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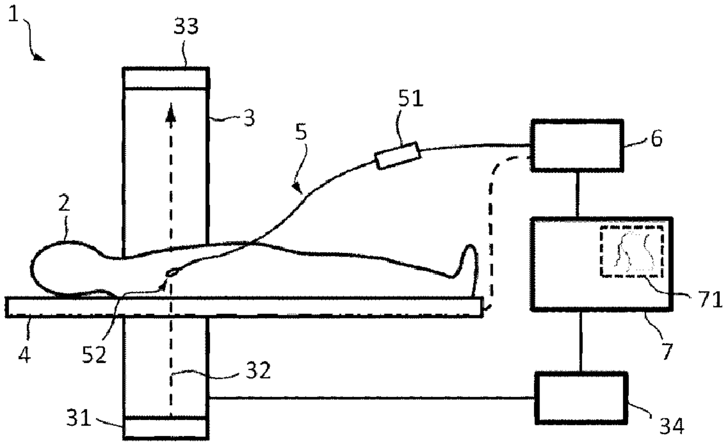

Fig. 1

(57) Abstract: A three-dimensional morphological vessel model (20) can be obtained by assigning diameters (14,15) along the vessel derived from a two-dimensional morphological projection (10) at locations in the three-dimensional model defined by the temporal locations (21,22) of a trackable instrument (5). An apparatus (7), a system (1) and a method (100) for use of the system (1) in characterizing the vessel of a living being (2) by rendering a three-5 dimensional morphological vessel model (20) are presented.

WO 2017/046288 A1

Apparatus for vessel characterization

FIELD OF THE INVENTION

The present invention relates to an apparatus, a system and method for characterization of vessels and for vessel modeling.

BACKGROUND OF THE INVENTION

A typical technique for identifying stenotic regions in a blood vessel is using angiography, whereas the functional impact of the stenosis is quantified with the fractional flow reserve (FFR) method. FFR is calculated from the ratio of pressures at the distal and proximal ends of the stenosis, measured with a sensor positioned at the tip of a wire. According to the FFR value the severity of the stenosis is established, specifically whether the stenosis limits blood flow within the vessel to an extent that treatment is required. Common treatment options include angioplasty, stenting or bypass.

Angiography, a fluoroscopy imaging technique in conjunction with radio-opaque contrast agents, can be used to visualize the vasculature of a patient.

US 4875165 A describes a method for determination of three-dimensional structure in biplane angiography, including determining the distances of perpendicular lines from the focal spots of respective x-ray sources to respective image planes and defining the origin of each biplane image as the point of intersection with the perpendicular line thereto, obtaining two biplane digital images at arbitrary orientations with respect to an object, identifying at least eight points in both images which correspond to respective points in the object, determining the image coordinates of the eight identified object points in the respective biplane unknowns based on the image coordinates of the object points and based on the known focal spot to image plane distances for the two biplane images; solving the linear equations to yield the eight unknowns, which represent the fundamental geometric parameters of the biplane imaging system; using the fundamental parameters to calculate the three-dimensional positions of the object points identified in the biplane images; and determination of the three-dimensional positions of the vessel segments between the object points.

WO 2013001388 A1 discloses a method, and system for providing a live 3D image of a body lumen. The 3D shape of a flexible surgical tool in the body lumen is determined using optical shape sensing. An x-ray image is taken of the body lumen, with at least one of the body lumen and the surgical tool being radiopaque. The determined 3D surgical tool shape is registered to the x-ray image.

SUMMARY OF THE INVENTION

It is an object of the invention to provide an apparatus for a simpler and more intuitive characterization of vessels of living beings.

According to a first aspect of the invention, this object is realized by an apparatus for characterizing a vessel of a living being, the apparatus comprising:

- a processor for processing measurement information,

wherein the apparatus is configured to be coupled to:

- a tracking unit for measuring temporal location information of a trackable instrument in a vessel,
- an imaging unit for generating morphological projection information of the vessel;,

the processor is configured to:

- derive a first diameter of the vessel from the morphological projection information corresponding to a first temporal location of a distal portion of the instrument,
- derive a second diameter of the vessel from the morphological projection information corresponding to a second temporal location of the distal portion of the instrument, and
- assign the first and second diameters of the vessel in a three-dimensional morphological model of the vessel at two locations defined by a relative position between the first and second temporal locations of the distal portion of the instrument.

Characterization of vessels is improved in that the diameter of the vessel is provided in a three-dimensional model of the vessel morphology, based on computation of the diameter from morphological projection information combined with the temporal location information of the tracked device. A major benefit is that a single angiographic projection is sufficient for construction of the three-dimensional morphological vessel model, and that the three-dimensional model is generated as the distal portion (e.g. tip or a radiopaque marker) of the instrument moves within the vessel lumen. The three-dimensional model is augmented with the withdrawal of the instrument, therefore a three-dimensional model is presented to the user only for the relevant segment of the vessel through which the distal portion of the instrument has been maneuvered, making the information presented to the user simpler and the interpretation of the information more intuitive. In an embodiment of the apparatus, the temporal location information of the instrument processed by the processor is derived from electromagnetic signals. Electromagnetic tracking of instruments is one of the typical localization techniques, whereby an electromagnetic field is detected by an electromagnetic sensor integrated into the instrument, and the temporal location of the senor in the electromagnetic field is derived from the strength of the signal.

In an embodiment of the apparatus, the temporal location information of the instrument processed by the processor is derived from laser radiation. Optical shape sensing is a technology that uses reflections of laser radiation from multiple optical fibers or from a multi-core optical fiber integrated into an instrument to measure local strains to which the instrument is exposed. The shape of the optical fibers, hence that of the instrument, is derived by processing optical reflection signals from within the optical fibers, received by a detector. The advantage of optical shape sensing over electromagnetic tracking is that the full three-dimensional shape of the instrument is known at all instances, whereas with electromagnetic tracking only the discrete positions of the electromagnetic sensors integrated into the instrument can be derived.

In an embodiment of the apparatus, the first and second temporal location information indicative for the location of the instrument in the vessel originate at same phase of a cyclical cardiac motion. Assigning the first and second diameters of the vessel in a three-dimensional morphological model based on gating to the phase of the cyclical cardiac and/or respiratory motion is critical in instances where real-time assessment is carried out on the condition of coronary arteries, with significant motion due to heart beat and respiration.

In an embodiment the apparatus further comprises a display, and the processor is configured to render a graphical representation of the three-dimensional morphological model with the assigned first and second diameters on the display. Visual aspect of the three-dimensional vessel model supports assessment of the condition of the vasculature, since stenotic regions are represented by a significant narrowing of the vessel, whereas aneurysms have a bulging aspect.

According to a second aspect of the invention a system comprises:

- the apparatus for characterizing a vessel of a living being,
- the trackable instrument for introduction into the vessel of the living being,
- the tracking unit for measuring temporal location information of the instrument in the vessel,

- the imaging unit for generating morphological projection information of the vessel. The trackable instrument comprises at least an electromagnetic sensor for sensing an electromagnetic field generated by the tracking unit, or at least an optical fiber for sensing strain to which the instrument is exposed when the tracking unit transmits and receives laser radiation from within the at least an optical fiber. A radiological imaging unit such as a fluoroscopy system or a system used for x-ray computed tomography, capable of providing radiographic projection, can be used for acquiring the morphological information of vessels by angiography. Other imaging techniques suitable for acquiring morphological information of vessels may however be used, such as ultrasound imaging, or magnetic resonance imaging. The tracking unit may be integrated into the imaging unit. The trackable instrument may comprise markers traceable with the imaging unit used for acquiring morphological information of the vessels. The markers on the instrument are recognizable with the respective imaging modalities, for instance ultrasound reflecting or absorbing markers in ultrasound imaging.

In an embodiment of the system, the trackable instrument comprises a sensor for measuring physiological information, and the processor is configured to assign at least a first physiological information to the three-dimensional morphological model of the vessel at the location defined by the first temporal location of the instrument. In an alternative embodiment, the processor is further configured to assign at least a second physiological information to the three-dimensional morphological model of the vessel at the location defined by the second temporal location of the instrument. Assigning physiological information to the three-dimensional model supports the physician in assessment of vessel condition, for instance change in visual aspect of the model due to narrowing or broadening vessel branch, by confirmation of a variation of pressure, FFR, blood flow velocity or blood flow resistance values.

According to further aspect of the invention a method for characterizing a vessel of a living being comprises:

- introducing a trackable instrument into the vessel,
- measuring temporal location information of the instrument in the vessel,
- generating morphological projection information of the vessel,
- deriving a first diameter of the vessel from the morphological projection information corresponding to a first temporal location of a distal portion of the instrument,
- deriving a second diameter of the vessel from the morphological projection information corresponding to a second temporal location of the distal portion of the

instrument, and

- assigning the first and second diameters of the vessel in a three-dimensional morphological model of the vessel at two locations defined by a relative position between the first and second temporal locations of the distal portion of the instrument.

In an embodiment of the method

- deriving the first and second diameters and measuring the first and second temporal locations of the instrument are performed for consecutive phases of a cyclical motion, and

- assigning the first and second diameters of the vessel in the three-dimensional morphological model of the vessel at two locations defined by the relative position between the first and second temporal locations of the distal portion of the instrument is performed for respective consecutive phases of the cyclical motion.

In an embodiment, the method further comprises the step of rendering a graphical representation of the three-dimensional morphological model on a display. The visual representation of the three-dimensional morphological model enables rapid assessment of various structural and functional nonconformities, such as vessel stenosis and/or presence of aneurysms.

Additional aspects and advantages of the invention will become more apparent from the following detailed description, which may be best understood with reference to and in conjunction with the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

In the drawings:

Fig. 1 shows schematically and exemplarily an embodiment of a system for characterizing a vessel of a living being, according to the invention.

Fig. 2 shows an exemplary angiographic projection of a branching vessel and the method of local vessel diameter calculation.

Fig. 3 shows an exemplary embodiment of a three-dimensional morphological vessel model rendered according to the invention based on an angiographic projection and electromagnetic tracking of an instrument.

Fig. 4 shows an exemplary embodiment of a three-dimensional morphological vessel model rendered based on an angiographic projection and optical shape tracking of an instrument.

Fig. 5 shows a schematic and exemplary embodiment of a three-dimensional morphological vessel model with assigned physiological information.

Fig. 6 schematically and exemplarily illustrates the steps of a method for characterizing a vessel of a living being.

DETAILED DESCRIPTION OF EMBODIMENTS

Fig. 1 shows schematically and exemplarily an embodiment of a system 1 according to the invention for characterizing a vessel of a living being 2 such as a person or an animal. In this embodiment, the system comprises a radiological imaging unit 3 for acquiring angiographic projection of the vessel structure of interest upon injection of a contrast agent bolus in the targeted vasculature. The radiological imaging unit 3 comprises an x-ray source 31 for emitting x-rays 32 traversing the person 2 lying on the support means 4. The radiological imaging unit 3 further comprises an x-ray detector 33 for detecting the x-rays 32 after having traversed the person 2. The x-ray detector 33 is adapted to generate detection signals being indicative of the detected x-rays 32. The detection signals are transmitted to a fluoroscopy control unit 34, which is adapted to control the x-ray source 31, the x-ray detector 32 and to generate two-dimensional morphological projection information depending on the received detection signals. The injection of the radiological contrast agent bolus in the targeted vasculature is performed with an instrument 5, which may be an interventional catheter. The instrument 5 comprises a lumen extending from the handgrip 51 to the distal tip 52 positioned at the target site for contrast agent bolus injection. Alternatively, the instrument may comprise an opening of the lumen on the sidewall of the elongated body, so that a contrast agent bolus can be injected at a different site in the vessel than where the distal tip 52 is located.

The system further comprises a tracking unit 6 for measuring temporal location information indicative for the location of the instrument in the vasculature of the person 2. Tracking of the temporal location of the instrument may be based on one of an electromagnetic, an optical or an ultrasound principle. Electromagnetic tracking of instruments is based on detection of an electromagnetic field by an electromagnetic sensor. The electromagnetic sensor is typically integrated into the distal tip 52 of the instrument 5, whereas the electromagnetic field generator is placed in the vicinity of the targeted vasculature. The field generator may be movably attached to either the support means 4 of the person 2 or to the radiological imaging unit 3. The tracking unit may be separate from the imaging unit, or it may be integrated into it. The electromagnetic field generator is integral part of the electromagnetic tracking unit 6. Multiple electromagnetic sensors may be integrated into the instrument 5, allowing simultaneous localization of multiple points, and supporting reconstruction of the shape of a segment of the instrument 5 comprising and connecting the localized points.

In an alternative embodiment, the tracking of the temporal location of the instrument is derived from laser radiation. For optical tracking, the instrument comprises multiple optical fibers or a multi-core optical fiber extending from distal end 52 to a proximal portion of the instrument, typically the handgrip 51, where optical connection to the optical tracking unit 6 is facilitated. The optical tracking unit 6 comprises a laser radiation generator configured to transmit laser radiation into at least an optical fiber in the instrument, and an optical detector configured to receive reflections from within the at least an optical fiber. The shape of the at least an optical fiber, hence that of the instrument 5 is derived by processing optical reflection signals from within the optical fibers, received by a detector. The reflections of laser radiation from within the at least an optical fiber are indicative of local strains to which the instrument 5 is exposed in tortuous vessel branch. Shape determination of a medical instrument is described in WO2008131303 A2 with more details. Optical shape sensing makes possible the localization of any points along the at least an optical fiber integrated into the instrument 5 at all instances.

A further alternative location tracking technique of the instrument is based on ultrasound. An ultrasound sensor is integrated into the distal tip 52 of the instrument 5. The ultrasound tracking unit 6 comprises electronics for driving an ultrasound probe which is either directly coupled onto the body of the person 2 or it is mounted onto the support means 4 such that the field of view of the ultrasound probe covers the region of interest of the target vasculature. Upon excitation of the external ultrasound probe with an electric signal, the generated ultrasound signal is transmitted into the body of the person 2 and a portion of the ultrasound signal is received by the ultrasound sensor integrated into the distal tip 52 of the instrument 5. The time of flight of the ultrasound signal is indicative of the position of the distal tip 52 of the instrument with respect to the external ultrasound probe.

A further alternative location tracking technique of the instrument is based on electrical impedance measurement. Electrical signals are sent into the patient by multiple electrically conductive patches distributed onto the body of the person 2. The distal end 52 of the trackable instrument 5 comprising an electrically conductive electrode receives the electrical signals which are transmitted to the tracking unit 6. The electrical impedances derived from the received electrical signals are indicative of the location of the conductive electrode on the distal tip 52 in the region of interest comprising the target vasculature.

The system further comprises an apparatus 7 for characterizing a vessel of a person 2. The apparatus 7 is configured to be coupled to the radiological imaging unit 3 for generating morphological projection information of the vessel. An exemplary two-dimensional angiographic projection 10 is illustrated in Fig. 2, where the vasculature comprises two branches 11 and 12. In the magnified portion 13 of the right vessel branch 12 a first diameter 14 and a second diameter 15 of the vessel are ascertained at two distinct locations 21,22 by measurement of the distance between the two outer borders 16,17 in a perpendicular direction to the center line of the two-dimensional angiographic vessel projection. The two diameters 14,15 correspond to the first and second temporal locations 21,22 of the tracked instrument 5, which are subsequent temporal positions of a point of a moving instrument, like schematically and exemplarily illustrated in Fig. 3. Alternatively, the two distinct positions of the instrument can be two different points of a position tracked instrument that is immobile with respect to the person 2 at the entry site into the vasculature, as illustrated in Fig. 4.

Fig. 3 shows an exemplary embodiment of a three-dimensional morphological vessel model 20 rendered according to the invention based on an angiographic projection 10 and electromagnetic tracking of an instrument 5. The location of the instrument 5 in the vasculature of the person 2 is tracked by sensing the strength of an electromagnetic field with an electromagnetic sensor in the distal tip 52 of the instrument 5. The distal tip 52 is withdrawn in the vessel branch 12 from a position 53 to a position 54. During the withdrawal the location of the distal tip 52 is continuously tracked and the diameters of the vessel branch are determined for all those locations. The registration of the two-dimensional angiographic projection to the location information of the distal tip is simple, since the metallic electromagnetic coil is considerably visible on a real-time x-ray projection after the contrast bolus has been diluted and carried away by the blood stream. An alternative solution is to use radiological marker on the distal tip of the instrument, placed in the transversal cross section through the center point of the integrated electromagnetic sensor coil. Once the temporal location information of the instrument is registered with the temporal location of the instrument in the two-dimensional morphological information of the vessel, the three-dimensional morphological vessel model 20 is generated along withdrawal path of the distal tip 52, extending between positions 53 and 54. Similar approach for construction of the three-dimensional vessel model 20 can be implemented when tracking the distal tip 52 of the instrument 5 based on ultrasound or electrical impedance.

Fig. 4 shows an exemplary embodiment of a three-dimensional morphological vessel model 20 rendered based on an angiographic projection 10 and optical shape tracking of an instrument 5. The shape of the at least an optical fiber integrated in the instrument 5, hence that of the instrument 5, is derived by processing optical reflection signals from within the optical fibers indicative of local strains to which the instrument 5 is exposed in the tortuous vasculature. The position of any points along the optical fiber in the target vasculature up to the position 55 is determined by the optical shape sensing technique at all instances, hence the instrument may be maintained in stationary position with respect to the entry site into the vasculature of the person 2. The registration of the two-dimensional angiographic projection 10 to the location information of the instrument 5 along the vessel branch 12 can be achieved by using radiological markers on the instrument 5. Similar to the optical shape sensing technique, three-dimensional morphological vessel model can be constructed without withdrawing the instrument with respect to the vessel branch 12 by using electromagnetic, ultrasound or electrical impedance based tracking, in case that the instrument 5 comprises multiple electromagnetic sensors, ultrasound sensors or electrodes integrated into the instrument 5 along its elongated body.

In an embodiment, the apparatus may further be configured to detect phase signal from the measurement information received from the tracking unit 6 or from the imaging unit 3, being indicative of motion phases of a periodic movement originating from cardiac and/or respiratory motion. The phase signal of cardiac motion can be derived from electrical information acquired by at least one of an electrode integrated into the instrument 5, or an electrode patch attached to the body of the person 2, which may be having also electrical impedance instrument tracking functionality. Alternatively, the phase signal can be derived from ultrasound measurement information used also for ultrasound based instrument tracking. The cyclical motion creates cyclical interaction of the tracked instrument with the vessel structure, which results in cyclical pattern in the acquired ultrasound information. Similarly, the phase signal can be derived from real-time radiological information acquired by the radiological imaging unit, on the premises that the tracked instrument is detectable by the radiological imaging unit, which is the case when electromagnetic sensor coil or radiological markers are integrated into the instrument. The processor can assign the first and second diameters of the vessel in a three-dimensional morphological model based on gating to the phase of the cyclical cardiac motion. In such way a three-dimensional morphological model is generated for each phase. The three-dimensional morphological models may be displayed on a screen in a consecutive order, corresponding to the respective timing in the cyclical motion.

In an alternative embodiment, the apparatus may further be configured to derive a first and a second diameter for each consecutive phase of the cyclical cardiac motion from the morphological projection 10 information corresponding to a first and a second temporal location 21,22 of the instrument, then to assign the first and second diameters 14,15 of the vessel in a three-dimensional morphological model 20of the vessel at locations defined by the first and second temporal locations 21,22 of the instrument for each consecutive phase of the cyclical cardiac motion.

Fig. 5 shows a schematic and exemplary embodiment of a three-dimensional morphological vessel model 20 with assigned physiological information. A sensor may be integrated into the distal end 52 of the instrument 5, and additional sensors may be integrated into the elongated body of the instrument 5. Typical sensors may be pressure sensors or flow sensors. The measurement information is transmitted to the apparatus 7, where the processor is configured to assign at least a first physiological information 24 to the three-dimensional morphological model 20 of the vessel at the location defined by the first temporal location of the instrument. In an alternative embodiment of the system, the processor is further configured to assign at least a second physiological information 25 to the three-dimensional morphological model 20 of the vessel at a location defined by the second temporal location of the instrument. The assigned physiological information may be quantities as measured, such as blood pressure or blood flow velocity, or they may be physiological information derived from the measurements, which may represent either FFR or blood flow resistance according to:

$$\mathrm{FFR} = \mathrm{P_d}/\mathrm{P_a} \qquad \text{(Eq. 1)}$$

$$\mathrm{P_a} - \mathrm{P_d} = \mathrm{R} \cdot \mathrm{Q} + \mathrm{V} \cdot \mathrm{Q}^2 \qquad \text{(Eq. 2)}$$

where P_d is the blood pressure distal to the first temporal location of the instrument, P_a is the blood pressure proximal to the first temporal location of the instrument, R is the linear blood flow resistance, V is the quadratic blood flow resistance and Q is the volumetric blood flow rate. The parameters of Eq. 2 can be determined by using a lumped component method. The physiological information 24 and 25 may be represented as discrete values on the three-dimensional morphological vessel model 20, or alternatively the vessel model may be color-coded according to a colormap indicative of values of the physiological information. At a specific temporal location of the instrument multiple physiological information may be assigned to the three-dimensional morphological vessel model 20.

A method 100 for characterizing a vessel of a living being is presented schematically in Fig. 6, the method comprising the following steps: 101 introducing a trackable instrument 5 into the vessel, 102 measuring temporal location information of the instrument 5 in the vessel, 103 generating morphological projection 10 information of the vessel, 104 deriving a first and a second diameter of the vessel from the morphological projection 10 information corresponding to a first and a second temporal location of the instrument, and 105 assigning the first and second diameters of the vessel in a three-dimensional morphological model of the vessel at locations defined by the first and second temporal locations of the instrument. The method may additionally comprise the step 106 of rendering a graphical representation of the three-dimensional morphological model 20 with the assigned first and second diameters on a display 71.

In an alternative embodiment of the method 100, the step 104 of deriving the first and second diameters 14,15 and the step 102 of measuring the first and second temporal locations 21,22 of the instrument are performed for consecutive phases of a cyclical motion, and the step 105 of assigning the first and second diameters 14,15 of the vessel in the three-dimensional morphological model 20 of the vessel at locations defined by the first and second temporal locations 21,22 of the instrument is performed for respective consecutive phases of the cyclical motion. Each three-dimensional morphological model 20 based on gating according to different phases of the cyclical cardiac motion and/or respiratory motion may represent a frame, and the frames may be rendered on a display in step 106 in consecutive order corresponding to the respective timing in the cyclical motion, resulting in a movie appearance on the display 71. Such visual representation allows immediate assessment of reactions to various agents, for instance vasodilators for producing hyperemia administered simultaneously with contrast agent bolus.

Although medical device was used in the exemplary description of the invention, that should not be construed as limiting the scope.

Other variations to the disclosed embodiments can be understood and effected by those skilled in the art in practicing the claimed invention, from a study of the drawings, the disclosure, and the appended claims.

A single unit or device may fulfill the functions of several items recited in the claims. The mere fact that certain measures are recited in mutually different dependent claims does not indicate that a combination of these measures cannot be used to advantage.

In the claims, the word "comprising" does not exclude other elements or steps, and the indefinite article "a" or "an" does not exclude a plurality.

Any reference signs in the claims should not be construed as limiting the scope.

CLAIMS:

1. An apparatus (7) for characterizing a vessel of a living being (2), the apparatus comprising:

- a processor for processing measurement information,

wherein the apparatus (7) is configured to be coupled to:

- a tracking unit (6) for measuring temporal location information of a trackable instrument (5) in a vessel,

- an imaging unit (3) for generating morphological projection (10) information of the vessel;

the processor is configured to:

- derive a first diameter (14) of the vessel from the morphological projection (10) information corresponding to a first temporal location (21) of a distal portion of the instrument (5);

characterized in that the processor is further configured to:

derive a second diameter (15) of the vessel from the morphological projection (10) information corresponding to a second temporal location (21) of the distal portion of the instrument (5); and

- assign the first and second diameters (14,15) of the vessel in a three-dimensional morphological model (20) of the vessel at two locations defined by a relative position between the first and second temporal locations (21,22) of the distal portion of the instrument (5).

2. The apparatus (7) according to claim 1, wherein the morphological projection (10) information of the vessel processed by the processor is derived from angiography.

3. The apparatus according to claim 1, wherein the temporal location information of the instrument (5) processed by the processor is derived from electromagnetic signals.

4. The apparatus (7) according to claim 1, wherein the temporal location information of the instrument processed by the processor is derived from laser radiation.

5. The apparatus (7) according to claim 1, wherein the first and second temporal location (21,22) information indicative for the location of the instrument (5) in the vessel originate at same phase of a cyclical cardiac or breathing motion of the living being (2).

6. The apparatus (7) according to any of the claims 1 to 5, wherein the apparatus further comprises a display (71), and the processor is configured to render a graphical representation of the three-dimensional morphological model (20) with the assigned first and second diameters (14,15) on the display.

7. A system (1) for characterizing a vessel of a living being (2), the system comprising:

- an apparatus (7) according to claim 1,
- the trackable instrument (5) for introduction into the vessel of the living being (2),
- the tracking unit (6) for measuring temporal location information of the instrument (5) in the vessel,
- the imaging unit (3) for generating morphological projection (10) information of the vessel.

8. The system (1) according to claim 7,

wherein the trackable instrument (5) comprises a sensor for measuring physiological information, and

wherein the processor is configured to assign at least a first physiological information (24) to the three-dimensional morphological model (20) of the vessel at the location defined by the first temporal location (21) of the instrument (5).

9. The system (1) according to claim 8,

wherein the processor is further configured to assign at least a second physiological information (25) to the three-dimensional morphological model (20) of the vessel at the location defined by the second temporal location (25) of the instrument (5).

10. The system (1) according to any of the claims 8 and 9, wherein the physiological information is at least one of a blood pressure, a blood flow velocity, FFR and

a blood flow resistance.

11. The system (1) according to claim 7, wherein
- the instrument (5) comprises at least an electromagnetic sensor,
- the tracking unit (6) comprises an electromagnetic field generator,
- the imaging unit (3) is a radiological imaging unit.

12. The system (1) according to claim 7, wherein
- the instrument (5) comprises at least an optical fiber
- the tracking unit (6) comprises

  a laser radiation generator configured to transmit laser radiation into the at least an optical fiber in the instrument (5), and

  an optical detector configured to receive reflections from within the at least an optical fiber,
- the imaging unit (3) is a radiological imaging unit.

13. A method (100) for characterizing a vessel of a living being (2), comprising:
- introducing (101) a trackable instrument (5) into the vessel,
- measuring (102) temporal location (21,22) information of the instrument (5) in the vessel,
- generating (103) morphological projection (10) information of the vessel,
- deriving (104) a first diameter (14) of the vessel from the morphological projection (10) information corresponding to a first temporal location (21) of a distal portion of the instrument (5);

characterized in that the method is further comprising:

deriving a second diameter (15) of the vessel from the morphological projection (10) information corresponding to a second temporal location (21) of the distal portion of the instrument (5), and
- assigning (105) the first and second diameters (14,15) of the vessel in a three-dimensional morphological model (20) of the vessel at two locations defined by a relative position between the first and second temporal locations (21,22) of the distal portion of the instrument (5).

14. The method (100) according to claim 13, wherein:

- deriving (104) the first and second diameters (14,15) and measuring (102) the first and second temporal locations (21,22) of the instrument are performed for consecutive phases of a cyclical motion indicative of a cardiac or a breathing motion of the living being (2), and
- assigning (105) the first and second diameters (14,15) of the vessel in the three-dimensional morphological model (20) of the vessel at two locations defined by the relative position between the first and second temporal locations (21,22) of the distal portion of the instrument is performed for respective consecutive phases of the cyclical motion.

15. The method (100) according to claim 13 or 14, further comprising:
- rendering (106) a graphical representation of the three-dimensional morphological model (20) with the assigned first and second diameters (14,15) on a display (71).

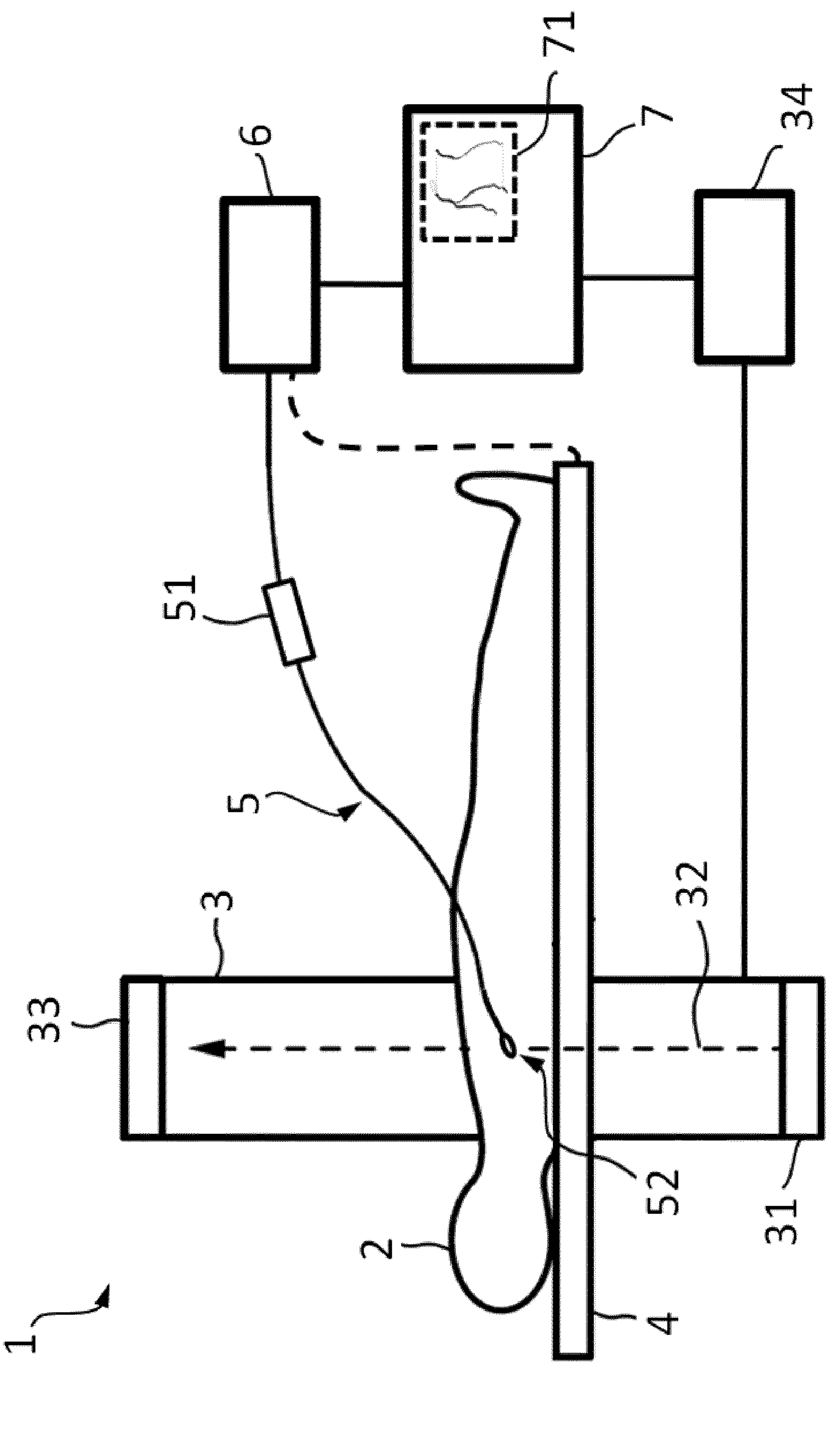

Fig. 1

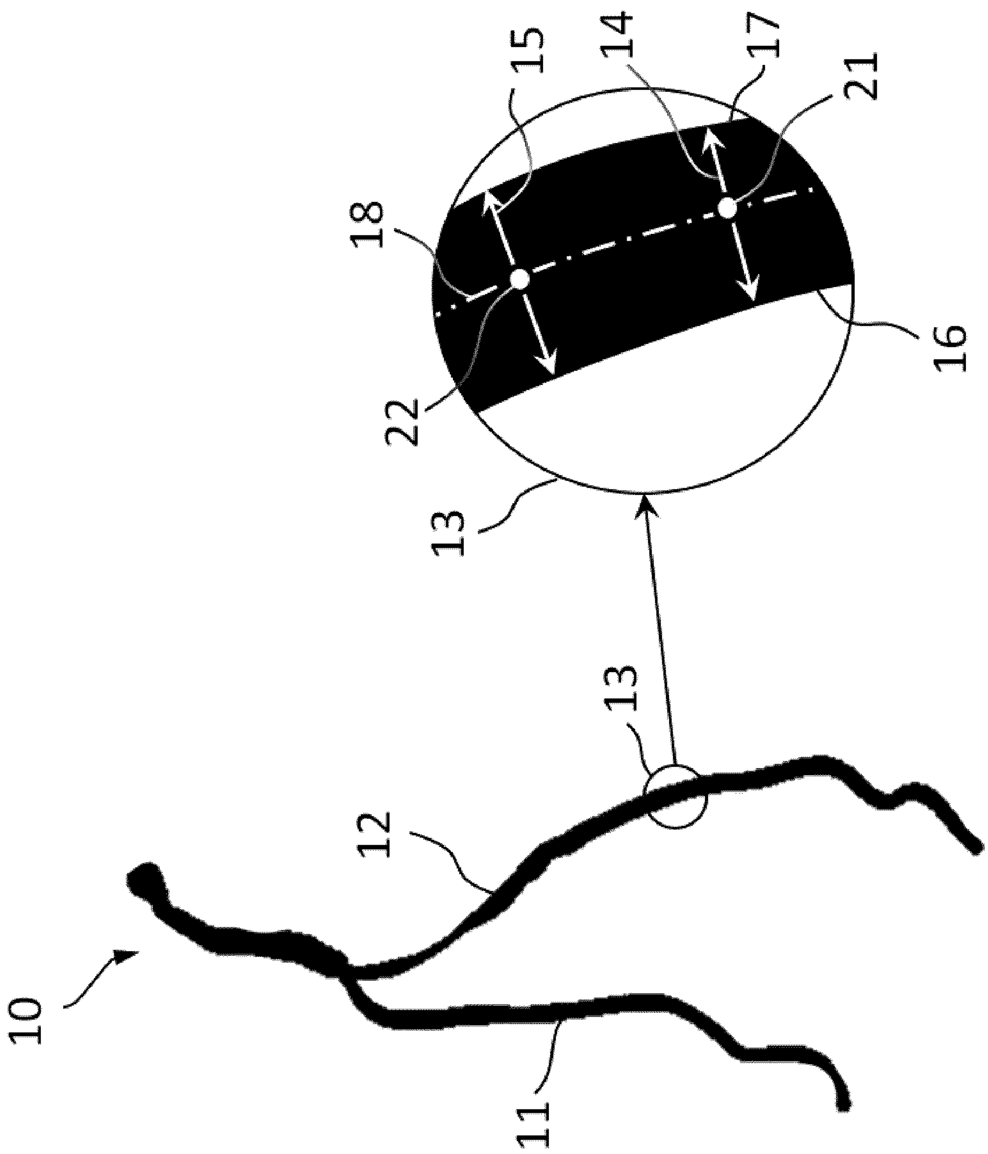

Fig. 2

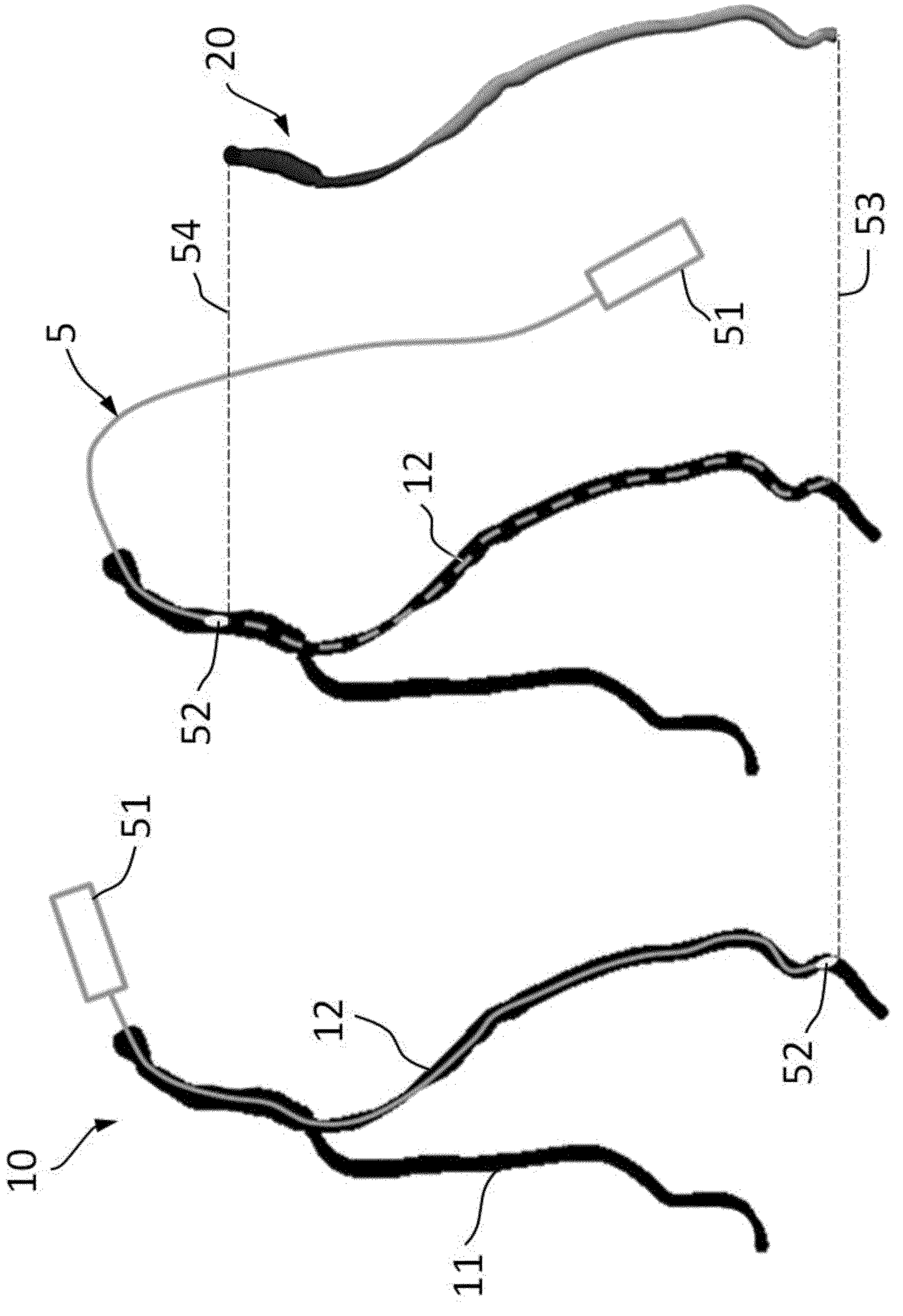

Fig. 3

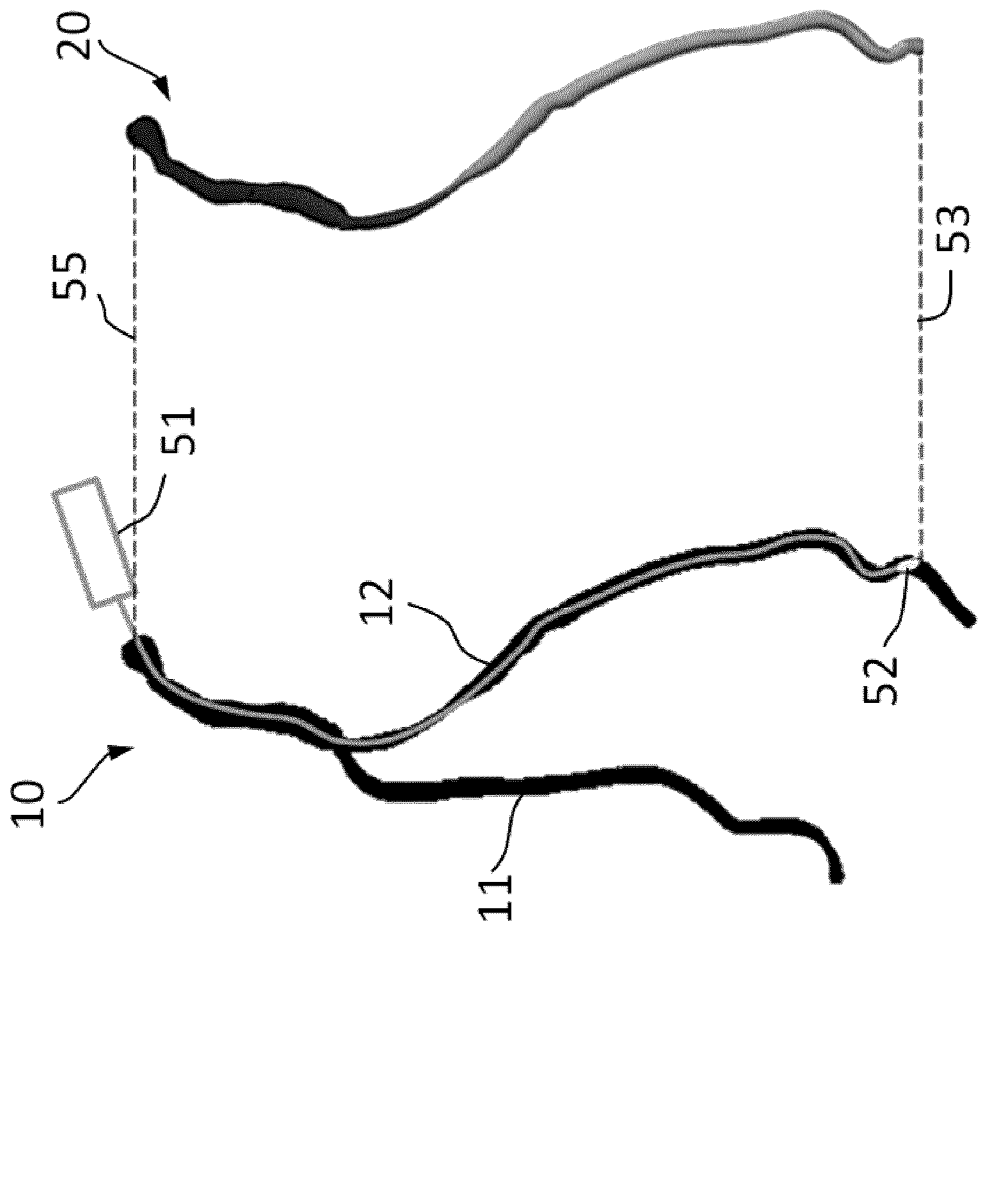

Fig. 4

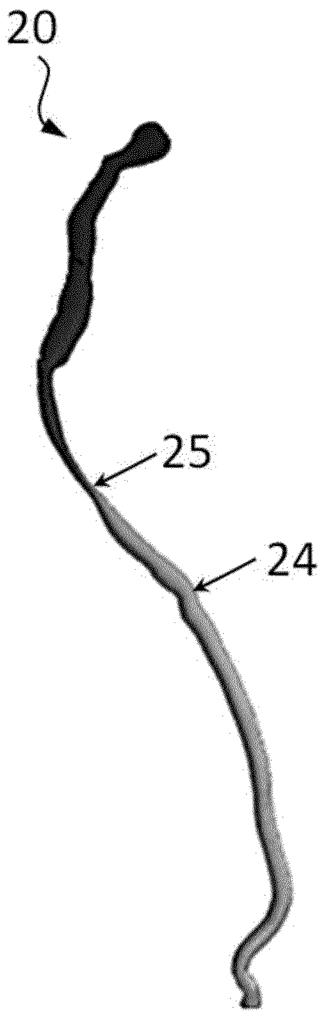

Fig. 5

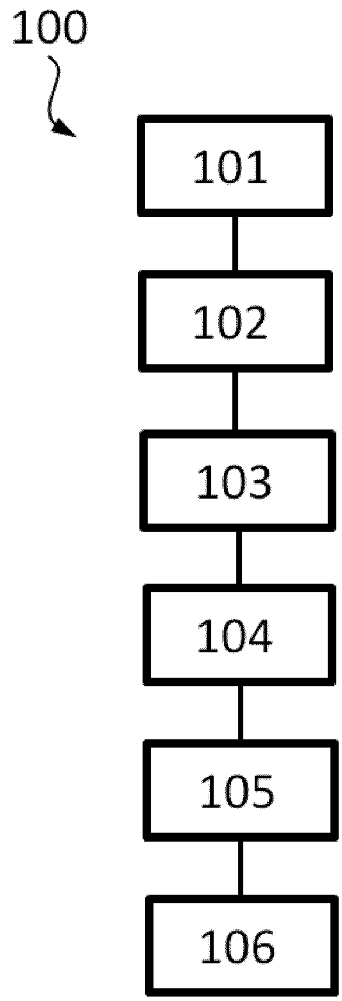

Fig. 6

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2016/071908

A. CLASSIFICATION OF SUBJECT MATTER
INV. A61B6/12 A61B6/00
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)
A61B

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

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

EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X Y	WO 2013/001388 A1 (KONINKL PHILIPS ELECTRONICS NV [NL]; JAIN AMEET KUMAR [US]) 3 January 2013 (2013-01-03) abstract paragraph [0002] - paragraph [0004] paragraph [0029] - paragraph [0032] paragraph [0036] - paragraph [0042] paragraph [0048] - paragraph [0049] figures 4,5 -----	1-7,12 5,8-11
Y	US 2015/161790 A1 (TAKAHASHI AKIHITO [JP] ET AL) 11 June 2015 (2015-06-11) abstract paragraph [0075] - paragraph [0077] paragraph [0084] - paragraph [0085] figure 8 ----- -/--	5,8-10

[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

"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	Date of mailing of the international search report
6 December 2016	16/12/2016

Name and mailing address of the ISA/	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Montes, Pau

1

Form PCT/ISA/210 (second sheet) (April 2005)

International application No
PCT/EP2016/071908

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	WO 2013/024418 A1 (KONINKL PHILIPS ELECTRONICS NV [NL]; MANZKE ROBERT [DE]; CHAN RAYMOND) 21 February 2013 (2013-02-21) abstract page 7, paragraph 3 -----	11

1

INTERNATIONAL SEARCH REPORT

International application No.
PCT/EP2016/071908

Box No. II Observations where certain claims were found unsearchable (Continuation of item 2 of first sheet)

This international search report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. [X] Claims Nos.: 13-15
because they relate to subject matter not required to be searched by this Authority, namely:
see FURTHER INFORMATION sheet PCT/ISA/210

2. [ ] Claims Nos.:
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:

3. [ ] Claims Nos.:
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box No. III Observations where unity of invention is lacking (Continuation of item 3 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

1. [ ] As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.

2. [ ] As all searchable claims could be searched without effort justifying an additional fees, this Authority did not invite payment of additional fees.

3. [ ] As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:

4. [ ] No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

Remark on Protest

[ ] The additional search fees were accompanied by the applicant's protest and, where applicable, the payment of a protest fee.

[ ] The additional search fees were accompanied by the applicant's protest but the applicable protest fee was not paid within the time limit specified in the invitation.

[ ] No protest accompanied the payment of additional search fees.

FURTHER INFORMATION CONTINUED FROM PCT/ISA/ 210

Continuation of Box II.1

Claims Nos.: 13-15

Claim 13 is directed to a method for characterizing a vessel of a living being which includes the step of introducing a trackable instrument into the vessel and implicitly requires moving said instrument along the vessel. Introducing into and moving an instrument along a vessel is a procedure carried out under supervision of specialised personnel. Although currently this procedure is carried out on a regular basis in radiology units of hospitals all over the world, it cannot be considered to be a safe routine technique. Indeed, said step is rather a physical intervention which involves a health risk for the patient even when carried out with the required medical professional care and expertise and is therefore of surgical nature. A method which comprises or encompasses a step of surgical nature is considered to be a method of treatment of the human or animal body by surgery. As a consequence, the methods defined in claims 13-15 fall under the provisions of Art. 17(2)(a)(i) and R. 39.1(iv) PCT .

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/EP2016/071908

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
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		EP 2723240 A1	30-04-2014
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		RU 2014110007 A	27-09-2015
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