure 5 page 2, paragraph 2 pages 5-8</p> <p>-----</p>	1-9, 11-17

INTERNATIONAL SEARCH REPORT

International application No.
PCT/IB2007/051811

Box 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.: 18
because they relate to subject matter not required to be searched by this Authority, namely:
Claim 18: Rule 39.1(vi) PCT - Program for computers
2. ☒ Claims Nos.: 10
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:
see FURTHER INFORMATION sheet PCT/ISA/210
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 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:

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.

FURTHER INFORMATION CONTINUED FROM PCT/ISA/ 210

Continuation of Box II.1

Claims Nos.: 18

Claim 18: Rule 39.1(vi) PCT - Program for computers

Continuation of Box II.2

Claims Nos.: 10

Claim 10 defines a first feature of "compensating a variability of the first volume flow over the cardiac cycle by a defined time of contrast agent injection" as well as the alternative feature "compensating a variability of the first volume flow over the cardiac cycle by compensation of the variability in a subsequent analysis".

Said features are vague and unclear and do not allow to determine the structural or functional features limiting the scope of claim 10. For this reason, a meaningful search of the subject-matter of claim 10 is not possible.

The applicant's attention is drawn to the fact that claims relating to inventions in respect of which no international search report has been established need not be the subject of an international preliminary examination (Rule 66.1(e) PCT). The applicant is advised that the EPO policy when acting as an International Preliminary Examining Authority is normally not to carry out a preliminary examination on matter which has not been searched. This is the case irrespective of whether or not the claims are amended following receipt of the search report or during any Chapter II procedure. If the application proceeds into the regional phase before the EPO, the applicant is reminded that a search may be carried out during examination before the EPO (see EPO Guideline C-VI, 8.5), should the problems which led to the Article 17(2) declaration be overcome.

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/IB2007/051811

Patent document cited in search report		Publication date	Patent family member(s)	Publication date
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