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(54) **HYDRAULICALLY-POWERED SYSTEM AND METHOD FOR ACHIEVING MAGNETIC RESONANCE ELASTOGRAPHY**

HYDRAULISCH ANGETRIEBENES SYSTEM UND VERFAHREN ZUR ERZIELUNG VON MAGNETRESONANZELASTOGRAFIE

SYSTÈME HYDRAULIQUE ET PROCÉDÉ POUR EFFECTUER UNE ÉLASTOGRAPHIE PAR RÉSONANCE MAGNÉTIQUE

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Description

BACKGROUND

[0001] Embodiments of the invention relate to a non-invasive medical imaging technique, such as magnetic resonance elastography ("MRE"), used in radiology to measure stiffness of soft tissues.

[0002] Current MRE technology uses an acoustic driver system, developed by radiology researchers at Mayo Clinic. Current MRE technology, however, is limited to low frequency vibrations (e.g., 100 Hz or less) because it is based on pneumatic actuation. The wavelengths from the low frequency vibrations are smaller than the dimensions of the liver. Therefore, current pneumatic systems can be used to generate stable stiffness maps for the liver, which can be used to diagnose liver diseases, such as liver fibrosis. However, the wavelengths from the lower frequency vibrations are longer than the dimensions of other organs. As a result, current pneumatic systems generating low frequency vibrations cannot be used to generate stable stiffness maps for many organs such as the heart, prostate, pancreas, spleen, eye, etc. This is because the current inversion (a mathematical process to convert wave images to a stiffness map) strategies assume that the waves are propagating in a uniform infinite medium (i.e. the wavelengths are smaller compared to the dimensions of the organs of interest).

[0003] US 2009/0209847 discloses a hydraulic MRE system, comprising a passive actuator which induces tissue vibration through an oscillating membrane. Since, in this set-up, the cuboidal passive actuator consists of only one oscillating surface, the application is rather limited and the handling is complex.

[0004] Furthermore, since the oscillation also means a significant volume change, this can lead to unfavorable effects on the contacted tissue.

[0005] US 005540052 describes a hydraulically-driven actuator in a piston-cylinder design in a usage as a common linear mechanical motor.

SUMMARY

[0006] Therefore, embodiments of the invention provide a hydraulically-powered magnetic resonance elastography ("MRE") vibration device used in conjunction with a magnetic resonance imaging ("MRI") scanner that uses an inversion to generate stable stiffness maps for various organs. The vibration device generates high frequency vibrations, up to approximately 1000 Hz, which non-invasively penetrate deeper into tissue than current MRE technology to identify a disease and diagnose the state of the disease for various organs of a human or an animal body.

[0007] In an embodiment, it is provided a system for inducing tissue vibration for magnetic resonance elastography. The system includes a passive actuator component, a first hose, a second hose, and a driving component. The passive actuator component is positionable proximate to a target tissue and includes a linearly movable piston assembly enclosed in a housing. The first hose is coupled to the passive actuator component on a first side of the piston assembly and the second hose is coupled to the passive actuator component on the opposite side of the piston assembly. The driving component includes a fluid pumping system and is configured to alternatingly pump a fluid through the first hose and through the second hose. When fluid is pumped through the first hose, the piston assembly moves in a first linear direction and, when fluid is pumped through the second hose, the piston assembly moves in the opposite direction. The alternating linear movement of the piston assembly induces vibration in the target tissue.

[0008] In another embodiment, it is provided a method of performing magnetic resonance elastography. A passive actuator component is positioned proximate to a target tissue on a patient. The passive actuator includes a linearly movable piston assembly. A fluid is then pumping alternatingly from a driving component through a first hose and a second hose. The first hose is coupled to the passive actuator component on a first side of the piston assembly such that pumping the fluid through the first hose causes the piston assembly to move in a first linear direction. The second hose is coupled to the passive actuator component on a second side of the piston assembly (opposite the first side) such that pumping the fluid through the second hose causes the piston assembly to move in a direction opposite the first linear direction. The alternating linear movement of the piston assembly induces a vibration in the target tissue. MRI data of the target tissue is acquired while the vibration is induced and a stiffness map of the tissue is generated based on the acquired MRI data.

The invention being defined by appended claims 1-15.

BRIEF DESCRIPTION OF THE DRAWINGS

[0009]

FIG. 1 is an illustration of a hydraulically-powered system used in conjunction with a magnetic resonance imaging ("MRI") device.

FIG. 2 is a schematic illustration of the system of FIG. 1 including a driving component, an application component, and a plurality of hoses connecting the components.

FIG. 3 is a schematic illustration of the driving component of FIG. 2 interfacing with the MRI device.

DETAILED DESCRIPTION

[0010] Before any embodiments of the invention are explained in detail, it is to be understood that the invention is not limited in its application to the details of construction

and the arrangement of components set forth in the following description or illustrated in the following drawings. The invention is capable of other embodiments and of being practiced or of being carried out in various ways.

[0011] FIG. 1 illustrates an example of a hydraulically-powered magnetic resonance elastography ("MRE") system including an application component 101, a driving component 103, and a plurality of hoses 105, 107, 109 connecting the application component 101 to the driving component 103. When a patient is placed in an MRI environment 111, the application component 101 (also referred to as a passive driver, a passive device, or a passive actuator) is adhered to the surface of a patient's body and generates vibrations perpendicular to the tissue surface or shear vibrations along the tissue surface. To prevent interference with the MRI system, the passive driver 101 is constructed of non-metallic/MR compatible components. However, in some constructions, the passive driver 101 includes a limited number of non-ferromagnetic metallic components.

[0012] The driving component 103 (also referred to as an active driver) includes pump mechanisms for driving the hydraulic system. As some of these components may be constructed of metal (including ferromagnetic metals), the driving component 103 is positioned outside of the MRI environment/scanning room. As described in detail below, the driving component 103 operates a hydraulic pumping system to control the frequency, displacement amplitude, and phase of the passive driver 101.

[0013] The system of FIG. 1 undergoes a three-stage process to produce spatial stiffness maps that estimates stiffness of biological tissues. First, the application component 101 is adhered to the surface of a human body and the driving component 103 causes the application component 101 to vibrate thereby inducing vibration of the biological tissues under study at a controlled frequency, amplitude, and phase. The MRI scanning system 111 is then used to capture data indicative of the transmitted waves in the region of interest ("ROI"). The wave/vibration data captured by the MRI scanning system 111 is then converted to spatial stiffness maps using a mathematical process called inversion. As described further below, the operation of the driving component 103 is coordinated with the phase of the MRI signal of the MRI scanning system 111. For example, the phase of the tissue vibration is synchronized with the phase of the MRI device to obtain optimal imaging. In some constructions, the MRE system can be used to control when to start imaging with the MRI scanner or vice-versa.

[0014] FIG. 2 illustrates the operational components of the hydraulically powered-vibration system in further detail. The driving component 103 includes at least one pump 201 or a combination of a pump and a valve system to provide flow and pressure of a liquid through the plurality of hoses 105, 107, 109 connected to the passive driver 101. The fluid pumped by the driving component 103 into the passive driver 101 causes a piston 203 to move back and forth periodically to induce vibration of the passive driver 101. The pump 201 of the driving component 103 forces fluid into the passive driver 101 through a first hose 105. The increased pressure on one side of the piston 203 causes the piston to move in a first direction (downward in the example of Fig. 2). At the same time, the fluid pump system 201 of the driving component 103 allows fluid on the opposite side of the piston 203 to drain through the second hose 109 as the piston moves.

[0015] The passive driver 101 is equipped with a fiber-optic displacement transducer 205 that measures the position of the piston 203 and provides feedback to the processing unit 207 of the driving component 103. Once the piston 203 reaches a defined displacement, the fluid pump system 201 forces fluid into the passive driver 101 through the second hose 109 and allows fluid to drain through the first hose 105. As a result, the piston 203 is moved in the opposite direction (upward in the example of Fig. 2). Although the example of Fig. 2 includes a displacement sensor 205 that is used to control the operation of the fluid pump system 201, other constructions can utilize other types of sensors to control the operation of the fluid pump system 201. For example, a pressure transducer can be configured to measure the difference in pressure between the first hose 105 and the second hose 109. The fluid pumping system 201 would then be controlled based on these measurements.

[0016] The processing unit 207 of the driving component 103 controls the amplitude of the vibration induced through the passive driver 101 by monitoring the displacement of the piston 203 and causing the fluid pump system 201 to reverse the direction of piston movement when a desired amplitude is reached. The frequency of the vibration is controlled by regulating the speed at which the fluid pump 201 forces the liquid into the passive driver 101.

[0017] In some embodiments, the fluid pump system 201 of the driving component 103 includes a conventional hydraulic pump that provides consistent flow and pressure to a four-way electro-hydraulic servo valve ("EHSV") to generate a controlled displacement waveform at the application component 101. The valve is electronically controlled by the processing unit to open in alternating directions of flow to send pressurized hydraulic fluid through either the first hose 105 or the second hose 109 to either side of the piston. In some embodiments, the EHSV includes a conventional nozzle flapper-type electro-hydraulic servo valve. In other constructions, the valve is a voice-coil system. A conventional pump that supplies consistent flow and pressure to piezoelectric liquid valves or a modified pump that supplies timed pulses of flow can also be used to generate a controlled displacement waveform at the application component.

[0018] As discussed above, the application component 103, shown in FIG. 2, converts supplied hydraulic flow and pressure into displacement of a moveable surface to cause tissue vibration. The application component may take on various embodiments based on established

technologies known to those skilled in the art. These include axial hydraulic actuators, such as a cylinder-piston-rod assembly, or chamber-diaphragm-rod assembly types. Other means of actuation, such as rotary actuators or hydraulic motors, could also be used to devise other embodiments of the application component. In the embodiment shown in FIG. 2, the application component comprises a cylinder with a piston and double-rod assembly. The rod is driven under hydraulic power by the piston such that it reciprocates in a fully-reversed linear motion. The rod, in turn, drives the part of the application component that articulates with the patient to generate a vibrational effect at the surface of the patient's body. It should be clear to those familiar with hydraulic technologies and skilled in the art that this vibrational effect could be generated by hydraulic devices of various constructions and designs. As noted above, the application component 101 in this example is non-metallic (e.g., includes plastic components), which makes it MR compatible. However, in some embodiments, the application component 101 includes at least some metallic components.

[0019] As described above, a plurality of hoses distributes a non-compressible liquid between the passive actuator 101 and the driving component 103. Pressurized hydraulic fluid supplied at the first hose 105 moves the piston and rod assembly 203 in the first direction (e.g., downward). Pressurized hydraulic fluid supplied at the second hose 109 moves the piston and rod assembly 203 in the opposite direction (e.g., upward). This motion is transferred to the surface of the passive actuator 101 to generate tissue vibrations. A third hose 107 is a low pressure return hose that allows leakage flow to return to a fluid reservoir of the driving component 103. The return hose 107 bleeds air from the lines and the cylinder internal volumes.

[0020] By using a virtually incompressible media (e.g., liquid) to drive the passive actuator 101, the hydraulically-powered system provides many advantages over pneumatic means of generating tissue vibration. For example, pneumatic systems are limited by gas (e.g., air) compliance to a frequency on an order of 100 Hz or less. This frequency limitation limits the resolution of the MRE to the imaging of smaller tissue structures. A liquid fluid means of driving the application head does not have this limitation as the media used to convey flow and pressure has negligible compliance. Therefore, higher transmitted frequencies are possible using the hydraulically-powered vibration device.

[0021] In addition, because of the virtual incompressibility of liquids, the performance of the system using the hydraulically-powered vibration device can be predicted with sufficient accuracy to allow the phase of the tissue vibrations to be adjusted to the phase of the applied MRI, which provides optimal imaging. The use of virtually incompressible media also makes it possible to generate higher forces that overcome attenuation of the transmitted energy, which results in the delivery of higher energies to the tissue of interest. Furthermore, because higher power can be transmitted by liquid fluidic means, flexibility in the design of the passive actuator 101 is accommodated. In particular, passive actuators can be implemented that transmit either longitudinal vibrations (i.e., perpendicular to the tissue surface) or shear vibrations (i.e., along the tissue surface). In general, the hydraulically-powered vibration device provides higher-frequency, phase-tuned tissue vibration that provides not only greater imaging resolution due to higher frequency vibration but also better clarity due to phase control.

[0022] In some embodiments, the fluid used in the vibration device can be doped with a contrast agent (e.g., super paramagnetic iron oxide) to suppress a signal provided by the fluid in the MRI scanner that can create possible artifacts in the resulting images. Similarly, the field of view can be limited by avoiding the driver or saturation bands that dephase the signal from the fluid to prevent these artifacts. Also, in some embodiments, the passive actuator can be flexible, and can be properly sealed to prevent any fluid leaks.

[0023] To further optimize the quality of vibration data acquired by the MRI scanning system 111, the driving component 103 is configured to communication (bidirectional or unidirectional) with the controller of the MRI scanning system 111 as illustrated in Fig. 3. The driving component 103 includes a processing unit (such as a microcontroller) and a memory storing executable instructions and data that, when executed by the processing unit, cause the driving component to operate the fluid pump system and communicate with the MRI scanning system 111. The MRI scanning system also includes a processing unit 303 and a memory 305.

[0024] The communication between the driving component 103 and the MRI scanning system 111 allows the vibration to be coordinated with and paced by the pulse sequencing of the MRI scanning system 111 or vice versa. As discussed above, the frequency and amplitude of the induced tissue vibration can be controlled by adjusting the speed at which fluid is pumped into the passive actuator 101 and the desired displacement of the piston and rod assembly 203, respectively. Conversely, in some constructions, the pulse sequencing of the MRI system 111 is controlled based on the frequency and amplitude of the vibrations caused by the driving component 103.

[0025] Thus, the invention provides, among other things, a hydraulic system for inducing vibrations in target tissue so that spatial stiffness maps can be generated using magnetic resonance elastography. Various features and advantages of the invention are set forth in the following claims.

Claims

1. A system for inducing tissue vibration for magnetic resonance elastography, the system comprising:

   a passive actuator (101) positionable proximate

to a target tissue, the passive actuator (101) including a linearly movable piston assembly (203) enclosed in a housing such that alternating linear movement of the linearly movable piston (203) causes vibration of the passive actuator (101) and induces vibration of the target tissue when the passive actuator (101) is positioned proximate to the target tissue;
a first hose (105) coupled to the passive actuator (101) on a first side of the piston assembly (203);
a second hose (109) coupled to the passive actuator (101) on a second side of the piston assembly (203) opposite the first side; and
a driving component (103) including a fluid pump (201), the driving component (103) configured to alternatingly pump a fluid through the first hose (105) causing the piston assembly (203) to move in a first linear direction and pump the fluid through the second hose (109) causing the piston assembly (203) to move in a second linear direction, the second linear direction being opposite the first linear direction.

2. The system of claim 1, wherein the driving component (103) is further configured to
passively allow fluid to drain from the passive actuator (101) through the second hose (109) when fluid is being pumped to the passive actuator through the first hose (105), and
passively allow fluid to drain from the passive actuator (101) through the first hose (105) when fluid is being pumped to the passive actuator through the second hose (109).

3. The system of any of the preceding claims, wherein the passive actuator (101) is constructed of only non-ferromagnetic component such that it is positionable within an MRI environment (111) and wherein the driving component is configured to be positioned outside of the MRI environment (111) during use.

4. The system of any of the preceding claims, wherein the driving component (103) is further configured to adjust a frequency of the induced tissue vibration by increasing a speed at which the fluid is pumped to the passive actuator (101) through the first hose (105) and the second hose (109), and
adjust an amplitude of the induced tissue vibration by increasing the displacement of the piston assembly (203).

5. The system of any of the preceding claims, wherein the passive actuator (101) further includes a displacement sensor (205) configured to provide a signal to the driving component (103) indicative of a linear position of the piston assembly (203), and wherein the driving component (103) is configured to switch from pumping the fluid through the first hose (105) to pumping the fluid through the second hose (109) when the signal from the displacement sensor (205) indicates that the linear position of the piston assembly (203) in the first linear direction meets or exceeds a displacement threshold, and
switch from pumping the fluid through the second hose (109) to pumping the fluid through the first hose (105) when the signal from the displacement sensor (205) indicates that the linear position of the piston assembly (203) in the second linear direction meets or exceeds the displacement threshold.

6. The system of any of the claims 1 to 4, further comprising a fluid pressure sensor configured to measure fluid pressure in the first hose (105) and fluid pressure in the second hose (109) and transmit a signal to the driving component (103) indicative of the fluid pressure in the first hose (105) and the fluid pressure in the second hose (109), wherein the fluid pressure is indicative of the displacement of the piston assembly (203) in the passive actuator (101), and wherein the driving component (103) is further configured to
switch from pumping the fluid through the first hose (105) to pumping the fluid through the second hose (109) when the signal from the fluid pressure sensor indicates that the fluid pressure in the first hose (105) meets or exceeds the fluid pressure in the second hose (109) by a defined displacement threshold, and
switch from pumping the fluid through the second hose (109) to pumping the fluid through the first hose (105) when the signal from the fluid pressure sensor indicates that the fluid pressure in the second hose (109) meets or exceeds the fluid pressure in the first hose (105) by the defined displacement threshold.

7. The system of any of the preceding claims, wherein the driving component (103) is further configured to electronically receive a message from an MRI scanning system (111) indicative of a desired change in at least one of an amplitude and a frequency of the vibration induced by the passive actuator (101), wherein the message is based on image data acquired by the MRI scanning system (111), and
adjust at least one of the frequency and the amplitude of the induced tissue vibration by the driving component (103) to synchronize to the encoding gradients of the MRI scanning system (111), wherein the driving component (103) is configured to adjust the frequency of the induced tissue vibration by increasing the frequency at which the valve shifts to alternate the supply of pressurized fluid to the respective sides of the piston assembly (203) of the passive actuator (101), and wherein the driving component (103) is configured to adjust the amplitude of the induced tissue vibration by adjusting a maximum displacement of the piston assembly (203).

8. The system of any of the preceding claims, wherein the driving component (103) is further configured to electronically receive a message from an MRI scanning system (111) indicating when the induced tissue vibration should begin, and
begin inducing the tissue vibration according to the message from the MRI scanning system (111).

9. The system of any of the claims 1 to 7, wherein the driving component (103) is further configured to electronically transmit a message to the MRI scanning system (111) indicating when the MRI scanning system (111) is to begin acquiring data, wherein the message is based on the induced tissue vibration.

10. The system of any of the preceding claims, wherein the first linear direction is perpendicular to a skin surface of the patient, and wherein the induced vibration is a longitudinal vibration.

11. The system of any of the claims 1 to 9, wherein the first linear direction is parallel to a skin surface of the patient, and wherein the induced vibration is a sheer vibration.

12. A method of performing magnetic resonance elastography, the method comprising:

positioning a passive actuator (101) proximate to a target tissue on a patient, the passive actuator (101) including a linearly movable piston assembly (203) enclosed in a housing;
alternatingly pumping a fluid from a driving component (103) through a first hose (105), the first hose (105) being coupled to the passive actuator (101) on a first side of the piston assembly (203), wherein pumping the fluid through the first hose (105) causes the piston assembly (203) to move in a first linear direction, and pumping a fluid from the driving component (103) through a second hose (109), the second hose (109) being coupled to the passive actuator (101) on a second side of the piston assembly (203) opposite the first side, wherein pumping the fluid through the second hose (109) causes the piston assembly (203) to move in a second linear direction opposite the first linear direction, and wherein the linear movement of the piston assembly (203) alternatingly in the first linear direction and the second linear direction causes vibration of the passive actuator (101) and induces vibration in the target tissue; and
acquiring MRI data of the target tissue while vibration of the target tissue is induced; and
generating a stiffness map of the tissue based on the acquired MRI data.

13. The method of claim 12, further comprising:

generating a phase image of the vibration of the tissue based on the MRI data; and
generating a stiffness map by performing an inversion on the phase image MRI data.

14. The method of any of the claims 12 or 13, further comprising regulating the amplitude and frequency of the vibration induced in the target tissue by regulating a displacement of the piston assembly (203) and a frequency at which pump flow is alternately diverted to the respective supply hoses of the passive actuator (101).

15. The method of any of the claims 12 to 14, wherein the act of alternatingly pumping a fluid from a driving component (103) further includes:

receiving a signal from a displacement sensor (205) indicative of the linear displacement of the piston assembly (203),
switching from pumping the fluid through the first hose (105) to pumping the fluid through the second hose (109) when the signal from the displacement sensor (205) indicates that the linear displacement of the piston assembly (203) in the first linear direction meets or exceeds a displacement threshold, and
switching from pumping the fluid through the second hose (109) to pumping the fluid through the first hose (105) when the signal from the displacement sensor (205) indicates that the linear displacement of the piston assembly (203) in the second linear direction meets or exceeds the displacement threshold.

Patentansprüche

1. System zum Anregen von Gewebeschwingung zur Magnetresonanzelastographie, wobei das System umfasst:

einen unmittelbar an einem Zielgewebe positionierbaren passiven Aktuator (101), wobei der passive Aktuator (101) eine linear bewegbare Kolbenanordnung (203) umfasst, die so in einem Gehäuse eingeschlossen ist, dass eine alternierende lineare Bewegung des linear bewegbaren Kolbens (203) eine Schwingung des passiven Aktuators (101) verursacht und eine Schwingung des Zielgewebes anregt wenn der passive Aktuator (101) unmittelbar an dem Zielgewebe positioniert wird;
einen ersten Schlauch (105), der mit dem passiven Aktuator (101) an einer ersten Seite der Kolbenanordnung (203) verbunden ist;
einen zweiten Schlauch (109), der mit dem passiven Aktuator (101) an einer zweiten Seite der

Kolbenanordnung (203), gegenüberliegend der ersten Seite, verbunden ist; und
eine Antriebskomponente (103) mit einer Flüssigkeitspumpe (201), wobei die Antriebskomponente (103) dazu konfiguriert ist, abwechselnd eine Flüssigkeit durch den ersten Schlauch (105) zu pumpen und damit die Kolbenanordnung (203) zu veranlassen sich in eine erste lineare Richtung zu bewegen, und durch den zweiten Schlauch (109) zu pumpen und damit die Kolbenanordnung (203) zu veranlassen sich in eine zweite lineare Richtung zu bewegen, wobei die zweite lineare Richtung entgegengesetzt der ersten linearen Richtung ist.

2. System nach Anspruch 1, wobei die Antriebskomponente (103) weiter dazu konfiguriert ist
passiv Flüssigkeit zu erlauben von dem passiven Aktuator (101) durch den zweiten Schlauch (109) abzufließen, wenn Flüssigkeit durch den ersten Schlauch (105) zu dem passiven Aktuator gepumpt wird, und
passiv Flüssigkeit zu erlauben von dem passiven Aktuator (101) durch den ersten Schlauch (105) abzufließen, wenn Flüssigkeit durch den zweiten Schlauch (109) zu dem passiven Aktuator gepumpt wird.

3. System nach einem der vorangegangenen Ansprüche, wobei der passive Aktuator (101) ausschließlich aus nicht-ferromagnetischen Komponenten gefertigt ist, so dass er innerhalb einer MRI-Umgebung (111) positionierbar ist und wobei die Antriebskomponente dazu konfiguriert ist während des Betriebs außerhalb der MRI-Umgebung (111) positioniert zu sein.

4. System nach einem der vorangegangenen Ansprüche, wobei die Antriebskomponente (103) weiter dazu konfiguriert ist
eine Frequenz der angeregten Gewebeschwingung durch Erhöhen einer Geschwindigkeit, mit der die Flüssigkeit durch den ersten Schlauch (105) und den zweiten Schlauch (109) zu dem passiven Aktuator (101) gepumpt wird, einzustellen, und
eine Amplitude der angeregten Gewebeschwingung durch Erhöhen der Auslenkung der Kolbenanordnung (203) einzustellen.

5. System nach einem der vorangegangenen Ansprüche, wobei der passive Aktuator (101) weiter einen Auslenkungssensor (205) umfasst, der dazu konfiguriert ist, ein Signal an die Antriebskomponente (103) zu liefern, welches eine lineare Position der Kolbenanordnung (203) anzeigt, und wobei die Antriebskomponente (103) dazu konfiguriert ist,
von Pumpen der Flüssigkeit durch den ersten Schlauch (105) zu Pumpen der Flüssigkeit durch den zweiten Schlauch (109) umzuschalten, wenn das Signal des Auslenkungssensors (205) anzeigt, dass die lineare Position der Kolbenanordnung (203) in der ersten linearen Richtung einem Auslenkungsgrenzwert entspricht oder diesen übertrifft, und
von Pumpen der Flüssigkeit durch den zweiten Schlauch (109) zu Pumpen der Flüssigkeit durch den ersten Schlauch (105) umzuschalten, wenn das Signal des Auslenkungssensors (205) anzeigt, dass die lineare Position der Kolbenanordnung (203) in der zweiten linearen Richtung dem Auslenkungsgrenzwert entspricht oder diesen übertrifft.

6. System nach einem der Ansprüche 1 bis 4, das weiter einen Flüssigkeitsdrucksensor umfasst, der dazu konfiguriert ist, einen Flüssigkeitsdruck in dem ersten Schlauch (105) und einen Flüssigkeitsdruck in dem zweiten Schlauch (109) zu messen und ein Signal an die Antriebskomponente (103) zu senden, das den Flüssigkeitsdruck in dem ersten Schlauch (105) und den Flüssigkeitsdruck in dem zweiten Schlauch (109) angibt, wobei der Flüssigkeitsdruck die Auslenkung der Kolbenanordnung (203) in dem passiven Aktuator (101) anzeigt, und wobei die Antriebskomponente (103) weiter dazu konfiguriert ist
von Pumpen der Flüssigkeit durch den ersten Schlauch (105) zu Pumpen der Flüssigkeit durch den zweiten Schlauch (109) umzuschalten, wenn das Signal des Flüssigkeitsdrucksensors anzeigt, dass bei einem definierten Auslenkungsgrenzwert der Flüssigkeitsdruck in dem ersten Schlauch (105) einem Flüssigkeitsdruck in dem zweiten Schlauch (109) entspricht oder diesen übertrifft, und
von Pumpen der Flüssigkeit durch den zweiten Schlauch (109) zu Pumpen der Flüssigkeit durch den ersten Schlauch (105) umzuschalten, wenn das Signal des Flüssigkeitsdrucksensors anzeigt, dass bei dem definierten Auslenkungsgrenzwert der Flüssigkeitsdruck in dem zweiten Schlauch (109) einem Flüssigkeitsdruck in dem ersten Schlauch (105) entspricht oder diesen übertrifft.

7. System nach einem der vorangegangenen Ansprüche, wobei die Antriebskomponente (103) weiter dazu konfiguriert ist
elektronisch eine Meldung von einem MRI-Scanner-System (111) zu erhalten, welche eine gewünschte Änderung einer Amplitude und/oder einer Frequenz der von dem passiven Aktuator (101) angeregten Schwingung angibt, wobei die Meldung auf von dem MRI-Scanner-System gewonnenen Bilddaten basiert, und
die Frequenz und/oder die Amplitude der von der Antriebskomponente (103) angeregten Gewebeschwingung einzustellen, um diese mit den Kodiergradienten des MRI-Scanner-Systems zu synchronisieren, wobei die Antriebskomponente (103) dazu konfiguriert ist die Frequenz der angeregten Gewe-

beschwingung einzustellen, indem sie die Frequenz, mit der das Ventil schaltet um die entsprechenden Seiten der Kolbenanordnung (203) des passiven Aktuators (101), welche mit unter Druck stehender Flüssigkeit versorgt werden, zu ändern, und wobei die Antriebskomponente (103) dazu konfiguriert ist, die Amplitude der angeregten Gewebeschwingung durch Einstellen der maximalen Auslenkung der Kolbenanordnung (203) zu ändern.

8. System nach einem der vorangegangenen Ansprüche, wobei die Antriebskomponente (103) weiter dazu konfiguriert ist,
elektronisch eine Meldung, die angibt wann die angeregte Gewebeschwingung beginnen soll, von einem MRI-Scanner-System (111) zu empfangen, und entsprechend der Meldung des MRI-Scanner-Systems (111) zu beginnen, die Gewebeschwingung anzuregen.

9. System nach einem der Ansprüche 1 bis 7, wobei die Antriebskomponente (103) weiter dazu konfiguriert ist, elektronisch eine Meldung an das MRI-Scanner-System (111) zu übertragen, die angibt wann das MRI-Scanner-System (111) starten soll Daten aufzunehmen, wobei die Meldung auf der angeregten Gewebeschwingung basiert.

10. System nach einem der vorangegangenen Ansprüche, wobei die erste lineare Richtung senkrecht zu einer Hautoberfläche eines Patienten ist, und wobei die angeregte Gewebeschwingung eine longitudinale Schwingung ist.

11. System nach einem der Ansprüche 1 bis 9, wobei die erste lineare Richtung parallel zu einer Hautoberfläche eines Patienten ist, und wobei die angeregte Gewebeschwingung eine Scherschwingung ist.

12. Methode zum Durchführen einer Magnetresonanzelastographie, wobei die Methode umfasst:

Positionieren eines passiven Aktuators (101) unmittelbar an einem Zielgewebe eines Patienten, wobei der passive Aktuator (101) eine in einem Gehäuse eingeschlossene linear bewegbare Kolbenanordnung (203) umfasst;
abwechselndes Pumpen einer Flüssigkeit von einer Antriebskomponente (103) durch einen ersten Schlauch (105), wobei der erste Schlauch (105) an einer ersten Seite der Kolbenanordnung (203) mit dem passiven Aktuator (101) verbunden ist, wobei das Pumpen der Flüssigkeit durch den ersten Schlauch (105) die Kolbenanordnung (203) in eine erste lineare Richtung bewegt, und Pumpen einer Flüssigkeit von der Antriebskomponente (103) durch den zweiten Schlauch (109), wobei der zweite Schlauch (109) an einer zweiten Seite der Kolbenanordnung (203) mit dem passiven Aktuator (101) verbunden ist, wobei das Pumpen der Flüssigkeit durch den zweiten Schlauch (109) die Kolbenanordnung (203) in eine zweite lineare Richtung entgegengesetzt der ersten linearen Richtung bewegt, und wobei die lineare Bewegung der Kolbenanordnung (203) abwechselnd in die erste lineare Richtung und die zweite lineare Richtung eine Schwingung des passiven Aktuators (101) verursacht und Schwingung in dem Zielgewebe anregt; und
Aufnehmen von MRI-Daten des Zielgewebes während eine Schwingung des Zielgewebes angeregt wird; und
erstellen einer Steifigkeitskarte des Gewebes basierend auf den aufgenommenen MRI-Daten.

13. Methode nach Anspruch 12, weiter umfassend:

Erstellen eines Phasenbilds der Schwingung des Gewebes basierend auf den MRI-Daten; und
Erstellen einer Steifigkeitskarte durch Durchführen einer Inversion der Phasenbild-MRI-Daten.

14. Methode nach einem der Ansprüche 12 oder 13, weiter umfassend
Regelung der Amplitude und Frequenz der in dem Zielgewebe angeregten Schwingung durch Regelung einer Auslenkung der Kolbenanordnung (203) und einer Frequenz, mit der Pumpendurchfluss wechselseitig zu den entsprechenden Versorgungsschläuchen des passiven Aktuators (101) verteilt wird.

15. Methode nach einem der Ansprüche 12 bis 14, wobei der Vorgang des wechselseitigen Pumpens einer Flüssigkeit von einer Antriebskomponente (103) weiter umfasst:

Erhalten eines Signals von einem Auslenkungssensor (205), welches die lineare Auslenkung der Kolbenanordnung (203) anzeigt,
Umschalten von Pumpen der Flüssigkeit durch den ersten Schlauch (105) zu Pumpen der Flüssigkeit durch den zweiten Schlauch (109) wenn das Signal des Auslenkungssensors (205) angibt, dass die lineare Auslenkung der Kolbenanordnung (203) in der ersten linearen Richtung einem Auslenkungsgrenzwert entspricht oder diesen übersteigt, und
Umschalten von Pumpen der Flüssigkeit durch den zweiten Schlauch (109) zu Pumpen der Flüssigkeit durch den ersten Schlauch (105) wenn das Signal des Auslenkungssensors (205) angibt, dass die lineare Auslenkung der Kolben-

anordnung (203) in der zweiten linearen Richtung einem Auslenkungsgrenzwert entspricht oder diesen übersteigt.

Revendications

1. Système d'induction d'une vibration tissulaire pour l'élastographie par résonance magnétique, le système comprenant :

un dispositif d'actionnement passif (101) pouvant être positionné près d'un tissu cible, le dispositif d'actionnement passif (101) comprenant un ensemble piston mobile de manière linéaire (203) enfermé dans un logement de sorte que le mouvement linéaire alterné du piston mobile de manière linéaire (203) entraîne la vibration du dispositif d'actionnement passif (101) et induit la vibration du tissu cible lorsque le dispositif d'actionnement passif (101) est positionné près du tissu cible ;
un premier tuyau (105) accouplé au dispositif d'actionnement passif (101) sur un premier côté de l'ensemble piston (203) ;
un second tuyau (109) accouplé au dispositif d'actionnement passif (101) sur un second côté de l'ensemble piston (203) opposé au premier côté ; et
un composant d'entraînement (103) comprenant une pompe de fluide (201), le composant d'entraînement (103) configuré pour pomper par alternance un fluide à travers le premier tuyau (105) amenant l'ensemble piston (203) à se déplacer dans un premier sens linéaire et à pomper le fluide à travers le second tuyau (109) amenant l'ensemble piston (203) à se déplacer dans un second sens linéaire, le second sens linéaire étant opposé au premier sens linéaire.

2. Système selon la revendication 1, le composant d'entraînement (103) étant en outre configuré pour
permettre passivement au fluide d'être drainé depuis le dispositif d'actionnement passif (101) à travers le second tuyau (109) lorsque le fluide est pompé vers le dispositif d'actionnement passif à travers le premier tuyau (105), et
permettre passivement au fluide d'être drainé depuis le dispositif d'actionnement passif (101) à travers le premier tuyau (105) lorsque le fluide est pompé vers le dispositif d'actionnement passif à travers le second tuyau (109).

3. Système selon l'une quelconque des revendications précédentes, dans lequel le dispositif d'actionnement passif (101) est construit uniquement à partir d'un composant non ferromagnétique afin d'être positionnable à l'intérieur d'un environnement MRI (111) et où le composant d'entraînement est configuré pour être positionné à l'extérieur de l'environnement MRI (111) durant l'utilisation.

4. Système selon l'une quelconque des revendications précédentes, le composant d'entraînement (103) étant en outre configuré pour
ajuster une fréquence de la vibration tissulaire induite en augmentant une vitesse à laquelle le fluide est pompé vers le dispositif d'actionnement passif (101) à travers le premier tuyau (105) et le second tuyau (109), et
ajuster une amplitude de la vibration tissulaire induite en augmentant le déplacement de l'ensemble piston (203).

5. Système selon l'une quelconque des revendications précédentes, le dispositif d'actionnement passif (101) comprenant en outre un capteur de déplacement (205) configuré pour fournir un signal au composant d'entraînement (103) indicatif d'une position linéaire de l'ensemble piston (203), et où le composant d'entraînement (103) est configuré pour
basculer depuis le pompage du fluide à travers le premier tuyau (105) au pompage du fluide à travers le second tuyau (109) lorsque le signal provenant du capteur de déplacement (205) indique que la position linéaire de l'ensemble piston (203) dans le premier sens linéaire correspond ou excède un seuil de déplacement, et
basculer depuis le pompage du fluide à travers le second tuyau (109) au pompage du fluide à travers le premier tuyau (105) lorsque le signal provenant du capteur de déplacement (205) indique que la position linéaire de l'ensemble piston (203) dans le second sens linéaire correspond ou excède le seuil de déplacement.

6. Système selon l'une quelconque des revendications 1 à 4, comprenant en outre un capteur de pression de fluide configuré pour mesurer la pression du fluide dans le premier tuyau (105) et la pression du fluide dans le second tuyau (109) et transmettre un signal au composant d'entraînement (103) indicatif de la pression du fluide dans le premier tuyau (105) et de la pression du fluide dans le second tuyau (109), où la pression du fluide est indicatrice du déplacement de l'ensemble piston (203) dans le dispositif d'actionnement passif (101), et où le composant d'entraînement (103) est en outre configuré pour
basculer depuis le pompage du fluide à travers le premier tuyau (105) au pompage du fluide à travers le second tuyau (109) lorsque le signal provenant du capteur de pression de fluide indique que la pression du fluide dans le premier tuyau (105) correspond ou excède la pression du fluide dans le second tuyau (109) selon un seuil de déplacement défini, et
basculer du pompage du fluide à travers le second

tuyau (109) au pompage du fluide à travers le premier tuyau (105) lorsque le signal provenant du capteur de pression de fluide indique que la pression du fluide dans le second tuyau (109) correspond ou excède la pression du fluide dans le premier tuyau (105) selon le seuil de déplacement défini.

7. Système selon l'une quelconque des revendications précédentes, le composant d'entraînement (103) étant en outre configuré pour
recevoir électroniquement un message provenant d'un système de balayage MRI (111) indicatif d'un changement souhaité dans au moins l'une d'une amplitude et d'une fréquence de la vibration induite par le dispositif d'actionnement passif (101), où le message est basé sur des données d'image acquises par le système de balayage MRI (111), et
ajuster au moins l'une de la fréquence et de l'amplitude de la vibration tissulaire induite par le composant d'entraînement (103) pour la synchronisation avec les gradients de codage du système de balayage MRI (111), où le composant d'entraînement (103) est configuré pour ajuster la fréquence de la vibration tissulaire induite en augmentant la fréquence à laquelle la vanne change pour faire alterner l'alimentation du fluide sous pression vers les côtés respectifs de l'ensemble piston (203) du dispositif d'actionnement passif (101), et où le composant d'entraînement (103) est configuré pour ajuster l'amplitude de la vibration tissulaire induite en ajustant un déplacement maximal de l'ensemble piston (203).

8. Système selon l'une quelconque des revendications précédentes, le composant d'entraînement (103) étant en outre configuré pour
recevoir électroniquement un message provenant d'un système de balayage MRI (111) indiquant lorsque la vibration tissulaire induite devrait commencer, et
commencer l'induction de la vibration tissulaire selon le message provenant du système de balayage MRI (111).

9. Système selon l'une quelconque des revendications 1 à 7, le composant d'entraînement (103) étant en outre configuré pour transmettre électroniquement un message au système de balayage MRI (111) indiquant lorsque le système de balayage MRI (111) doit commencer à acquérir des données, où le message est basé sur la vibration tissulaire induite.

10. Système selon l'une quelconque des revendications précédentes, dans lequel le premier sens linéaire est perpendiculaire à une surface cutanée du patient, et où la vibration induite est une vibration longitudinale.

11. Système selon l'une quelconque des revendications 1 à 9, dans lequel le premier sens linéaire est parallèle à une surface cutanée du patient, et où la vibration induite est une vibration de cisaillement.

12. Procédé d'exécution de l'élastographie par résonance magnétique, le procédé comprenant :

le positionnement d'un dispositif d'actionnement passif (101) près d'un tissu cible sur un patient, le dispositif d'actionnement passif (101) comprenant un ensemble piston mobile de manière linéaire (203) enfermé dans un logement ; le pompage par alternance d'un fluide provenant d'un composant d'entraînement (103) à travers un premier tuyau (105), le premier tuyau (105) étant accouplé au dispositif d'actionnement passif (101) sur un premier côté de l'ensemble piston (203), où le pompage du fluide à travers le premier tuyau (105) amène l'ensemble piston (203) à se déplacer dans un premier sens linéaire, et le pompage d'un fluide depuis le composant d'entraînement (103) à travers un second tuyau (109), le second tuyau (109) étant accouplé au dispositif d'actionnement passif (101) sur un second côté de l'ensemble piston (203) opposé au premier côté, où le pompage du fluide à travers le second tuyau (109) amène l'ensemble piston (203) à se déplacer dans un second sens linéaire opposé au premier sens linéaire, et où le mouvement linéaire de l'ensemble piston (203) de manière alternée dans le premier sens linéaire et le second sens linéaire entraîne la vibration du dispositif d'actionnement passif (101) et induit la vibration dans le tissu cible ; et l'acquisition de données MRI sur le tissu cible lorsque la vibration du tissu cible est induite ; et la production d'une carte de rigidité du tissu sur la base des données MRI acquises.

13. Procédé selon la revendication 12, comprenant en outre :

la production d'une image de phase de la vibration du tissu sur la base des données MRI ; et la production d'une carte de rigidité en effectuant une inversion sur les données MRI d'image de phase.

14. Procédé selon l'une quelconque des revendications 12 ou 13, comprenant en outre la régulation de l'amplitude et de la fréquence de la vibration induite dans le tissu cible en régulant un déplacement de l'ensemble piston (203) et une fréquence à laquelle l'écoulement de la pompe est dévié par alternance vers les tuyaux d'alimentation respectifs du dispositif d'actionnement passif (101).

15. Procédé selon l'une quelconque des revendications

12 à 14, dans lequel l'acte de pompage par alternance d'un fluide depuis un composant d'entraînement (103) comprend en outre :

la réception d'un signal à partir d'un capteur de déplacement (205) indicatif du déplacement linéaire de l'ensemble piston (203),
le basculement du pompage du fluide à travers le premier tuyau (105) vers le pompage du fluide à travers le second tuyau (109) lorsque le signal provenant du capteur de déplacement (205) indique que le déplacement linéaire de l'ensemble piston (203) dans le premier sens linéaire correspond ou excède un seuil de déplacement, et le basculement du pompage du fluide à travers le second tuyau (109) au pompage du fluide à travers le premier tuyau (105) lorsque le signal provenant du capteur de déplacement (205) indique que le déplacement linéaire de l'ensemble piston (203) dans le second sens linéaire correspond ou excède le seuil de déplacement.

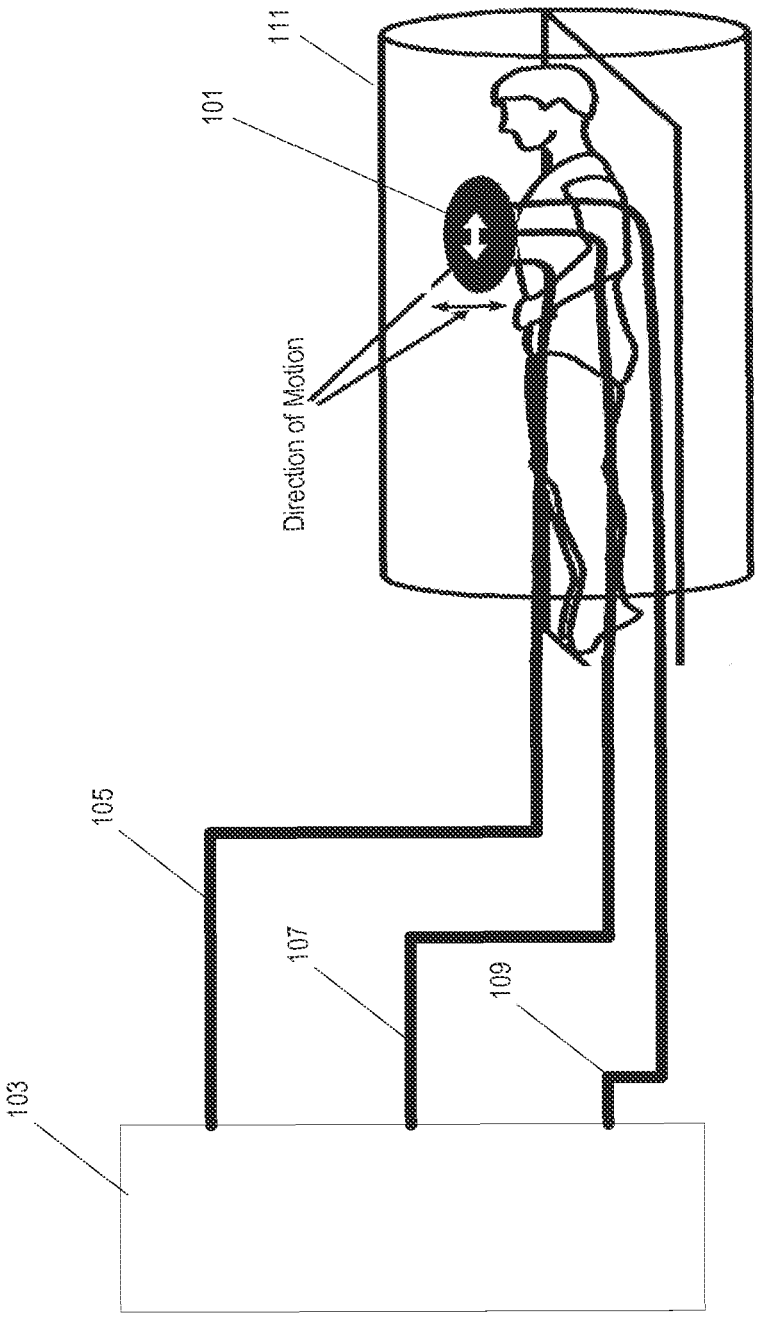

Fig. 1

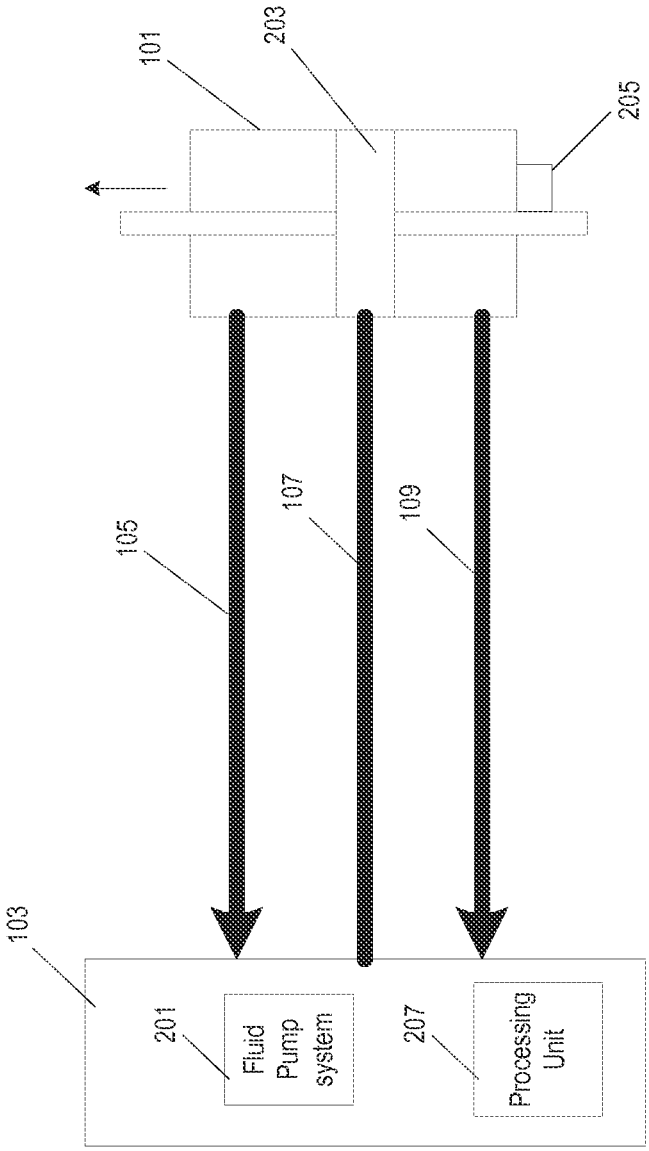
101
203
205
105
107
109
103
201
Fluid Pump system
207
Processing Unit

Fig. 2

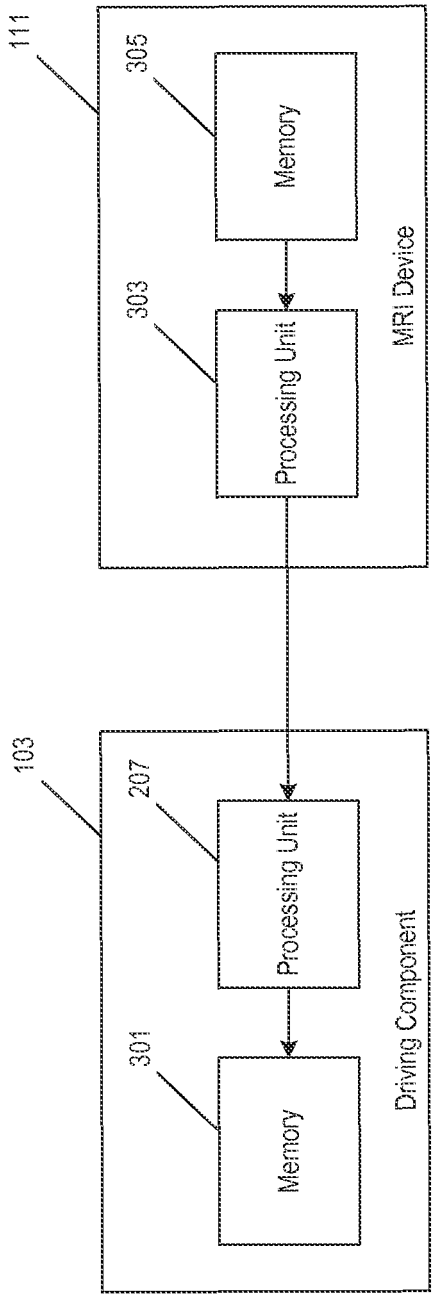
111
305
Memory
303
Processing Unit
MRI Device
103
207
Processing Unit
301
Memory
Driving Component

Fig. 3

REFERENCES CITED IN THE DESCRIPTION

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Patent documents cited in the description

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- US 005540052 A **[0005]**

专利名称(译)	用于实现磁共振弹性成像的液压动力系统和方法		
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[标]申请(专利权)人(译)	俄亥俄州立大学		
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外部链接	Espacenet		

摘要(译)

描述了一种用于引发磁共振弹性成像的组织振动的系统。该系统包括被动致动器部件，第一软管，第二软管和驱动部件。被动致动器部件可定位在目标组织附近，并且包括封闭在壳体中的可线性移动的活塞组件。驱动部件包括流体泵送系统，并且构造成通过第一软管和第二软管交替地泵送流体。当流体被泵送通过第一软管时，活塞组件沿第一线性方向移动，并且当流体被泵送通过第二软管时，活塞组件沿相反方向移动。活塞组件的交替线性运动引起目标组织中的振动。

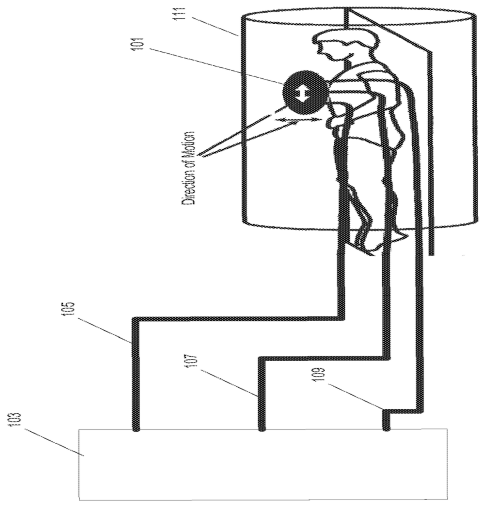

Fig. 1