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(54) METHOD AND APPARATUS FOR ULTRASONIC ANALYSIS OF BRAIN ACTIVITY IN STROKE PATIENTS

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A61B 8/02	(2006.01)

(52) **U.S. Cl.**

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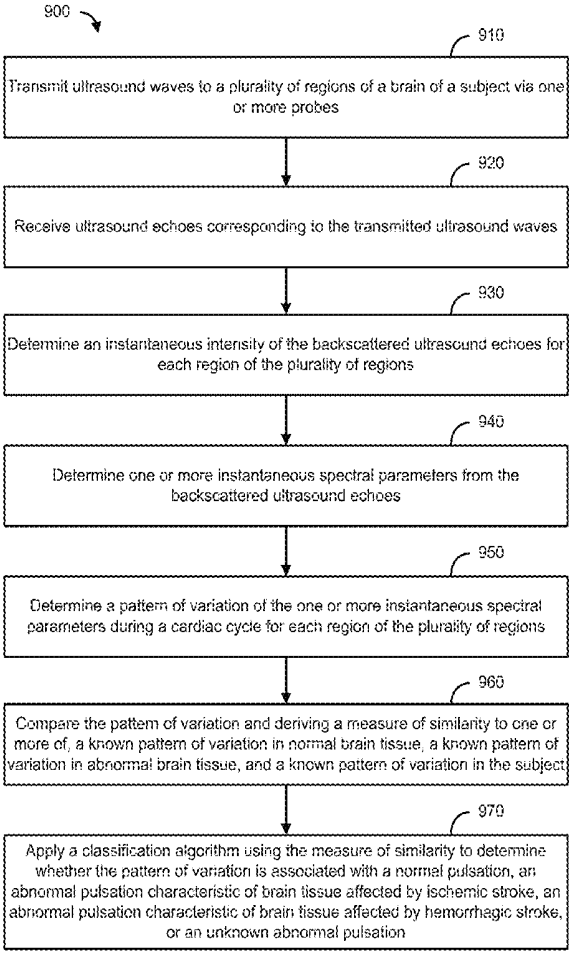
(57) **ABSTRACT**

Methods are disclosed comprising transmitting ultrasound waves to a plurality of regions of a brain of a subject via one or more probes, receiving ultrasound echoes corresponding to the transmitted ultrasound waves, determining a parameter based on the ultrasound echoes for each region of the plurality of regions, determining a time course for each parameter, and one or more of: comparing the time courses for each region of the plurality of regions to determine a pulsatility measurement for each region of the plurality of regions and comparing the time courses to one or more of, a known time course in normal brain tissue and a known time course in abnormal brain tissue to classify each region of the plurality of regions as comprising normal brain tissue or abnormal brain tissue.



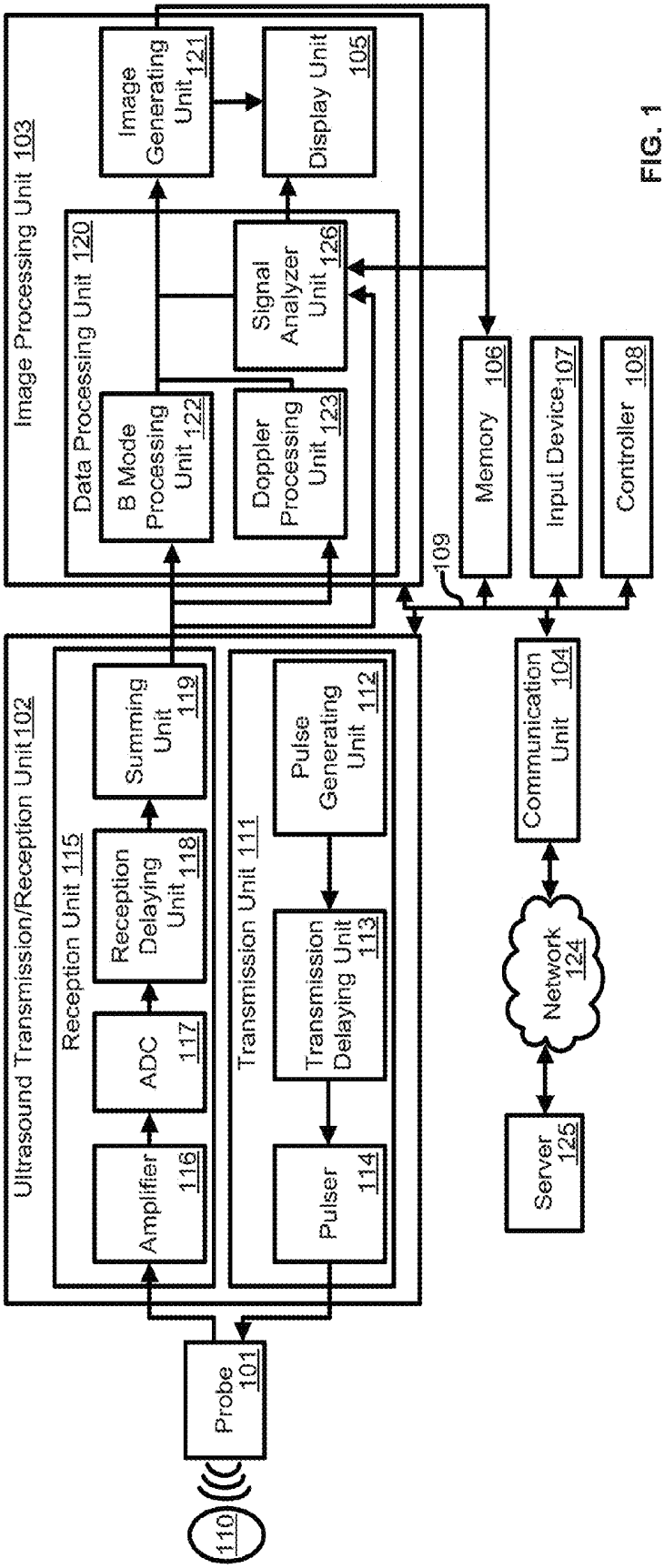


Image Processing Unit 103
Image Generating Unit 121
Display Unit 105
Data Processing Unit 120
Signal Analyzer Unit 126
B Mode Processing Unit 122
Doppler Processing Unit 123
Memory 106
Input Device 107
Controller 108
109
Ultrasound Transmission/Reception Unit 102
Reception Unit 115
Summing Unit 119
Reception Delaying Unit 118
ADC 117
Amplifier 116
Transmission Unit 111
Pulse Generating Unit 112
Transmission Delaying Unit 113
Pulser 114
Communication Unit 104
Network 124
Server 125
Probe 101
110

FIG. 1

FIG. 2

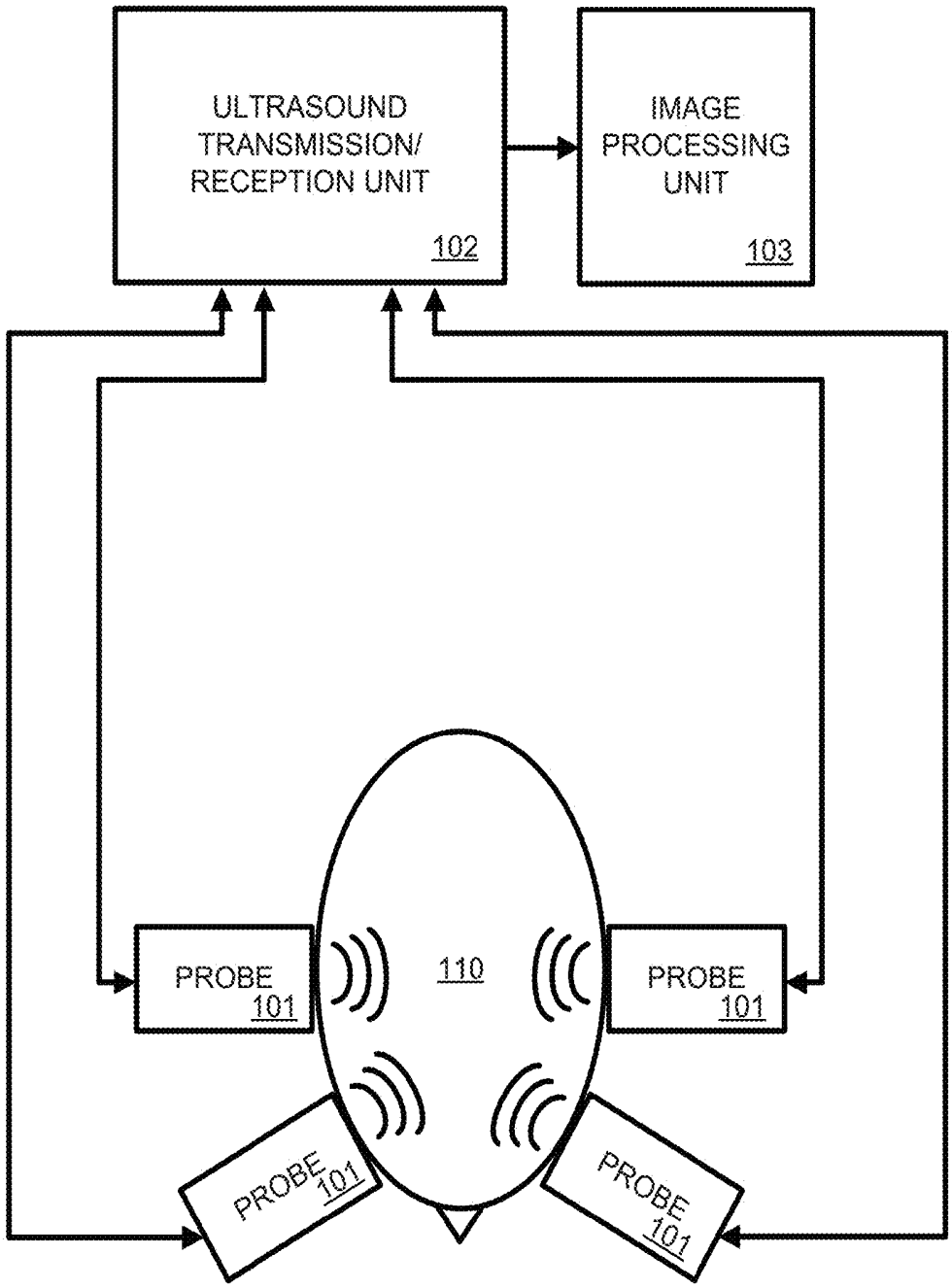

ULTRASOUND TRANSMISSION/ RECEPTION UNIT
102
IMAGE PROCESSING UNIT
103
PROBE 101
110
PROBE 101
PROBE 101
PROBE 101

FIG. 3A

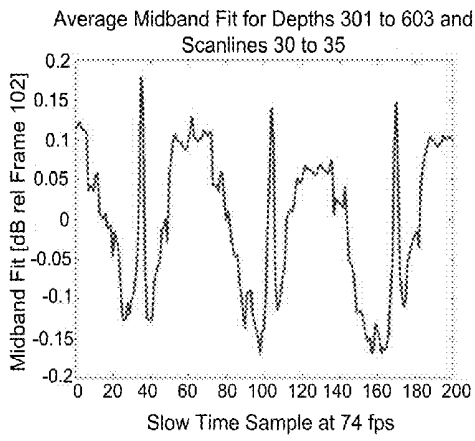


FIG. 3B

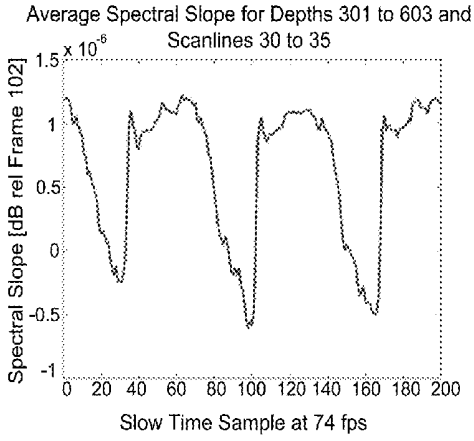


FIG. 3C

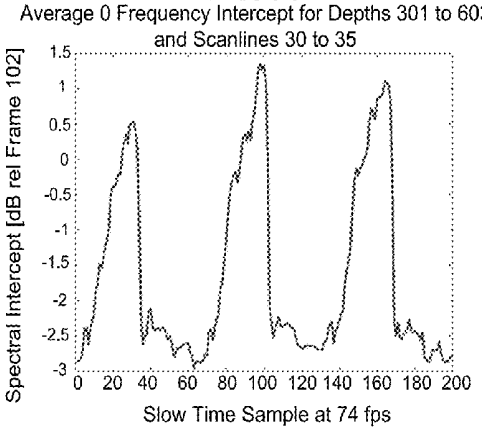


FIG. 3D

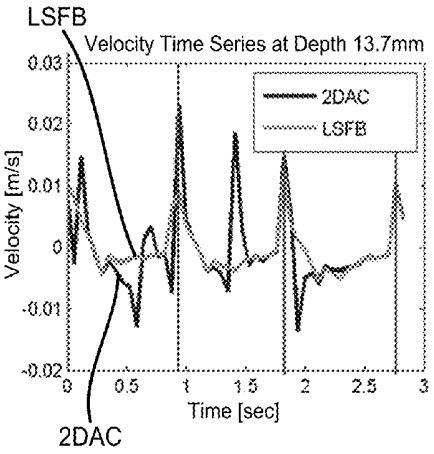


FIG. 4A

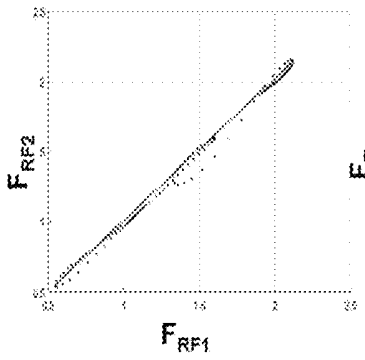


FIG. 4B

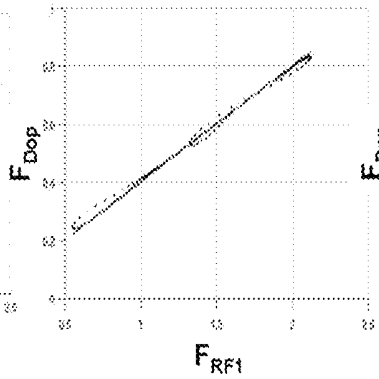
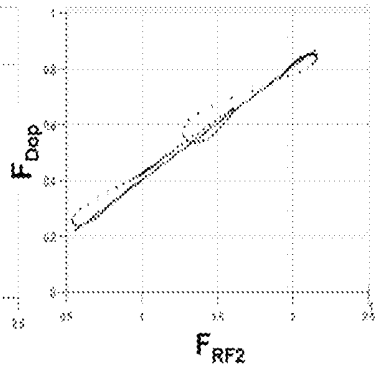


FIG. 4C



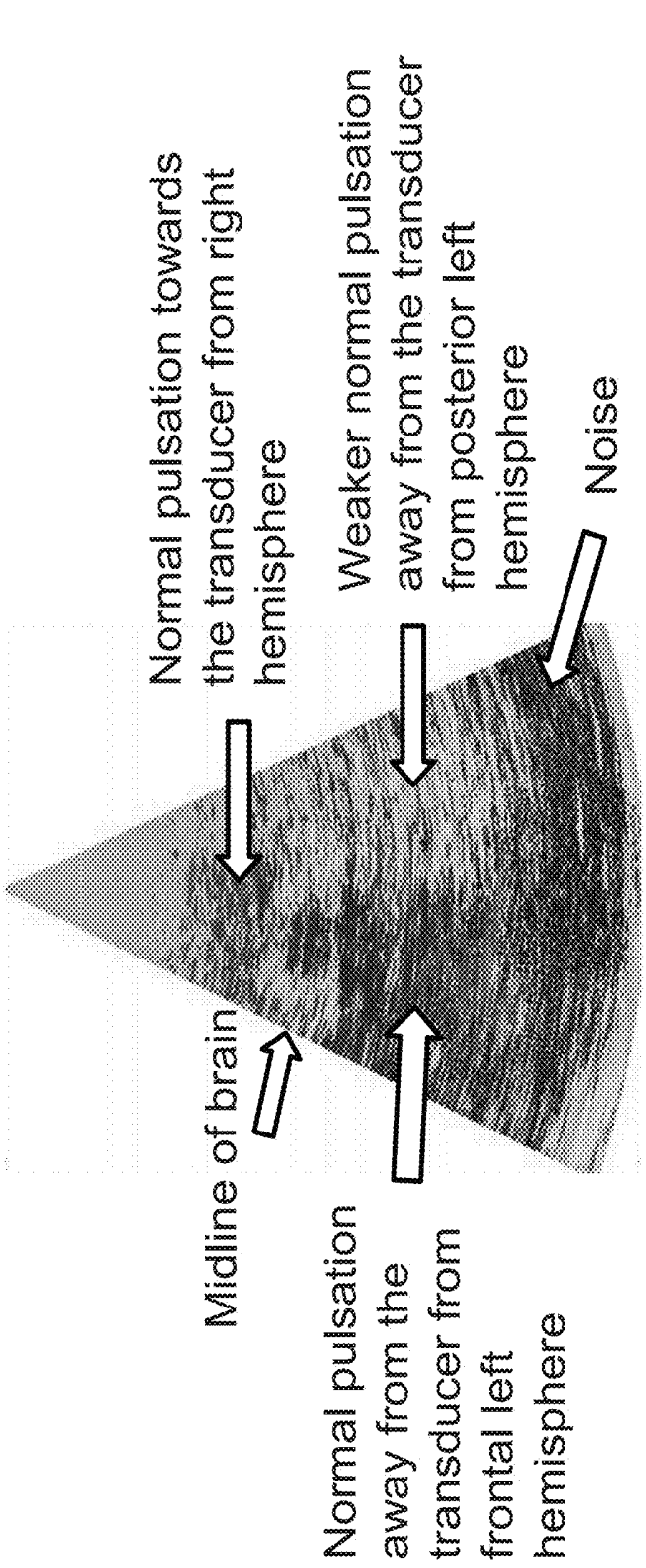

Normal pulsation towards the transducer from right hemisphere
Weaker normal pulsation away from the transducer from posterior left hemisphere
Noise
Midline of brain
Normal pulsation away from the transducer from frontal left hemisphere

FIG. 5

FIG. 6

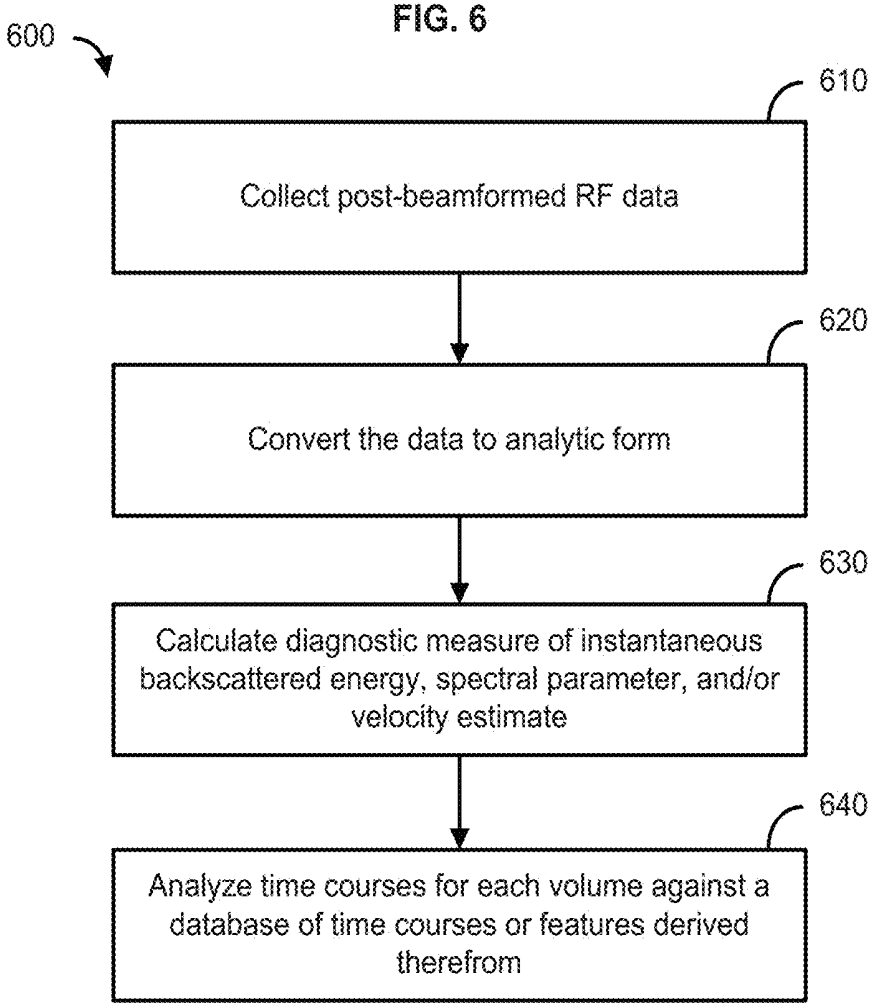

600
610
Collect post-beamformed RF data
620
Convert the data to analytic form
630
Calculate diagnostic measure of instantaneous backscattered energy, spectral parameter, and/or velocity estimate
640
Analyze time courses for each volume against a database of time courses or features derived therefrom

FIG. 7

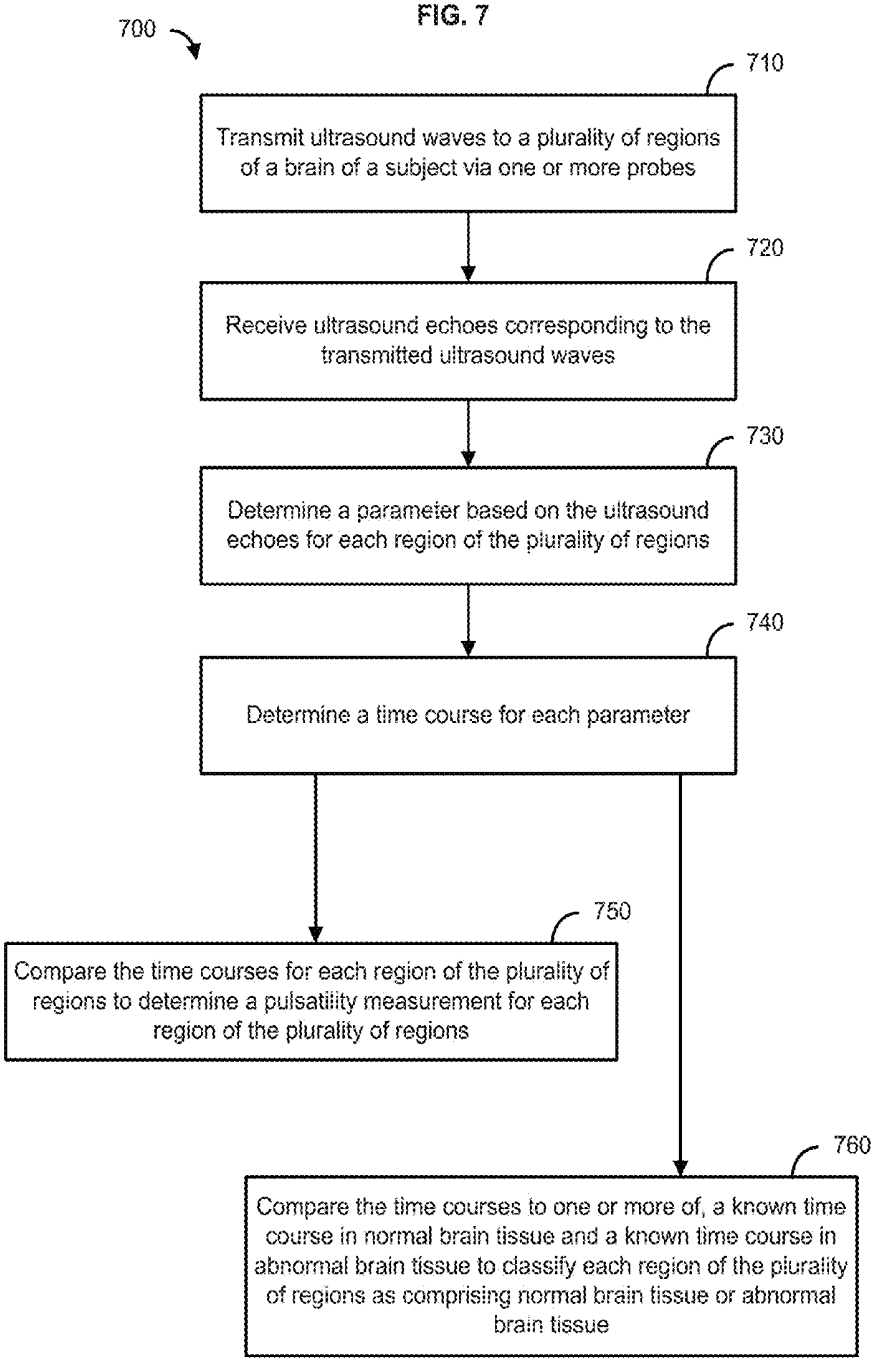

700
710
Transmit ultrasound waves to a plurality of regions of a brain of a subject via one or more probes
720
Receive ultrasound echoes corresponding to the transmitted ultrasound waves
730
Determine a parameter based on the ultrasound echoes for each region of the plurality of regions
740
Determine a time course for each parameter
750
Compare the time courses for each region of the plurality of regions to determine a pulsatility measurement for each region of the plurality of regions
760
Compare the time courses to one or more of, a known time course in normal brain tissue and a known time course in abnormal brain tissue to classify each region of the plurality of regions as comprising normal brain tissue or abnormal brain tissue

FIG. 8

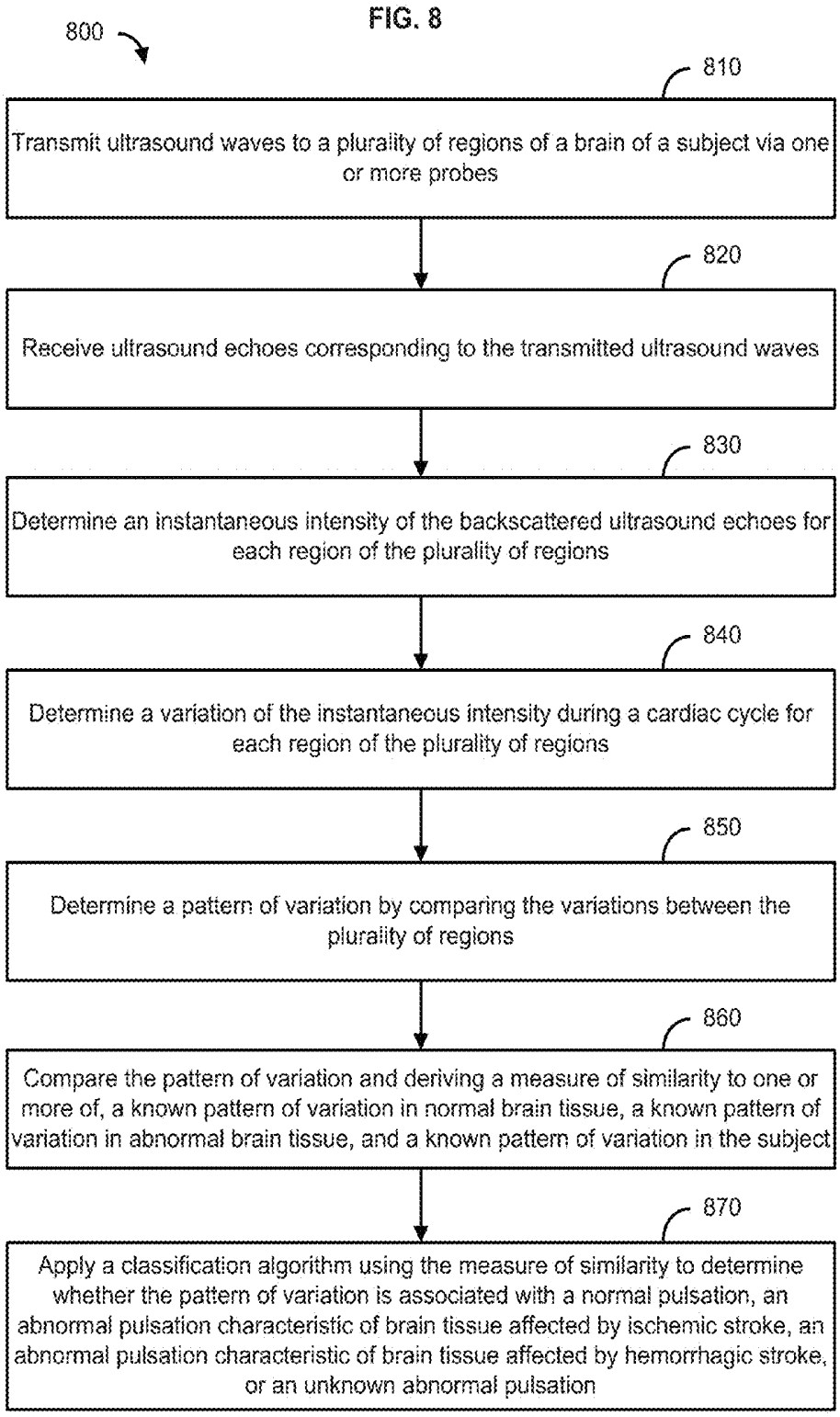

800
810
Transmit ultrasound waves to a plurality of regions of a brain of a subject via one or more probes
820
Receive ultrasound echoes corresponding to the transmitted ultrasound waves
830
Determine an instantaneous intensity of the backscattered ultrasound echoes for each region of the plurality of regions
840
Determine a variation of the instantaneous intensity during a cardiac cycle for each region of the plurality of regions
850
Determine a pattern of variation by comparing the variations between the plurality of regions
860
Compare the pattern of variation and deriving a measure of similarity to one or more of, a known pattern of variation in normal brain tissue, a known pattern of variation in abnormal brain tissue, and a known pattern of variation in the subject
870
Apply a classification algorithm using the measure of similarity to determine whether the pattern of variation is associated with a normal pulsation, an abnormal pulsation characteristic of brain tissue affected by ischemic stroke, an abnormal pulsation characteristic of brain tissue affected by hemorrhagic stroke, or an unknown abnormal pulsation

FIG. 9

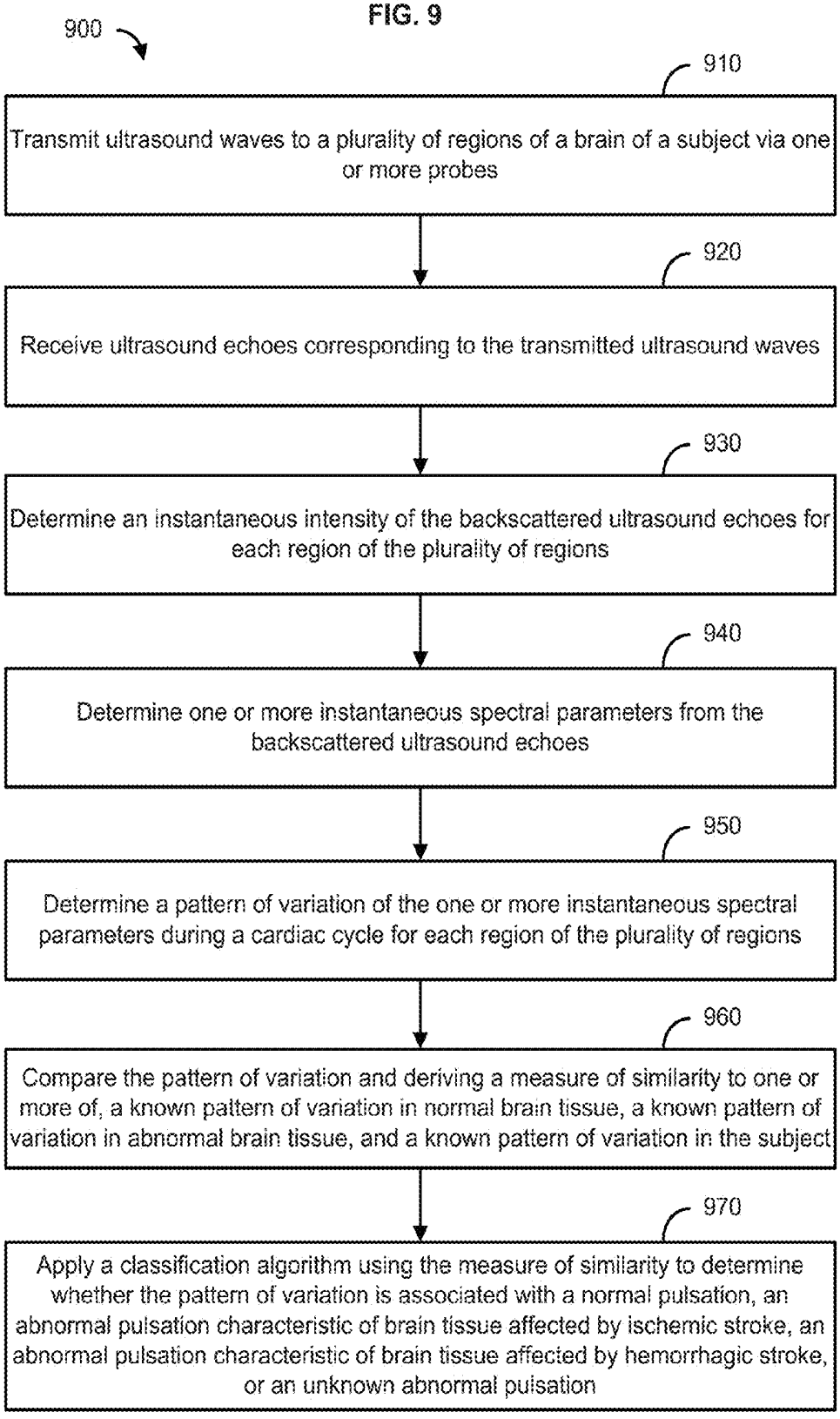

900
910
Transmit ultrasound waves to a plurality of regions of a brain of a subject via one or more probes
920
Receive ultrasound echoes corresponding to the transmitted ultrasound waves
930
Determine an instantaneous intensity of the backscattered ultrasound echoes for each region of the plurality of regions
940
Determine one or more instantaneous spectral parameters from the backscattered ultrasound echoes
950
Determine a pattern of variation of the one or more instantaneous spectral parameters during a cardiac cycle for each region of the plurality of regions
960
Compare the pattern of variation and deriving a measure of similarity to one or more of, a known pattern of variation in normal brain tissue, a known pattern of variation in abnormal brain tissue, and a known pattern of variation in the subject
970
Apply a classification algorithm using the measure of similarity to determine whether the pattern of variation is associated with a normal pulsation, an abnormal pulsation characteristic of brain tissue affected by ischemic stroke, an abnormal pulsation characteristic of brain tissue affected by hemorrhagic stroke, or an unknown abnormal pulsation

FIG. 10

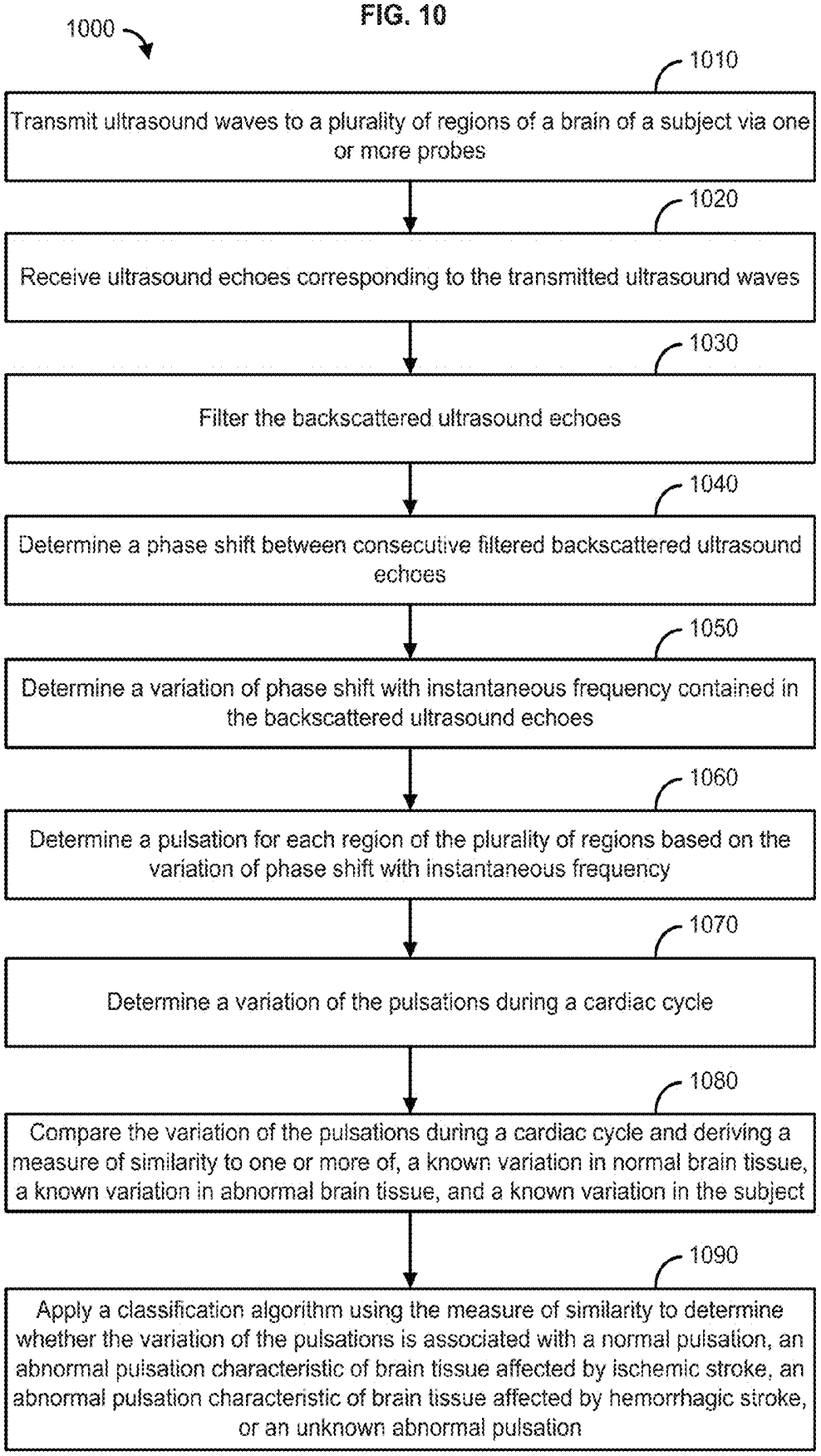
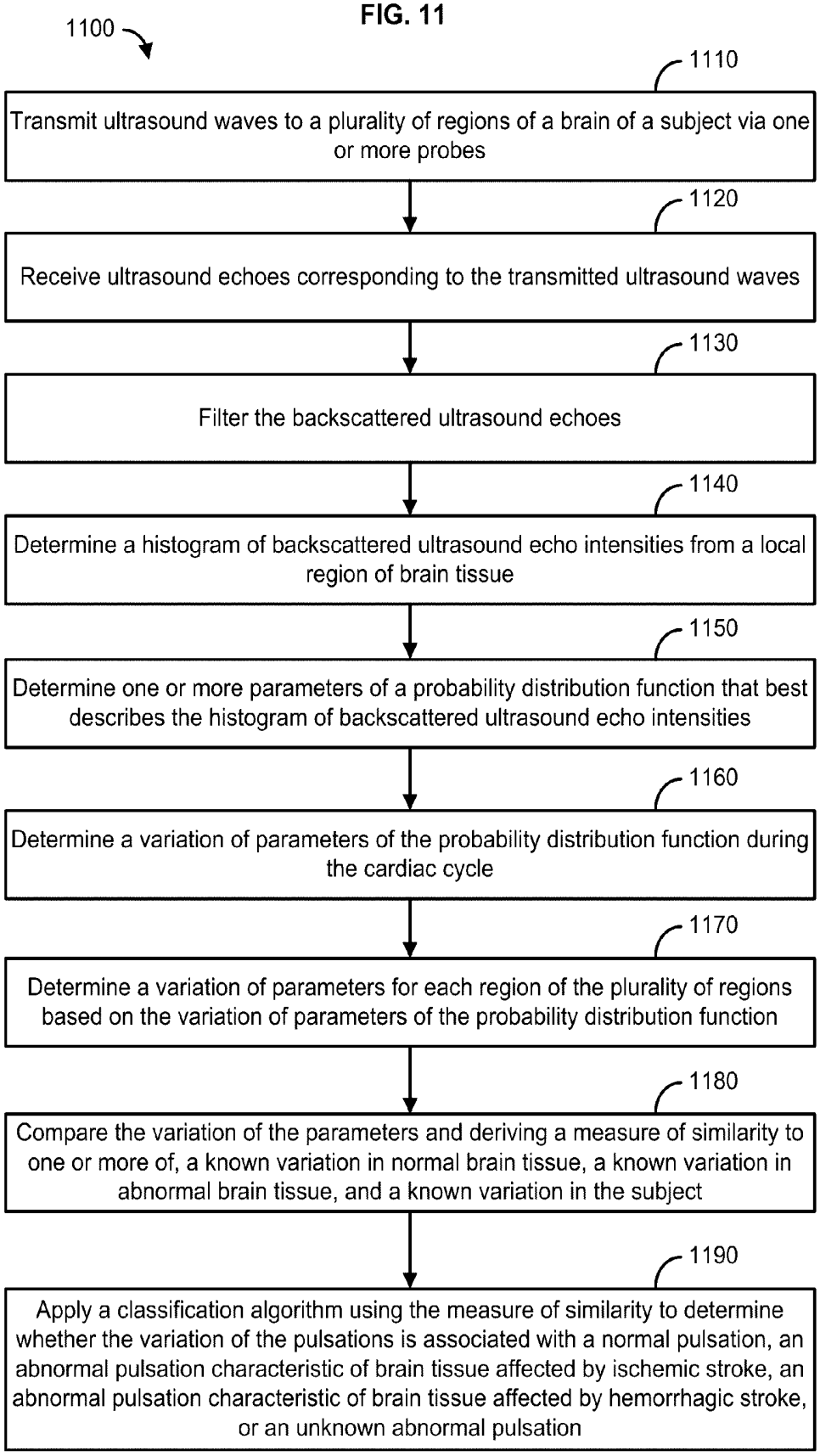

1000
1010
Transmit ultrasound waves to a plurality of regions of a brain of a subject via one or more probes
1020
Receive ultrasound echoes corresponding to the transmitted ultrasound waves
1030
Filter the backscattered ultrasound echoes
1040
Determine a phase shift between consecutive filtered backscattered ultrasound echoes
1050
Determine a variation of phase shift with instantaneous frequency contained in the backscattered ultrasound echoes
1060
Determine a pulsation for each region of the plurality of regions based on the variation of phase shift with instantaneous frequency
1070
Determine a variation of the pulsations during a cardiac cycle
1080
Compare the variation of the pulsations during a cardiac cycle and deriving a measure of similarity to one or more of, a known variation in normal brain tissue, a known variation in abnormal brain tissue, and a known variation in the subject
1090
Apply a classification algorithm using the measure of similarity to determine whether the variation of the pulsations is associated with a normal pulsation, an abnormal pulsation characteristic of brain tissue affected by ischemic stroke, an abnormal pulsation characteristic of brain tissue affected by hemorrhagic stroke, or an unknown abnormal pulsation

FIG. 11


1100
1110
Transmit ultrasound waves to a plurality of regions of a brain of a subject via one or more probes
1120
Receive ultrasound echoes corresponding to the transmitted ultrasound waves
1130
Filter the backscattered ultrasound echoes
1140
Determine a histogram of backscattered ultrasound echo intensities from a local region of brain tissue
1150
Determine one or more parameters of a probability distribution function that best describes the histogram of backscattered ultrasound echo intensities
1160
Determine a variation of parameters of the probability distribution function during the cardiac cycle
1170
Determine a variation of parameters for each region of the plurality of regions based on the variation of parameters of the probability distribution function
1180
Compare the variation of the parameters and deriving a measure of similarity to one or more of, a known variation in normal brain tissue, a known variation in abnormal brain tissue, and a known variation in the subject
1190
Apply a classification algorithm using the measure of similarity to determine whether the variation of the pulsations is associated with a normal pulsation, an abnormal pulsation characteristic of brain tissue affected by ischemic stroke, an abnormal pulsation characteristic of brain tissue affected by hemorrhagic stroke, or an unknown abnormal pulsation

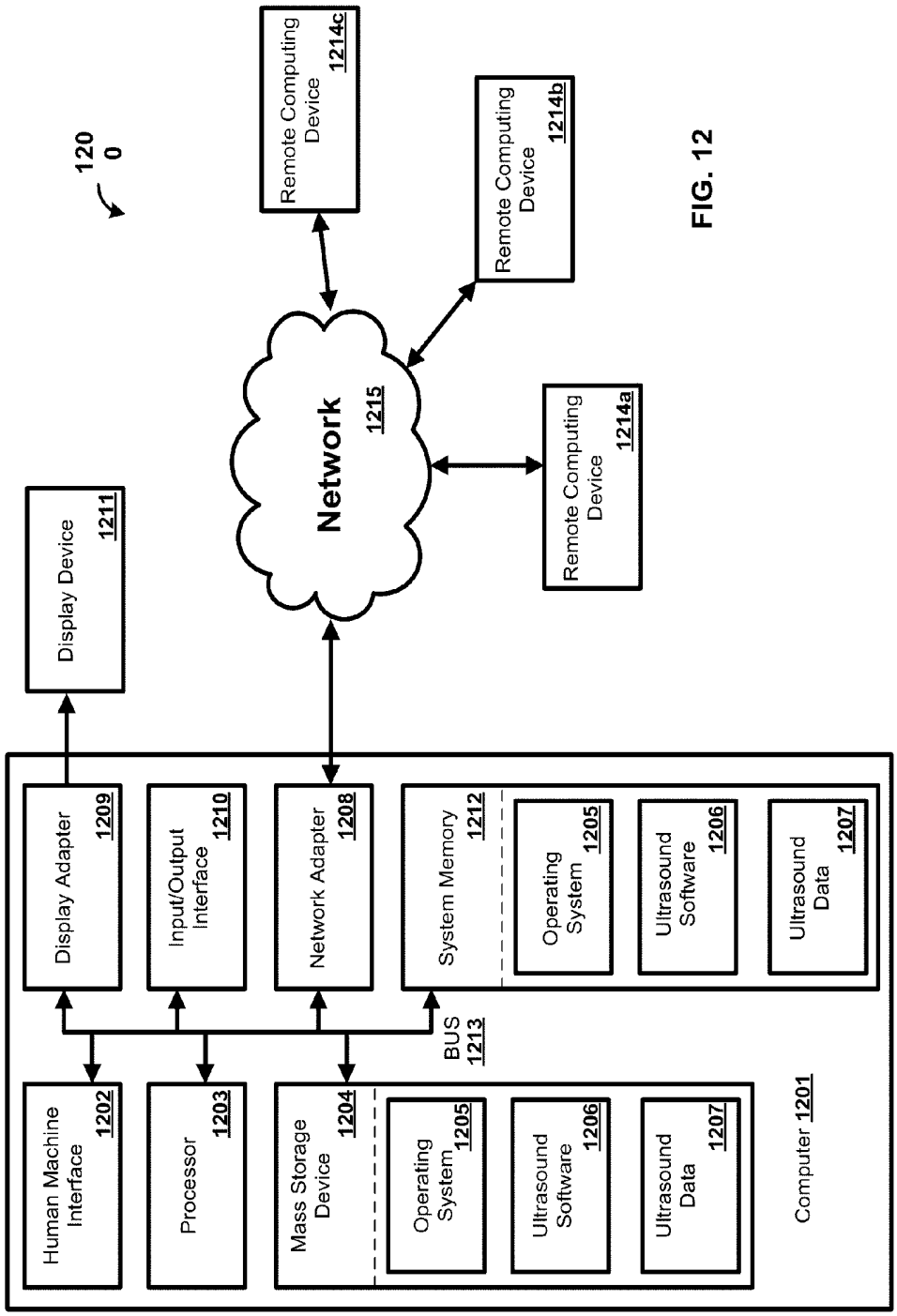

120 0
Remote Computing Device 1214c
Remote Computing Device 1214b
Remote Computing Device 1214a
Network 1215
Display Device 1211
Display Adapter 1209
Input/Output Interface 1210
Network Adapter 1208
System Memory 1212
Operating System 1205
Ultrasound Software 1206
Ultrasound Data 1207
BUS 1213
Human Machine Interface 1202
Processor 1203
Mass Storage Device 1204
Operating System 1205
Ultrasound Software 1206
Ultrasound Data 1207
Computer 1201

FIG. 12

METHOD AND APPARATUS FOR ULTRASONIC ANALYSIS OF BRAIN ACTIVITY IN STROKE PATIENTS

CROSS REFERENCE TO RELATED PATENT APPLICATION

[0001] This application claims priority to U.S. Provisional Application No. 62/170,153 filed Jun. 3, 2015, herein incorporated by reference in its entirety.

BACKGROUND

[0002] Approximately three quarters of a million people suffer a stroke even year. Stroke has a mortality rate greater than 15% and contributes to significant disabilities in those who survive. Early diagnosis and treatment is critical to improve prognosis, since brain tissue is lost if treatment is not performed promptly. A critical decision that must be made before administering treatment is the differentiation between ischemic stroke associated with a blockage of a blood vessel in the brain and hemorrhagic stroke caused by bleeding in the brain. If the stroke is caused by a blockage due to a blood clot, an anticoagulant, such as tPA, should be administered as soon as possible to dissolve the blood clot. If the stroke is hemorrhagic, anticoagulant therapy could be fatal and should not be administered. Currently this differentiation between ischemic and hemorrhagic stroke only can be performed in a hospital setting using advanced imaging.

[0003] In standard practice, stroke diagnosis requires the use of computed tomography (CT) scans. The supporting machinery is large and not conducive to point of care measurements. These scans are consequently performed once a patient has arrived at a hospital. The ability to differentiate between the type of stroke in the shortest amount of time can result in saving as much brain tissue from disease as possible. In addition, once a patient is receiving treatment for stroke, the ability to monitor the brain tissue at the bedside without performing repeated CT scans would lead to better ability to manage the treatment of the patient.

[0004] It would be desirable, therefore, to develop new technologies for assessing stroke that overcomes these and other limitations of the prior art.

SUMMARY

[0005] It is to be understood that both the following general description and the following detailed description are exemplary and explanatory only and are not restrictive. Methods, systems, and apparatuses are disclosed comprising transmitting ultrasound waves to a plurality of regions of a brain of a subject via one or more probes, receiving ultrasound echoes corresponding to the transmitted ultrasound waves, determining a parameter based on the ultrasound echoes for each region of the plurality of regions, determining a time course for each parameter, and one or more of: comparing the time courses for each region of the plurality of regions to determine a pulsatility measurement for each region of the plurality of regions and comparing the time courses to one or more of, a known time course in normal brain tissue and a known time course in abnormal brain tissue to classify each region of the plurality of regions as comprising normal brain tissue or abnormal brain tissue.

[0006] Additional advantages will be set forth in part in the description which follows or may be learned by practice. The advantages will be realized and attained by means of the elements and combinations particularly pointed out in the appended claims.

BRIEF DESCRIPTION OF THE DRAWINGS

[0007] The accompanying drawings, which are incorporated in and constitute a part of this specification, illustrate embodiments and together with the description, serve to explain the principles of the methods and systems:

[0008] FIG. **1** is an example ultrasound apparatus;

[0009] FIG. **2** is an example probe configuration for the ultrasound apparatus;

[0010] FIG. **3**A illustrates an example of the variation of the spectral parameter mid-band-fit during the cardiac cycle in a region of normal brain tissue;

[0011] FIG. **3**B illustrates an example of the variation of the spectral parameter spectral slope during the cardiac cycle in a region of normal brain tissue;

[0012] FIG. **3**C is illustrates an example of the variation of the spectral parameter zero-frequency-intercept during the cardiac cycle in a region of normal brain tissue;

[0013] FIG. **3**D illustrates a time course of estimated brain tissue velocity for three cardiac cycles using the disclosed phase shift method (least squares fit of filter bank outputs, LSFB) compared to method described in the prior art (two-dimensional autocorrelation 2DAC);

[0014] FIG. **4**A illustrates a 3D geometric view of constrained filtered signals from a pair of consecutive reflected ultrasound echoes (RF frequency from pulse **1** to pulse **2**);

[0015] FIG. **4**B illustrates a 3D geometric view of constrained filtered signals from a pair of consecutive reflected ultrasound echoes (RF frequency of pulse **1** to Doppler frequency);

[0016] FIG. **4**C illustrates a 3D geometric view of constrained filtered signals from a pair of consecutive reflected ultrasound echoes (RF frequency of pulse **2** to Doppler frequency);

[0017] FIG. **5** is an example spatial map;

[0018] FIG. **6** is a flowchart illustrating an example method;

[0019] FIG. **7** is a flowchart illustrating an example method;

[0020] FIG. **8** is a flowchart illustrating an example method;

[0021] FIG. **9** is a flowchart illustrating an example method;

[0022] FIG. **10** is a flowchart illustrating an example method;

[0023] FIG. **11** is a flowchart illustrating an example method; and

[0024] FIG. **12** is an example operating environment.

DETAILED DESCRIPTION

[0025] Before the present methods and systems are disclosed and described, it is to be understood that the methods and systems are not limited to specific methods, specific components, or to particular implementations. It is also to be understood that the terminology used herein is for the purpose of describing particular embodiments only and is not intended to be limiting.

[0026] As used in the specification and the appended claims, the singular forms "a," "an," and "the" include plural referents unless the context clearly dictates otherwise.

Ranges may be expressed herein as from "about" one particular value, and/or to "about" another particular value. When such a range is expressed, another embodiment includes from the one particular value and/or to the other particular value. Similarly, when values are expressed as approximations, by use of the antecedent "about," it will be understood that the particular value forms another embodiment. It will be further understood that the endpoints of each of the ranges are significant both in relation to the other endpoint, and independently of the other endpoint.

[0027] "Optional" or "optionally" means that the subsequently described event or circumstance may or may not occur, and that the description includes instances where said event or circumstance occurs and instances where it does not.

[0028] Throughout the description and claims of this specification, the word "comprise" and variations of the word, such as "comprising" and "comprises," means "including but not limited to," and is not intended to exclude, for example, other components, integers or steps. "Exemplary" means "an example of" and is not intended to convey an indication of a preferred or ideal embodiment. "Such as" is not used in a restrictive sense, but for explanatory purposes.

[0029] Disclosed are components that can be used to perform the disclosed methods and systems. These and other components are disclosed herein, and it is understood that when combinations, subsets, interactions, groups, etc. of these components are disclosed that while specific reference of each various individual and collective combinations and permutation of these may not be explicitly disclosed, each is specifically contemplated and described herein, for all methods and systems. This applies to all aspects of this application including, but not limited to, steps in disclosed methods. Thus, if there are a variety of additional steps that can be performed it is understood that each of these additional steps can be performed with any specific embodiment or combination of embodiments of the disclosed methods.

[0030] The present methods and systems may be understood more readily by reference to the following detailed description of preferred embodiments and the examples included therein and to the Figures and their previous and following description.

[0031] As will be appreciated by one skilled in the art, the methods and systems may take the form of an entirely hardware embodiment, an entirely software embodiment, or an embodiment combining software and hardware aspects. Furthermore, the methods and systems may take the form of a computer program product on a computer-readable storage medium having computer-readable program, instructions (e.g., computer software) embodied in the storage medium. More particularly, the present methods and systems may take the form of web-implemented computer software. Any suitable computer-readable storage medium may be utilized including hard disks, CD-ROMs, optical storage devices, or magnetic storage devices.

[0032] Embodiments of the methods and systems are described below with reference to block diagrams and flowchart illustrations of methods, systems, apparatuses and computer program products. It will be understood that each block of the block diagrams and flowchart illustrations, and combinations of blocks in the block diagrams and flowchart illustrations, respectively, can be implemented by-computer program instructions. These computer program instructions may be loaded onto a general purpose computer, special purpose computer, or other programmable data processing apparatus to produce a machine, such that the instructions which execute on the computer or other programmable data processing apparatus create a means for implementing the functions specified in the flowchart block or blocks.

[0033] These computer program instructions may also be stored in a computer-readable memory that can direct a computer or other programmable data processing apparatus to function in a particular manner, such that the instructions stored in the computer-readable memory produce an article of manufacture including computer-readable instructions for implementing the function specified in the flowchart block or blocks. The computer program instructions may also be loaded onto a computer or other programmable data processing apparatus to cause a series of operational steps to be performed on the computer or other programmable apparatus to produce a computer-implemented process such that the instructions that execute on the computer or other programmable apparatus provide steps for implementing the functions specified in the flowchart block or blocks.

[0034] Accordingly, blocks of the block diagrams and flowchart illustrations support combinations of means for performing the specified functions, combinations of steps for performing the specified functions and program instruction means for performing the specified functions. It will also be understood that each block of the block diagrams and flowchart illustrations, and combinations of blocks in the block diagrams and flowchart illustrations, can be implemented by special purpose hardware-based computer systems that perform the specified functions or steps, or combinations of special purpose hardware and computer instructions.

[0035] Throughout the specification, an "ultrasound image" can refer to an image of an object, which is obtained using ultrasound waves. Furthermore, an "object" may be a human, an animal, or a part of a human or animal. For example, the object may be an organ (e.g., the liver, the heart, the brain, the abdomen, and the like), a blood vessel, or a combination thereof. Also, the object may be a phantom. The phantom means a material having a density, an effective atomic number, and a volume that are approximately the same as those of an organism.

[0036] The present disclosure relates to methods, systems, and apparatuses for using ultrasound to assess brain activity to differentiate between ischemic and hemorrhagic strokes. The methods, systems, and apparatuses can use novel ultrasound methods and apparatuses to derive brain tissue properties with the application of detecting, localizing, and characterizing affected tissue. Normal brain tissue has a characteristic pulsation due to the cardiac cycle. The cardiac cycle defines the blood dynamics associated with each beat of the heart. In a simple description, the cardiac cycle is comprised of two phases: systole and diastole. Systole describes period over which the heart contracts and results in increased blood pressure. Correspondingly, systole results in increased blood flow through vessels and tissue. Diastole describes the period when the heart muscles relax and the pressure begins to decrease. A single cardiac cycle refers to the period from the onset of systole from one heart beat to the onset of systole in the next heartbeat. Both blood vessels and brain tissue will exhibit pulsations that reflect the changes in the volume of blood that is passing through them at a given moment in time. If blood flow is disrupted to a

local region of tissue, the nature of the pulsation of that local region of tissue is expected to change significantly. The methods, systems, and apparatuses include novel signal processing methods to robustly quantify these pulsations. This characterization is significantly different from traditional ultrasound imaging techniques, which do not provide adequate performance. In an aspect, methods are disclosed that can examine brain tissue characteristics using ultrasonic signals. The methods are based on changes in brain tissue characteristics during the cardiac cycle and their measurement using backscattered ultrasonic echoes that enables measurement of tissue property changes in conditions such as stroke.

[0037] A patient suffering an ischemic stroke has a blood clot preventing blood to flow to brain tissue while a hemorrhagic stroke involves bleeding in the brain. For ischemic stroke, the region of the brain that is impacted is expected to exhibit decreased pulsatile tissue motion during the cardiac cycle. The methods disclosed can use ultrasound signals and image processing to detect the velocity of brain tissue motion during these pulsations and/or changes in spectral parameters that relate to impedance, density of scatterers, and/or size of scatterers in the brain. Using these methods, it has been shown that normal brain tissue exhibits a pattern of cyclic parameter changes during the cardiac cycle. Brain tissue that has been affected by-stroke is not expected to have similar cyclic parametric changes as a result of restricted blood flow and thus, can be distinguished from normal brain tissue. For hemorrhagic stroke, blood enters the brain and compresses the tissue it surrounds. Such behavior will modify the pattern of cyclic parameter changes during the cardiac cycle, and this modified pattern is expected to be different than normal brain tissue. Therefore incorporation of spectral parameters into assessment of tissue properties can lead to the differentiation between the two types of strokes.

[0038] The methods, systems, and apparatuses disclosed can perform stroke type detection and stroke localization. In an aspect, the methods can comprise calculating tissue parameters, normalization of the tissue parameters relative to a measured reference, and evaluation of the tissue parameters over time. Comparison of tissue through the brain can be made such that areas that behave abnormally can be identified. The manner in which the measures deviate between affected tissue and normal tissue provides can be used to differentiate between stroke type. In an aspect, the measures can be calculated for each pulse individually. This can reduce errors associated with motion and allow for slower frame rates of acquisition.

[0039] In an aspect, the methods, systems, and apparatuses can utilize Transcranial pulsatility imaging (TPI). TPI directly measures tissue velocity by means of Doppler frequency estimation. This measure relies explicitly on the phase relationship between successive ultrasonic pulses. However, the methods disclosed are not explicitly derivative of the Doppler information (e.g., tissue velocity). Ultrasonic spectral parameter estimation (USPE) can be used to assess tissue properties such as impedance, scatterer density, and size of scatterer. Existing methods focus on tissue spectral with the underlying assumption that the parameters are stationary over time. The methods, systems, and apparatuses disclosed can use the assumption that these parameters are in fact dynamic. The cyclic variation of integrated backscatter (CVIB) is a closely related topic to the present disclosure as CVIB measures tissue properties across multiple pulses but not in a Doppler sense. The methods, systems, and apparatuses can be based on cyclic variation in brain tissue properties. The methods, systems, and apparatuses further include developing images based on cyclic variations. Both TPI and USPE are imaging based approaches but do not focus on cyclic variations of tissue parameters. CVIB provides information on cyclic variations, but does not focus on generating images. The present methods, systems, and apparatuses are more robust than TPI measures that are reliant on information derivative of individual pulses. Motion between ultrasound pulses can significantly degrade the velocity estimate whereas spectral parameters are calculated at significantly higher rate.

[0040] In an aspect, the methods and systems can comprise an ultrasound apparatus. FIG. **1** illustrates an example ultrasound apparatus **100**. The ultrasound apparatus **100** may further include configurations not shown in FIG. **1** or may omit some of the configurations illustrated in FIG. **1**. Also, the configurations illustrated in FIG. **1** may be substituted by equivalents.

[0041] The ultrasound apparatus **100** may include one or more probes **101**, an ultrasound transmission/reception unit (e.g., transceiver) **102**, an image processing unit **103**, a communication unit **104**, a display unit **105**, a memory **106**, an input device **107**, and a controller **108**, which may be connected to one another via buses **109**.

[0042] The ultrasound apparatus **100** may be a cart type apparatus or a portable type apparatus. Examples of portable ultrasound apparatuses may include, but are not limited to, a picture archiving and communication system (PACS) viewer, a smartphone, a laptop computer, a personal digital assistant (PDA), and a tablet PC.

[0043] The probe **101** transmits ultrasound waves to an object **110** in response to a driving signal applied by the ultrasound transmission/reception unit **102** and receives echo signals reflected by the object **110**. The probe **101** includes a plurality of transducers, and the plurality of transducers oscillate in response to electric signals and generate acoustic energy, that is, ultrasound waves. Furthermore, the probe **101** may be connected to the main body of the ultrasound apparatus **100** by wire or wirelessly, and according to embodiments, the ultrasound apparatus **100** may include a plurality of probes **101**.

[0044] FIG. **2** illustrates an example configuration for one or more probes **101**. Hie object **110** can comprise a head (e.g., a human head). And the one or more probes **101** can be positioned at either side of the object **110** and at either side of a forehead of the object **110**. The one or more probes can be coupled to the ultrasound transmission/reception unit **102** and can operate as disclosed herein, in an aspect, the one or more probes **101** can be configured as a helmet or belt that can be affixed to the object **110** (e.g., a subject's head). In an aspect, the one or more probes **101** can be integrated into a cylindrical device within which a subject's head is placed, similar in appearance to a magnetic resonance imaging (MRI) head coil.

[0045] Returning to FIG. **1**, a transmission unit **111** supplies a driving signal to the probe **101**. The transmission unit **111** includes a pulse generating unit **112**, a transmission delaying unit **113**, and a pulser **114**. The pulse generating unit **112** generates pulses for forming transmission ultrasound waves based on a predetermined pulse repetition frequency (PRF), and the transmission delaying unit **113**

delays the pulses by delay times necessary for determining transmission directionality. The pulses which have been delayed correspond to a plurality of piezoelectric vibrators included in the probe **101**, respectively. The pulser **114** applies a driving signal (or a driving pulse) to the probe **101** based on timing corresponding to each of the pulses which have been delayed.

[0046] A reception unit **115** generates ultrasound data by processing echo signals received from the probe **101**. The reception unit **115** may include an amplifier **116**, an analog-to-digital converter (ADC) **117**, a reception delaying unit **118**, and a summing unit **119**. The amplifier **116** amplifies echo signals in each channel, and the ADC **117** performs analog-to-digital conversion with respect to the amplified echo signals. The reception delaying unit **118** delays digital echo signals output by the ADC **117** by delay times necessary for determining reception directionality, and the summing unit **119** generates ultrasound data by summing the echo signals processed by the reception delaying unit **118**. In some aspects, the reception unit **115** may not include the amplifier **116**. In other words, if the sensitivity of the probe **101** or the capability of the ADC **117** to process bits is enhanced, the amplifier **116** may be omitted.

[0047] The image processing unit **103** generates one or more ultrasound images by processing ultrasound data generated by the ultrasound transmission/reception unit **102**. The image processing unit **103** can comprise a data processing unit **120** and an image generating unit **121**. The image processing unit **103** can process the ultrasound data via scan-converting, for example. However, according to aspects, the scan-converting may be omitted. The ultrasound image may be not only a grayscale ultrasound image obtained by scanning an object in an amplitude (A) mode, a brightness (B) mode, and a motion (M) mode, but also a Doppler image showing a movement of an object via a Doppler effect. The Doppler image may be a blood flow Doppler image showing flow of blood (also referred to as a color Doppler image), a tissue Doppler image showing a movement of tissue, or a spectral Doppler image showing a moving speed of an object as a waveform.

[0048] The data processing unit **120** can comprise a B mode processing unit **122** and/or a Doppler processing unit **123**. The B mode processing unit **122** extracts B mode components from ultrasound data and processes the B mode components. The image generating unit **121** may generate an ultrasound image indicating signal intensities as brightness based on the extracted B mode components. The Doppler processing unit **123** may extract Doppler components from the ultrasound data. The image generating unit **121** may generate a Doppler image indicating a movement of an object as colors or waveforms based on the extracted Doppler components.

[0049] The data processing unit **120** can further comprise a signal analyzer unit **126**. The signal analyzer unit **126** can receive ultrasound data from the reception unit **115**. The signal analyzer unit **126** can analyze the ultrasound data to compare ultrasound reflections from different brain regions to determine whether the brain regions are normal or are affected by ischemic or hemorrhagic stroke.

[0050] In an aspect, the signal analyzer unit **126** can estimate an instantaneous intensity of backscattered ultrasound echoes from, a region of brain tissue. The signal analyzer unit **126** conditions the analog backscattered signal for digitization by the ADC **117** through the operations of amplification and of filtering. The received digital signal is converted to analytic form (e.g., complex valued) through a Hilbert transform or quadrature filtering operation. The magnitude of the complex valued received signal is defined as the instantaneous backscattered intensity and may be summed over spatially adjoining samples in depth and/or lateral directions to comprise one image voxel. The instantaneous backscattered intensity is calculated for every voxel in the field of regard of the ultrasound transmission. The time course of the instantaneous backscattered intensity in each voxel will exhibit cyclic oscillations with a period equal to that of the cardiac cycle. The time courses for instantaneous backscattered intensity measures from multiple cardiac cycles may be time synchronized and averaged together. The time synchronization can be achieved through time course resampling or phase adjustments using the peak systolic time instant as a reference. The electrocardiogram signal can be used to obtain a reference indicator of the phases of the cardiac cycle. The duration of the cardiac cycle can also be derived from the intrinsic period of the signals derived from brain tissue motion. The time course, and intrinsic features thereof, of the backscattered intensity across the cardiac cycle are compared for each voxel against: 1) previously stored known variations in normal brain tissue, 2) previously stored patterns or time courses of abnormal brain tissue, 3) previously stored historical patterns or time courses from the same subject, if available, for monitoring treatment. Any number of classification algorithms (including but not limited to Bayesian, neural network, support vector machines, k-nearest neighbor, and binary decision) can be used to determine whether the observed brain tissue region exhibits (a) normal pulsation, (b) abnormal pulsation characteristic of brain tissue affected by ischemic stroke, (c) abnormal pulsation characteristic of brain tissue affected by hemorrhagic stroke or (d) unknown abnormal pulsation.

[0051] In another aspect, the signal analyzer unit **126** can estimate the instantaneous frequency spectrum of the backscattered ultrasound echoes from a region of brain tissue, and calculate a number of instantaneous spectral parameters from the reflected ultrasound signal. The signal analyzer unit **126** conditions the analog backscattered signal for digitization by the ADC **117** through the operations of amplification and of filtering. The received digital signal is converted to analytic form (e.g. complex valued) through a Hilbert transform or quadrature filtering operation. The frequency spectrum is calculated for a set of L samples by one or more of a number of methods including but not limited to Fast Fourier Transform, Welch periodogram averaging, or autoregressive spectrum estimation. Features of the resultant spectra are then calculated. Features include, but are not limited to, mid-band fit, spectral slope, and zero-frequency intercept. Mid-band fit, β, is calculated as the average of the N frequency bins of the calculated spectrum, Z. Mid-band fit is measured as

$$\beta = \frac{1}{N}\sum_{n} Z_n$$

Spectral slope is calculated as

$$m = \sum_n \frac{12(n - N/2)Z_n}{(N^3 + 2N)\Delta f},$$

where Δf is the frequency spacing of the spectral estimate. The zero frequency intercept is calculated as a function of midband fit and spectral slope, $I=\beta-f_c n$, where f_c is the central frequency of the spectrum. Alternatively, these parameters may also be estimated by using a weighted least-squares method from the spectral estimate. Spectral parameters may be averaged over spatially adjoining samples in depth and/or lateral directions to comprise one image voxel. The spectral parameters are calculated for every voxel in the field of regard of the ultrasound transmission. The time course of the spectral parameters in each voxel will exhibit cyclic oscillations with a period equivalent to that of the cardiac cycle. The time courses for spectral parameters from multiple cardiac cycles may be time synchronized and averaged together. The time synchronization can be achieved through time course resampling or phase adjustments using the peak systolic time instant as a reference. The electrocardiogram signal can be used to obtain a reference indicator of the phases of the cardiac cycle. The duration of the cardiac cycle can also be derived from the intrinsic period of the signals derived from, brain tissue motion. The time course, and intrinsic features thereof, of the backscattered intensity across the cardiac cycle are compared for each voxel against: 1) previously-stored known variations in normal brain tissue, 2) previously stored patterns or time courses of abnormal brain tissue, 3) previously stored historical patterns or time courses from the same subject, if available, for monitoring treatment. Any number of classification algorithms (including but not limited to Bayesian, neural network, support vector machines, k-nearest neighbor, and binary decision) can be used to determine whether the observed brain tissue region exhibits (a) normal pulsation, (b) abnormal pulsation characteristic of brain tissue affected by ischemic stroke, (c) abnormal pulsation characteristic of brain tissue affected by hemorrhagic stroke or (d) unknown abnormal pulsation.

[0052] In another aspect, the signal analyzer unit **126** can estimate the statistical properties of the backscattered ultrasound echoes from a region of brain tissue, and calculate a number of parameters describing the statistical properties of the reflected ultrasound signal. The signal analyzer unit **126** conditions the analog backscattered signal for digitization by the ADC **117** through the operations of amplification and of filtering. The envelope of the backscattered radiofrequency signal is determined by one of several methods previously described in the art, including computing the root-mean-squared amplitude, or by converting the signal to analytic form through a Hilbert transform or quadrature filtering operation and computing the magnitude. The histogram of the backscattered intensities from a local region of brain tissue is then computed. The histogram of backscattered intensities may draw from samples taken from multiple cardiac cycles. The samples may be time synchronized and averaged together. The time synchronization can be achieved through time course resampling or phase adjustments using the peak systolic time instant as a reference. The electrocardiogram signal can be used to obtain a reference indicator of the phases of the cardiac cycle. The duration of the cardiac cycle can also be derived from the intrinsic period of the signals derived from brain tissue motion. The similarity of the histogram to a known probability distribution function is then determined using a similarity measure, such as the maximum likelihood function, and maximizing the similarity through an optimization algorithm. Examples of known probability distribution functions include, but are not limited to, the Rayleigh distribution, the Nakagami distribution, the gamma distribution, the Homodyned-K distribution, or a mixture of such distributions. Examples of optimization algorithms that can be used to maximize similarity include, but are not limited to, the quasi-Newton algorithm. The parameters of the probability distribution function that is most similar to the histogram of backscattered intensities are calculated for every voxel in the field of regard of the ultrasound transmission. The time course of the parameters in each voxel will exhibit cyclic oscillations with a period equivalent to that of the cardiac cycle. The time course, and intrinsic features thereof, of the parameters across the cardiac cycle are compared for each voxel against: 1) previously stored known values, and their variations in normal brain tissue, 2) previously stored patterns or time courses of abnormal brain tissue, 3) previously-stored historical values and patterns or time courses from the same subject, if available, for monitoring treatment. Any number of classification algorithms (including but not limited to Bayesian, neural network, support vector machines, k-nearest neighbor, and binary decision) can be used to determine whether the observed brain tissue region exhibits (a) normal pulsation, (b) abnormal pulsation characteristic of brain tissue affected by ischemic stroke, (c) abnormal pulsation characteristic of brain tissue affected by hemorrhagic stroke or (d) unknown abnormal pulsation.

[0053] FIG. **3**A illustrates an example of the variation of the spectral parameter mid-band-fit during the cardiac cycle in a region of normal brain tissue. FIG. **3**B illustrates an example of the variation of the spectral parameter spectral slope during the cardiac cycle in a region of normal brain tissue. FIG. **3**C illustrates an example of the variation of the spectral parameter zero-frequency-intercept during the cardiac cycle in a region of normal brain tissue.

[0054] Returning to FIG. **1**, in another aspect, the signal analyzer unit **126** can filter received ultrasound echoes using a bank of bandpass filters, and estimate a phase shift between consecutive filtered ultrasound echoes to calculate a variation of phase shift with instantaneous frequency contained in the received ultrasound echo. Based on this calculation, the signal analyzer unit **126** can estimate a pulsation of a region of brain tissue that is robust to a number of sources of noise. The signal analyzer unit **126** can further calculate a variation of this pulsation during the cardiac cycle, and compare these parameters and their variation between brain regions, and can compare these parameters against: 1) previously stored known variations in normal brain tissue, 2) previously stored patterns or time courses of abnormal brain tissue, 3) previously stored historical patterns or time courses from a specific subject. A classification algorithm is then used to determine whether the observed brain tissue region exhibits (a) normal pulsation, (b) abnormal pulsation characteristic of brain tissue affected by ischemic stroke, (c) abnormal pulsation characteristic of brain tissue affected by hemorrhagic stroke or (d) unknown abnormal pulsation. FIG. **3**D illustrates a time course of

estimated brain tissue velocity for three cardiac cycles using the disclosed phase shift method (least squares fit of filter bank outputs, LSFB) compared to method described in the prior art (two-dimensional autocorrelation 2DAC).

[0055] FIG. **4**A, FIG. **4**B, and FIG. **4**C illustrate a 3D geometric view of constrained filtered signals from a pair of consecutive reflected ultrasound echoes. The filter bank output for each filter for a single depth is shown by dots. The solution of the estimator is shown in green as a solid line through the distribution of filter bank outputs. The subsequent component images show: FIG. **4**A: RF frequency from pulse **1** to pulse **2**, FIG. **4**B: RF frequency of pulse **1** to Doppler frequency, and FIG. **4**C: RF frequency of pulse **2** to Doppler frequency. The slope of the 3D scatterplot can be used as a parametric measure of the instantaneous velocity of pulsation of the brain at that location.

[0056] Returning to FIG. **1**, according to an aspect, the image generating unit **121** may generate a three-dimensional (3D) ultrasound image via volume-rendering with respect to volume data and may also generate an elasticity image by imaging deformation of the object **110** due to pressure. Furthermore, the image generating unit **121** may display various pieces of additional information in an ultrasound image by using text and graphics. In addition, the generated ultrasound image may be stored in the memory **106**.

[0057] The display unit **105** displays the generated ultrasound image. The display unit **105** may display not only an ultrasound image, but also various pieces of information processed by the ultrasound apparatus **100** on a screen image via a graphical user interface (GUI). In addition, the ultrasound apparatus **100** may include two or more displays **105** according to aspects.

[0058] The display unit **105** can also display one or more results of the signal analyzer unit **126**. In an aspect, the display unit **105** can display one or more of a composite spatial map of brain tissue pulsatility and/or a parametric spatial map indicating whether different brain regions exhibit pulsations and tissue properties that are (a) normal, (b) characteristic of ischemic stroke, (c) characteristic of hemorrhagic stroke, or (d) indeterminate. FIG. **5** illustrates an example of a spatial map of pulsatility from a normal subject capable of being displayed via the display unit **105**.

[0059] In an aspect, a physician can use the information displayed on the display unit **105** to determine the type of stroke suffered by a subject. This information aids the physician in determining the proper course of treatment such as, but not limited to, the application of anticoagulating drugs in the case of ischemic stroke. In another aspect, a physician can use the information displayed on the display unit **105** to determine the degree to which a previous diagnosis has changed. Observations from a region previously determined to be characteristic of stroke that now shows improvement may result in the continued course of treatment. Whereas on the other hand observed degradation or lack of response to a treatment may alter the physicians plan of care.

[0060] The communication unit **104** can be connected to a network **124** by wire or wirelessly to communicate with an external device or a server. The communication unit **104** may exchange data with a hospital server or another medical apparatus in a hospital, which is connected thereto via a PACS. Furthermore, the communication unit **104** may perform data communication according to the digital imaging and communications in medicine (DICOM) standard.

[0061] The communication unit **104** may transmit or receive data related to diagnosis of an object e.g., an ultrasound image, ultrasound data, and Doppler data of the object, via the network **124** and may also transmit or receive medical images captured by another medical apparatus, e.g., a computed tomography (CT) apparatus, a magnetic resonance imaging (MRI) apparatus, or an X-ray apparatus. Furthermore, the communication unit **104** may receive information about a diagnosis history or medical treatment schedule of a patient from a server and utilizes the received information to diagnose the patient. Furthermore, the communication unit **104** may perform data communication not only with a server or a medical apparatus in a hospital, but also with a portable terminal of a medical doctor or patient.

[0062] The communication unit **104** can be connected to the network **124** by wire or wirelessly to exchange data with a server **125** (e.g., a medical apparatus, portable terminal, and the like). The communication unit **104** may include one or more components for communication with external devices. For example, the communication unit **104** may include a local area communication unit, a wired communication unit, and/or a wireless communication unit. The local area communication unit can be a module for local area communication within a predetermined distance. Examples of local area communication techniques according to an aspect may include, but are not limited to, wireless LAN, Wi-Fi, Bluetooth, ZigBee, Wi-Fi Direct (WFD), ultra wideband (UWB), infrared data association (IrDA), Bluetooth low energy (BLE), and near field communication (NFC). The wired communication unit can be a module for communication using electric signals or optical signals. Examples of wired communication techniques according to an aspect may include communication via a twisted pair cable, a coaxial cable, an optical fiber cable, and an Ethernet cable. The wireless communication unit can transmit or receive wireless signals to or from at least one selected from a base station, an external terminal, and a server on a mobile communication network. The wireless signals may be voice call signals, video call signals, or various types of data for transmission and reception of text/multimedia messages.

[0063] The memory **106** can store various data processed by the ultrasound apparatus **100**. For example, the memory **106** may store medical data related to diagnosis of an object, such as ultrasound data and an ultrasound image that are input or output, and may also store algorithms or programs which are to be executed in the ultrasound apparatus **100**. The memory **106** may be any of various storage media, e.g., a flash memory, a hard disk drive, EEPROM, etc. Furthermore, the ultrasound apparatus **100** may utilize web storage or a cloud server that performs the storage function of the memory **106** online.

[0064] The input device **107** can be configured to receive one or more user inputs for controlling the ultrasound apparatus **100**. The input device **107** may include hardware components, such as a keypad, a mouse, a touch panel, a touch screen, and a jog switch. However, aspects are not limited thereto, and the input device **107** may further include any of various other input units including an electrocardiogram (ECG) measuring module, a respiration measuring module, a voice recognition sensor, a gesture recognition sensor, a fingerprint recognition sensor, an iris recognition sensor, a depth sensor, a distance sensor, etc.

[0065] The controller **108** may control one or more operations of the ultrasound apparatus **100**. In other words, the

controller **108** may control operations among the probe **101**, the ultrasound transmission/reception unit **102**, the image processing unit **103**, the communication unit **104**, the memory **106**, and the input device **107** shown in FIG. **1**.

[0066] All or some of the probe **101**, the ultrasound transmission/reception unit **102**, the image processing unit **103**, the communication unit **104**, the memory **106**, the input device **107**, and the controller **108** may be implemented as software modules. However, aspects are not limited thereto, and some of the components stated above may be implemented as hardware modules. Furthermore, at least one selected from the ultrasound transmission/reception unit **102**, the image processing unit **103**, and the communication unit **104** may be included in the controller **108**. However, embodiments of the present methods, systems, and apparatuses are not limited thereto.

[0067] In an aspect, illustrated in FIG. **6**, provided is a method **600** that represents at least a portion of the collection and analysis steps described with relation the ultrasound apparatus **100** in FIG. **1**. In block **610**, post-beamformed RF data is collected. In block **620**, the diagnostic measure of instantaneous backscattered energy, spectral parameter, and/or velocity estimate is calculated for each volume under analysis. In block **630**, the time courses for each volume are analyzed against the database of time courses or features derived therefrom.

[0068] In an aspect, illustrated in FIG. **7**, provided is a method **700** comprising transmitting ultrasound waves to a plurality of regions of a brain of a subject via one or more probes at block **710**. The method **700** can comprise receiving ultrasound echoes corresponding to the transmitted ultrasound waves at block **720**. The method **700** can comprise determining a parameter based on the ultrasound echoes for each region of the plurality of regions at block **730**. The parameter can comprise one or more of, a backscattered intensity, a measure derived from the probability distribution of backscattered intensities from a local brain region, a spectral slope of an instantaneous frequency of each ultrasound echo, a mid-band fit of an instantaneous frequency of each ultrasound echo, a zero-frequency offset of an instantaneous frequency of each ultrasound echo, and a phase shift across different frequencies. The method **700** can comprise determining a time course for each parameter at block **740**.

[0069] In an aspect, the method **700** can proceed to one or both of block **750** and block **760**. At block **750**, the method **700** can comprise comparing the time courses for each region of the plurality of regions to determine a pulsatility measurement for each region of the plurality of regions. At block **760**, the method **700** can comprise comparing the time courses to one or more of, a known time course in normal brain tissue and a known time course in abnormal brain tissue to classify each region of the plurality of regions as comprising normal brain tissue or abnormal brain tissue. The known time course in abnormal brain tissue can comprise a known time course associated with brain tissue affected by ischemic stroke and a known time course associated with brain tissue affected by hemorrhagic stroke.

[0070] The method **700** can further comprise receiving a signal from an electrocardiogram to determine the timing of a cardiac cycle, and a timing of brain tissue pulsations relative to the cardiac cycle, and differentiating between normal and abnormal brain tissue by comparing pulsations during a certain portion of the cardiac cycle, and/or the delay between the peak of the pulsations to the beginning of the cardiac cycle.

[0071] The method **700** can further comprise filtering the backscattered ultrasound echoes through one or more band-pass filters to determine the phase shift across different frequencies.

[0072] The method **700** can further comprise accessing a database comprising a plurality of known time courses in the subject and determining a measure of degree to which the time course has changed over time relative to the plurality of known time courses.

[0073] The method **700** can further comprise outputting a composite spatial map of brain tissue pulsatility based on the pulsatility measurements. The method **700** can further comprise outputting a parametric spatial map indicating whether each region of the plurality of regions is one of, normal, characteristic of ischemic stroke, characteristic of hemorrhagic stroke, or indeterminate.

[0074] In another aspect, illustrated in FIG. **8**, provided is a method **800** comprising transmitting ultrasound waves to a plurality of regions of a brain of a subject via one or more probes at block **810**. The method **800** can comprise receiving backscattered ultrasound echoes corresponding to the transmitted ultrasound waves at block **820**. The method **800** can comprise determining an instantaneous intensity of the backscattered ultrasound echoes for each region of the plurality of regions at block **830**. The method **800** can comprise determining a variation of the instantaneous intensity during a cardiac cycle for each region of the plurality of regions at block **840**. The method **800** can comprise determining a pattern of variation by comparing the variations between the plurality of regions at block **850**. The method **800** can comprise comparing the pattern of variation and deriving a measure of similarity to one or more of, a known pattern of variation in normal brain tissue, a known pattern of variation in abnormal brain tissue, and a known pattern of variation in the subject at block **860**. The method **800** can comprise applying a classification algorithm using the measure of similarity to determine whether the pattern of variation is associated with a normal pulsation, an abnormal pulsation characteristic of brain tissue affected by ischemic stroke, an abnormal pulsation characteristic of brain tissue affected by hemorrhagic stroke, or an unknown abnormal pulsation at block **870**.

[0075] In another aspect, illustrated in FIG. **9**, provided is a method **900** comprising transmitting ultrasound waves to a plurality of regions of a brain of a subject via one or more probes at block **910**. The method **900** can comprise receiving backscattered ultrasound echoes corresponding to the transmitted ultrasound waves at block **920**. The method **900** can comprise determining one or more instantaneous spectral parameters from the backscattered ultrasound echoes at block **930**. The method **900** can comprise determining a pattern of variation of the one or more instantaneous spectral parameters during a cardiac cycle for each region of the plurality of regions at block **940**. The method **900** can comprise comparing the pattern of variation and deriving a measure of similarity to one or more of, a known pattern of variation in normal brain tissue, a known pattern of variation in abnormal brain tissue, and a known pattern of variation in the subject at block **950**. The method **900** can comprise applying a classification algorithm using the measure of similarity to determine whether the pattern of variation is

associated with a normal pulsation, an abnormal pulsation characteristic of brain tissue affected by ischemic stroke, an abnormal pulsation characteristic of brain tissue affected by hemorrhagic stroke, or an unknown abnormal pulsation at block **960**.

[0076] In another aspect, illustrated in FIG. **10**, provided is a method **1000** comprising transmitting ultrasound waves to a plurality of regions of a brain of a subject via one or more probes at block **1010**.

[0077] The method **1000** can comprise receiving backscattered ultrasound echoes corresponding to the transmitted ultrasound waves at block **1020**.

[0078] The method **1000** can comprise filtering the backscattered ultrasound echoes at block **1030**. The method **1000** can comprise determining a phase shift between consecutive filtered backscattered ultrasound echoes at block **1040**.

[0079] The method **1000** can comprise determining a variation of phase shift with instantaneous frequency contained in the backscattered ultrasound echoes at block **1050**. The method **1000** can comprise determining a pulsation for each region of the plurality of regions based on the variation of phase shift with instantaneous frequency at block **1060**. The method **1000** can comprise determining a variation of the pulsations during a cardiac cycle at block **1070**.

[0080] The method **1000** can comprise comparing the variation of the pulsations during a cardiac cycle and deriving a measure of similarity to one or more of, a known variation in normal brain tissue, a known variation in abnormal brain tissue, and a known variation in the subject at block **1080**.

[0081] The method **1000** can comprise applying a classification algorithm using the measure of similarity to determine whether the variation of the pulsations is associated with a normal pulsation, an abnormal pulsation characteristic of brain tissue affected by ischemic stroke, an abnormal pulsation characteristic of brain tissue affected by hemorrhagic stroke, or an unknown abnormal pulsation at block **1090**.

[0082] In another aspect, illustrated in FIG. **11**, provided is a method **1100** comprising transmitting ultrasound waves to a plurality of regions of a brain of a subject via one or more probes at block **1110**. The method **1100** can comprise receiving backscattered ultrasound echoes corresponding to the transmitted ultrasound waves at block **1120**. The method **1100** can comprise determining a histogram of backscattered ultrasound echo intensities from a local region of brain tissue at block **1130**. The method **1100** can comprise determining one or more parameters of a probability distribution function that best describes the histogram of backscattered ultrasound echo intensities at block **1140**. The method **1100** can comprise determining a variation of parameters of the probability distribution function during the cardiac cycle at block **1150**. The method **1100** can comprise determining a variation of parameters for each region of the plurality of regions based on the variation of parameters of the probability distribution function at block **1160**. The method **1100** can comprise comparing the variation of the parameters and deriving a measure of similarity to one or more of, a known variation in normal brain tissue, a known variation in abnormal brain tissue, and a known variation in the subject at block **1170**. The method **1100** can comprise applying a classification algorithm using the measure of similarity to determine whether the variation of the pulsations is associated with a normal pulsation, an abnormal pulsation characteristic of brain tissue affected by ischemic stroke, an abnormal pulsation characteristic of brain tissue affected by hemorrhagic stroke, or an unknown abnormal pulsation at block **1180**.

[0083] In an exemplary aspect, the methods and systems can be implemented on a computer **1201** as illustrated in FIG. **12** and described below. By way of example, the ultrasound apparatus **100** and/or the server **125** of FIG. **1** can be a computer **1201** as illustrated in FIG. **6**. Similarly, the methods and systems disclosed can utilize one or more computers to perform one or more functions in one or more locations. FIG. **12** is a block diagram illustrating an exemplary operating environment **1200** for performing the disclosed methods. This exemplary operating environment **1200** is only an example of an operating environment and is not intended to suggest any limitation as to the scope of use or functionality of operating environment architecture. Neither should the operating environment **1200** be interpreted as having any dependency or requirement relating to any one or combination of components illustrated in the exemplary operating environment **1200**.

[0084] The present methods and systems can be operational with numerous other general purpose or special purpose computing system environments or configurations. Examples of well known computing systems, environments, and/or configurations that can be suitable for use with the systems and methods comprise, but are not limited to, personal computers, server computers, laptop devices, and multiprocessor systems. Additional examples comprise set top boxes, programmable consumer electronics, network PCs, minicomputers, mainframe computers, distributed computing environments that comprise any of the above systems or devices, and the like.

[0085] The processing of the disclosed methods and systems can be performed by-software components. The disclosed systems and methods can be described in the general context of computer-executable instructions, such as program modules, being executed by one or more computers or other devices. Generally, program modules comprise computer code, routines, programs, objects, components, data structures, and/or the like that perform particular tasks or implement particular abstract data types. The disclosed methods can also be practiced in grid-based and distributed computing environments where tasks are performed by remote processing devices that are linked through a communications network. In a distributed computing environment, program modules can be located in local and/or remote computer storage media including memory storage devices.

[0086] Further, one skilled in the art will appreciate that the systems and methods disclosed herein can be implemented via a general-purpose computing device in the form of a computer **1201**. The computer **1201** can comprise one or more components, such as one or more processors **1203**, a system memory **1212**, and a bus **1213** that couples various components of the computer **1201** including the one or more processors **1203** to the system memory **1212**. In the case of multiple processors **1203**, the system can utilize parallel computing.

[0087] The bus **1213** can comprise one or more of several possible types of bus structures, such as a memory bus, memory controller, a peripheral bus, an accelerated graphics port, and a processor or local bus using any of a variety of bus architectures. By way of example, such architectures can

comprise an Industry-Standard Architecture (ISA) bus, a Micro Channel Architecture (MCA) bus, an Enhanced ISA (EISA) bus, a Video Electronics Standards Association (VESA) local bus, an Accelerated Graphics Port (AGP) bus, and a Peripheral Component Interconnects (PCI), a PCT-Express bus, a Personal Computer Memory Card Industry Association (PCMCIA), Universal Serial Bus (USB) and the like. The bus **1213**, and all buses specified in this description can also be implemented over a wired or wireless network connection and one or more of the components of the computer **1201**, such as the one or more processors **1203**, a mass storage device **1204**, an operating system **1205**, ultrasound software **1206**, ultrasound data **1207**, a network adapter **1208**, system memory **1212**, an Input/Output Interface **1210**, a display adapter **1209**, a display device **1211**, and a human machine interface **1202**, can be contained within one or more remote computing devices **1214***a,b,c* at physically separate locations, connected through buses of this form, in effect implementing a fully distributed system.

[0088] The computer **1201** typically comprises a variety of computer readable media. Exemplary readable media can be any available media that is accessible by the computer **1201** and comprises, for example and not meant to be limiting, both volatile and non-volatile media, removable and non-removable media. The system memory **1212** can comprise computer readable media in the form of volatile memory, such as random access memory (RAM), and/or non-volatile memory, such as read only memory (ROM). The system memory **1212** typically can comprise data such as ultrasound data **1207** and/or program modules such as operating system **1205** and ultrasound software **1206** that are accessible to and/or are operated on by the one or more processors **1203**.

[0089] In another aspect, the computer **1201** can also comprise other removable/non-removable, volatile/non-volatile computer storage media. The mass storage device **1204** can provide non-volatile storage of computer code, computer readable instructions, data structures, program modules, and other data for the computer **1201**. For example, a mass storage device **1204** can be a hard disk, a removable magnetic disk, a removable optical disk, magnetic cassettes or other magnetic storage devices, flash memory cards, CD-ROM, digital versatile disks (DVD) or other optical storage, random access memories (RAM), read only memories (ROM), electrically erasable programmable read-only memory (EEPROM), and the like.

[0090] Optionally, any number of program modules can be stored on the mass storage device **1204**, including by way of example, an operating system **1205** and ultrasound software **1206**. One or more of the operating system **1205** and ultrasound software **1206** (or some combination thereof) can comprise elements of the programming and the ultrasound software **1206**. Ultrasound data **1207** can also be stored on the mass storage device **1204**. Parameters derived from the ultrasound data **1207** can be stored in any of one or more databases known in the art. Examples of such databases comprise, DB2®, Microsoft® Access, Microsoft® SQL Server, Oracle®, mySQL, PostgreSQL, SQLite, and the like. The databases can be centralized or distributed across multiple locations within the network or local to the device itself. **1215**.

[0091] In another aspect, the user can enter commands and information into the computer **1201** via an input device (not shown). Examples of such input devices comprise, but are not limited to, a keyboard, pointing device (e.g., a computer mouse, remote control), a microphone, a joystick, a scanner, tactile input devices such as gloves, and other body coverings, motion sensor, and the like. These and other input devices can be connected to the one or more processors **1203** via a human machine interface **1202** that is coupled to the bus **1213**, but can be connected by other interface and bus structures, such as a parallel port, game port, an IEEE 1394 Port (also known as a Firewire port), a serial port, network adapter **1208**, and/or a universal serial bus (USB).

[0092] In yet another aspect, a display device **1211** can also be connected to the bus **1213** via an interface, such as a display adapter **1209**. It is contemplated that the computer **1201** can have more than one display adapter **1209** and the computer **1201** can have more than one display device **1211**. For example, a display device **1211** can be a monitor, an LCD (Liquid Crystal Display), light emitting diode (LED) display, television, smart lens, smart glass, and/or a projector. In addition to the display device **1211**, other output peripheral devices can comprise components such as speakers (not shown) and a printer (not shown), which can be connected to the computer **1201** via Input/Output Interface **1210**. Any step and/or result of the methods can be output in any form to an output device. Such output can be any form of visual representation, including, but not limited to, textual, graphical, animation, audio, tactile, and the like. The display **1211** and computer **1201** can be part of one device, or separate devices.

[0093] The computer **1201** can operate in a networked environment using logical connections to one or more remote computing devices **1214***a,b,c*. By way of example, a remote computing device **1214***a,b,c* can be a personal computer, computing station (e.g., workstation), portable computer (e.g., laptop, mobile phone, tablet device), smart device (e.g., smartphone, smart watch, activity tracker, smart apparel, smart accessory), security and/or monitoring device, a server, a router, a network computer, a peer device, edge device or other common network node, and so on. Logical connections between the computer **1201** and a remote computing device **1214***a,b,c* can be made via a network **1215**, such as a local area network (LAN) and/or a general wide area network (WAN). Such network connections can be through a network adapter **1208**. A network adapter **1208** can be implemented in both wired and wireless environments. Such networking environments are conventional and commonplace in dwellings, offices, enterprise-wide computer networks, intranets, and the Internet.

[0094] For purposes of illustration, application programs and other executable program components such as the operating system **1205** are illustrated herein as discrete blocks, although it is recognized that such programs and components can reside at various times in different storage components of the computing device **1201**, and are executed by the one or more processors **1203** of the computer **1201**. An implementation of ultrasound software **1206** can be stored on or transmitted across some form of computer readable media. Any of the disclosed methods can be performed by computer readable instructions embodied on computer readable media. Computer readable media can be any available media that can be accessed by a computer. By way of example and not meant to be limiting, computer readable media can comprise "computer storage media" and "communications media." "Computer storage media" can comprise volatile and non-volatile, removable and non-

removable media implemented in any methods or technology for storage of information such as computer readable instructions, data structures, program modules, or other data. Exemplary computer storage media can comprise RAM, ROM, EEPROM, flash memory or other memory technology, CD-ROM, digital versatile disks (DVD) or other optical storage, magnetic cassettes, magnetic tape, magnetic disk storage or other magnetic storage devices, or any other medium which can be used to store the desired information and which can be accessed by a computer.

[0095] The methods and systems can employ artificial intelligence (AI) techniques such as machine learning and iterative learning. Examples of such techniques include, but are not limited to, expert systems, case based reasoning, Bayesian networks, behavior based AI, neural networks, fuzzy systems, evolutionary computation (e.g. genetic algorithms), swarm intelligence (e.g. ant algorithms), and hybrid intelligent systems (e.g. Expert inference rules generated through a neural network or production rules from statistical learning).

[0096] While the methods and systems have been described in connection with preferred embodiments and specific examples, it is not intended that the scope be limited to the particular embodiments set forth, as the embodiments herein are intended in all respects to be illustrative rather than restrictive.

[0097] Unless otherwise expressly stated, it is in no way intended that any method set forth herein be construed as requiring that its steps be performed in a specific order. Accordingly, where a method claim does not actually recite an order to be followed by its steps or it is not otherwise specifically stated in the claims or descriptions that the steps are to be limited to a specific order, it is no way intended that an order be inferred, in any respect. This holds for any possible non-express basis for interpretation, including: matters of logic with respect to arrangement of steps or operational flow; plain meaning derived from grammatical organization or punctuation; the number or type of embodiments described in the specification.

[0098] It will be apparent to those skilled in the art that various modifications and variations can be made without departing from the scope or spirit. Other embodiments will be apparent to those skilled in the art from consideration of the specification and practice disclosed herein. It is intended that the specification and examples be considered as exemplary only, with a true scope and spirit being indicated by the following claims.

What is claimed is:

1. A method comprising:

transmitting ultrasound waves to a plurality of regions of a brain of a subject via one or more probes;

receiving ultrasound echoes corresponding to the transmitted ultrasound waves;

determining a parameter based on the ultrasound echoes for each region of the plurality of regions;

determining a time course for each parameter; and

comparing the time courses for each region of the plurality of regions to determine a pulsatility measurement for each region of the plurality of regions.

2. The method of claim **1**, further comprising:

comparing the time courses to one or more of, a known time course in normal brain tissue and a known time course in abnormal brain tissue to classify each region of the plurality of regions as comprising normal brain tissue or abnormal brain tissue.

3. The method of claim **1**, further comprising receiving a signal from an electrocardiogram to determine the timing of a cardiac cycle, and a timing of brain tissue pulsations relative to the cardiac cycle, and differentiating between normal and abnormal brain tissue by comparing pulsations during a certain portion of the cardiac cycle, and/or the delay between the peak of the pulsations to the beginning of the cardiac cycle.

4. The method of claim **1**, wherein the parameter comprises one or more of, a backscattered intensity, a measure derived from the probability distribution of backscattered intensities from a local brain region, a spectral slope of an instantaneous frequency of each ultrasound echo, a mid-band fit of an instantaneous frequency of each ultrasound echo, a zero-frequency offset of an instantaneous frequency of each ultrasound echo, and a phase shift across different frequencies.

5. The method of claim **4**, further comprising filtering the backscattered ultrasound echoes through one or more band-pass filters to determine the phase shift across different frequencies.

6. The method of claim **1**, wherein the known time course in abnormal brain tissue comprises a known time course associated with brain tissue affected by ischemic stroke and a known time course associated with brain tissue affected by hemorrhagic stroke.

7. The method of claim **1**, further comprising:

accessing a database comprising a plurality of known time courses in the subject; and

determining a measure of degree to which the time course has changed over time relative to the plurality of known time courses.

8. The method of claim **1**, further comprising outputting a composite spatial map of brain tissue pulsatility based on the pulsatility measurements.

9. The method of claim **1**, further comprising outputting a parametric spatial map indicating whether each region of the plurality of regions is one of, normal, characteristic of ischemic stroke, characteristic of hemorrhagic stroke, or indeterminate.

10. A method comprising:

transmitting ultrasound waves to a plurality of regions of a brain of a subject via one or more probes;

receiving ultrasound echoes corresponding to the transmitted ultrasound waves;

determining a parameter based on the ultrasound echoes for each region of the plurality of regions;

determining a time course for each parameter; and

comparing the time courses to one or more of, a known time course in normal brain tissue and a known time course in abnormal brain tissue to classify each region of the plurality of regions as comprising normal brain tissue or abnormal brain tissue.

11. The method of claim **10**, further comprising:

comparing the time courses for each region of the plurality of regions to determine a pulsatility measurement for each region of the plurality of regions.

12. The method of claim **10**, further comprising receiving a signal from an electrocardiogram to determine the timing of a cardiac cycle, and a timing of brain tissue pulsations relative to the cardiac cycle, and differentiating between normal and abnormal brain tissue by comparing pulsations

during a certain portion of the cardiac cycle, and/or the delay between the peak of the pulsations to the beginning of the cardiac cycle.

13. The method of claim **10**, wherein the parameter comprises one or more of, a backscattered intensity, a measure derived from the probability distribution of backscattered intensities from a local brain region, a spectral slope of an instantaneous frequency of each ultrasound echo, a mid-band fit of an instantaneous frequency of each ultrasound echo, a zero-frequency offset of an instantaneous frequency of each ultrasound echo, and a phase shift across different frequencies.

14. The method of claim **13**, further comprising filtering the backscattered ultrasound echoes through one or more bandpass filters to determine the phase shift across different frequencies.

15. The method of claim **10**, wherein the known time course in abnormal brain tissue comprises a known time course associated with brain tissue affected by ischemic stroke and a known time course associated with brain tissue affected by hemorrhagic stroke.

16. The method of claim **10**, further comprising:

accessing a database comprising a plurality of known time courses in the subject; and

determining a measure of degree to which the time course has changed over time relative to the plurality of known time courses.

17. The method of claim **10**, further comprising outputting a composite spatial map of brain tissue pulsatility based on the pulsatility measurements.

18. The method of claim **10**, further comprising outputting a parametric spatial map indicating whether each region of the plurality of regions is one of, normal, characteristic of ischemic stroke, characteristic of hemorrhagic stroke, or indeterminate.

19. A system comprising:

one or more ultrasound transducers configured to transmit ultrasound waves to a plurality of regions of an object and receive backscattered ultrasound echoes corresponding to the transmitted ultrasound waves;

a processor, coupled to the one or more ultrasound transducers, wherein the processor is configured to,

transmit ultrasound waves to a plurality of regions of a brain of a subject via one or more probes;

receive ultrasound echoes corresponding to the transmitted ultrasound waves;

determine a parameter based on the ultrasound echoes for each region of the plurality of regions;

determine a time course for each parameter; and

compare the time courses for each region of the plurality of regions to determine a pulsatility measurement for each region of the plurality of regions.

20. The system of claim **19**, wherein the processor is further configured to:

compare the time courses to one or more of, a known time course in normal brain tissue and a known lime course in abnormal brain tissue to classify each region of the plurality of regions as comprising normal brain tissue or abnormal brain tissue.

* * * * *

专利名称(译)	脑卒中患者脑活动超声分析的方法和装置		
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摘要(译)

公开了一种方法，包括经由一个或多个探头向对象的大脑的多个区域发射超声波，接收对应于所发射的超声波的超声回波，基于多个区域中的每个区域的超声回波确定参数，确定每个参数的时间过程，以及以下中的一个或多个：比较所述多个区域中的每个区域的时程，以确定所述多个区域中的每个区域的搏动测量，并将所述时程与以下中的一个或多个比较： ，正常脑组织中的已知时间过程和异常脑组织中的已知时间过程，以将多个区域中的每个区域分类为包括正常脑组织或异常脑组织。