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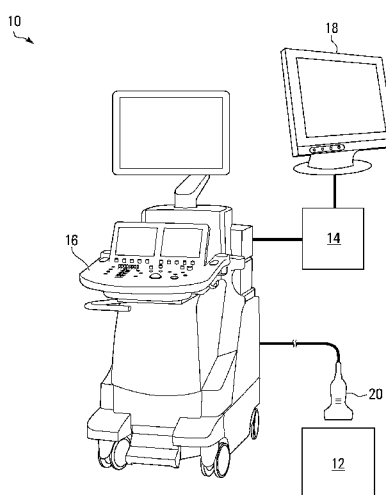


FIG. 1

(57) Abstract: A method of facilitating ultrasonic analysis of a subject is provided. The method involves producing signals for causing a set of outgoing ultrasonic signals to be transmitted to the subject, wherein the set of outgoing ultrasonic signals is defined at least in part by a variable imaging parameter that varies over time in accordance with a variable imaging parameter function, the variable imaging parameter function represented or representable at least in part by a function characteristic, receiving signals representing a time dependent representation of the subject generated from a set of received ultrasonic signals scattered by the subject, determining at least one property representation of the subject based on the function characteristic and the time dependent representation of the subject, and producing signals representing the at least one property representation of the subject to facilitate analysis of the subject. Systems, non-transitory computer readable media, and other methods are also provided.

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ULTRASONIC ANALYSIS OF A SUBJECT

RELATED APPLICATION

5 This application claims the benefit of U.S. Provisional Application No. **62/732,904** entitled "ULTRASONIC ANALYSIS OF A SUBJECT", filed on September **18, 2018**, which is hereby incorporated by reference herein in its entirety.

BACKGROUND

1. Field

10 Embodiments of this invention relate to nondestructive testing and more particularly to nondestructive testing using ultrasonic analysis of a subject.

2. Description of Related Art

15 Nondestructive Testing ("NDT") may be used to analyze or characterize various subjects, such as, for example, materials, tissue, tools, devices, tissue/organs, or other subjects where damage to the subject is undesirable, but analysis of the subject is required. Some NDT techniques may involve using microscopy or analysis of a single ultrasound image. However, such known NDT techniques may be difficult to set up and perform and/or may not perform well in detecting or
20 characterizing subtle properties of the subjects, such as, for example where a change in or loss of signal caused by the property may be negligible.

SUMMARY

25 In accordance with various embodiments, there is provided a method of facilitating ultrasonic analysis of a subject, the method involving producing signals for causing a set of outgoing ultrasonic signals to be transmitted to the subject, wherein the set of outgoing ultrasonic signals is defined at least in part by a variable imaging parameter that varies over time in accordance with a variable imaging parameter function, the variable imaging parameter function represented or representable at
30 least in part by a function characteristic, receiving signals representing a time dependent representation of the subject generated from a set of received

5 ultrasonic signals scattered by the subject, determining at least one property representation of the subject based on the function characteristic and the time dependent representation of the subject, and producing signals representing the at least one property representation of the subject to facilitate analysis of the subject.

10 The set of outgoing ultrasonic signals may be a temporally ordered set of outgoing ultrasonic signals and the variable imaging parameter may vary over the temporally ordered set of outgoing ultrasonic signals.

15 The set of outgoing ultrasonic signals may include at least one ultrasonic beam and producing the signals for causing the set of outgoing ultrasonic signals to be transmitted to the subject may involve producing signals for causing the at least one ultrasonic beam to be transmitted to the subject, the at least one ultrasonic beam defined at least in part by the variable imaging parameter.

20 The variable imaging parameter may be a focal depth of the at least one ultrasonic beam and producing the signals for causing the at least one ultrasonic beam to be transmitted to the subject may involve producing signals for causing the focal depth of the at least one ultrasonic beam to vary over time according to the variable imaging parameter function.

25 The variable imaging parameter function may include a periodic function that varies over time at an imaging parameter frequency and the function characteristic may include the imaging parameter frequency.

30 Determining the at least one property representation of the subject may involve applying a band-pass filter to the time dependent representation of the subject, the band-pass filter configured to pass the imaging parameter frequency.

Determining the at least one property representation of the subject may involve applying a discrete Fourier transform to the time dependent representation of the subject to determine one or more imaging parameter frequency components, each of the one or more imaging parameter frequency components associated with the
5 imaging parameter frequency.

The method may involve, for each of the one or more imaging parameter frequency components, applying at least one anomaly criterion to the imaging parameter frequency component to determine whether the imaging parameter frequency
10 component indicates presence of an anomaly in the subject.

Applying the at least one anomaly criterion may involve determining whether the imaging parameter frequency component is outside of a predetermined normal range.
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Producing the signals representing the at least one property representation of the subject may involve producing signals for causing at least one display to display a representation of the subject including indicators identifying the one or more imaging parameter frequency components determined to be outside of the
20 predetermined normal range.

Producing the signals representing the at least one property representation of the subject may involve producing signals for causing at least one display to display a representation of the one or more imaging parameter frequency components.
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The periodic function may be a first periodic function and the imaging parameter frequency may be a first imaging parameter frequency. The variable imaging parameter function may include a second periodic function that varies over time at a second imaging parameter frequency, different from the first imaging parameter
30 frequency such that the variable imaging parameter function is represented at least in part by the second imaging parameter frequency. Determining the at least one

property representation of the subject based on the function characteristic and the time dependent representation of the subject may involve determining the at least one property representation of the subject based on the first imaging parameter frequency, the second imaging parameter frequency, and the time dependent representation of the subject.

The set of outgoing ultrasonic signals may be a first set of outgoing ultrasonic signals, the variable imaging parameter may be a first variable imaging parameter, the variable imaging parameter function may be a first variable imaging parameter function, and the function characteristic may be a first function characteristic. The method may involve producing signals for causing a second set of outgoing ultrasonic signals to be transmitted to the subject, wherein the second set of outgoing ultrasonic signals is defined at least in part by a second variable imaging parameter that varies over time in accordance with a second variable imaging parameter function, the second variable imaging parameter function represented at least in part by a second function characteristic, and receiving signals representing a second time dependent representation of the subject generated from a second set of received ultrasonic signals scattered by the subject. Determining the at least one property representation of the subject may involve determining the at least one property representation of the subject based on the first function characteristic, the second function characteristic, and the time dependent representation of the subject.

The subject may be a composite material.

In accordance with various embodiments, there is provided a system for facilitating ultrasonic analysis of a subject comprising at least one processor configured to perform any of the above methods.

In accordance with various embodiments, there is provided a non-transitory computer readable medium having stored thereon codes which when executed by

at least one processor cause the at least one processor to perform any of the above methods.

5 Other aspects and features of embodiments of the invention will become apparent to those ordinarily skilled in the art upon review of the following description of specific embodiments of the invention in conjunction with the accompanying figures.

BRIEF DESCRIPTION OF THE DRAWINGS

In drawings which illustrate embodiments of the invention,

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Figure 1 is a schematic view of a system for facilitating ultrasonic analysis of a subject, according to various embodiments of the invention;

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Figure 2 is a schematic view of an analyzer of the system shown in Figure 1 including a processor circuit in accordance with various embodiments of the invention;

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Figure 3 is a flowchart depicting blocks of code for directing the analyzer of the system shown in Figure 1 to perform subject analysis functions in accordance with various embodiments of the invention;

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Figure 4 is a representation of an exemplary ultrasound instruction message that may be used in the system shown in Figure 1 in accordance with various embodiments of the invention;

Figure 5 is a representation of an exemplary image record that may be used in the system shown in Figure 1 in accordance with various embodiments of the invention;

- Figure 6 is a flowchart depicting blocks of code that may be included in the flowchart shown in Figure 3 in accordance with various embodiments of the invention;
- 5 Figure 7 is a representation of images that may be used in the system shown in Figure 1 in accordance with various embodiments of the invention;
- Figure 8 is a flowchart depicting blocks of code that may be included in the flowchart shown in Figure 3 in accordance with various embodiments of the invention;
- 10 Figure 9 is a representation of an exemplary anomaly range record that may be used in the system shown in Figure 1 in accordance with various embodiments of the invention;
- 15 Figure 10 is a representation of an exemplary anomaly indicating image and an image that may be used in the system shown in Figure 1 in accordance with various embodiments of the invention;
- 20 Figure 11 is a representation of how an image of the system may fit as a plane of voxels in a larger 3D representation in Figure 1 in accordance with various embodiments of the invention
- Figure 12 is a representation of an exemplary ultrasound instruction message that may be used in the system shown in Figure 1 in accordance with various embodiments of the invention;
- 25 Figure 13 is a representation of an exemplary ultrasound instruction message that may be used in the system shown in Figure 1 in accordance with various embodiments of the invention;
- 30

Figure **14** is a representation of an exemplary ultrasound instruction message that may be used in the system shown in Figure **1** in accordance with various embodiments of the invention; and

- 5 Figure **15** is a schematic view of a system for facilitating ultrasonic analysis of a subject, according to various embodiments of the invention.

DETAILED DESCRIPTION

10 Referring to Figure **1**, there is provided a schematic representation of a system **10** for facilitating ultrasonic analysis of a subject **12**, in accordance with various embodiments described herein. The system includes a computer-implemented analyzer **14** and an ultrasound machine **16** in communication with the analyzer **14**. In various embodiments, the system **10** may also include a display **18** in communication with the analyzer **14**.

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In some embodiments, the system **10** may facilitate ultrasonic analysis of materials or parts to allow detection of subtle defects in the materials, which may be difficult to detect using conventional NDT analysis. In some embodiments, the system **10** may facilitate ultrasonic analysis of advanced composite parts, such as parts made from fibre-reinforced composite materials, for example. In various embodiments, defects may include, for example, porosity, foreign object debris, impact-induced delamination, heat-induced resin degradation, and/or waviness of fibres or wrinkles in the fibres. In various embodiments, the system **10** may facilitate easier implementation of NDT without affecting workflow of a production factory and/or may provide improved detection of defects or properties of a subject, when compared to conventional NDT techniques.

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In various embodiments, a user of the system **10** may initiate ultrasonic analysis of the subject **12** through interaction with the analyzer **14**. For example, in some embodiments, the user may initiate ultrasonic analysis of the subject **12** during quality assurance testing of the subject **12**. Upon initiation of the analysis, the

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analyzer **14** may be configured to produce signals for causing a set of outgoing ultrasonic signals to be transmitted to the subject **12**, wherein the transmitted ultrasonic signals are defined at least in part by a variable imaging parameter that varies over time in accordance with a variable imaging parameter function and the variable imaging parameter function is represented or representable at least in part by a function characteristic. In various embodiments, the set of outgoing ultrasonic signals may be a temporally ordered set of outgoing ultrasonic signals and the variable imaging parameter may vary over the temporally ordered set of outgoing ultrasonic signals.

In various embodiments, varying at least one imaging parameter of the transmitted ultrasonic signals may result in a variation of the ultrasound point spread function used in the imaging system of the system **10**. Backscattered RF data sensed for a point x_0 in the imaging system may be defined by the following equation:

$$I(x_0, t) = PSF(x_0) * s(x_0) + \frac{\partial PSF(x_0)}{\partial x} * s(x_0) A \sin(\omega t) + n$$

where $PSF(x_0)$ is an ultrasound point spread function at a point x_0 that is convolved with $s(x_0)$, the scattering function for the subject **12** at the same point, to generate $I(x_0, t)$, and n represents random noise, A is the amplitude of a micro vibration at point x_0 or the amplitude of variation in the ultrasound point spread function at point x_0 , and ω is the frequency of variation in the ultrasound point spread function at point x_0 .

Accordingly, knowledge of a function characteristic which may represent how the point spread function varies may be used to characterize or identify properties of the subject scattering function and therefore, may be used to characterize or identify properties of the subject **12**.

In some embodiments, the variable imaging parameter that defines the transmitted ultrasonic signals may be a focal depth of the transmitted signals and the analyzer **14** may cause the ultrasound machine **16** to transmit ultrasonic signals to the subject **12**, via a transducer **20** of the ultrasound machine, that have a focal depth that varies over time according to a variable imaging parameter function or focal depth function. In some embodiments, the focal depth function may be periodic at a focal depth variation frequency and this frequency may act as a function characteristic of the focal depth function. In various embodiments, the analyzer **14** may store the focal depth variation frequency for use later during analysis or characterization of the subject **12**.

The ultrasound machine **16** may cause the transducer **20** to transmit, based on the signals received from the analyzer **14**, a set of ultrasonic signals to the subject **12** and receive a set of reflected ultrasonic signals scattered by the subject. The ultrasound machine **16** may generate a time dependent representation of the subject **12** based on the received reflected ultrasonic signals and may send the time dependent representation to the analyzer **14**. In some embodiments, the time dependent representation may include a temporally ordered set or sequence of image representations of the subject **12** representing the subject **12** over a time period. In some embodiments, this time dependent representation may be taken for a fixed location or volume in the subject **12**, during that time period.

The analyzer **14** may receive signals representing the time dependent representation of the subject. For example, in some embodiments, the analyzer **14** may receive the sequence of image representations, from the ultrasound machine **16**.

The analyzer **14** may then determine at least one property representation of the subject based on the function characteristic and the time dependent representation of the subject **12**. In various embodiments, by basing the determination in part on the function characteristic, a representation of the subject **12** that would otherwise

be difficult or impossible to discern may be determined. For example, in some embodiments, the time dependent imaging parameter function may be a periodic focal depth function and the analyzer **14** may use the frequency of the focal depth function as the function characteristic to generate one or more images, acting as
5 property representations of the subject **12**, based on the frequency of the focal depth function and the time dependent representation of the subject **12**.

In some embodiments, determining the at least one property representation may involve applying a discrete Fourier transform (DFT) such as, for example, a fast
10 Fourier transform, to the time dependent representation of the subject and choosing a component or filtering to determine the component of the result that corresponds to the frequency of the focal depth function. For example, in some embodiments, the time dependent representation of the subject may include a sequence of image representations of the subject as shown in Figure **2**, and the
15 analyzer **14** may apply an FFT to each sequence of values for each pixel location. The analyzer **14** may then, for each pixel location, choose the FFT component that corresponds to the frequency of the focal depth function and set that component as an imaging parameter frequency component.

20 In various embodiments, determining the at least one property representation may involve the analyzer **14** generating an image representation of the determined imaging parameter frequency components. In some embodiments, determining the at least one property representation may involve the analyzer **14** applying at least one anomaly criterion to each of the determined imaging parameter
25 frequency components to determine whether each respective one of the imaging parameter frequency components indicates presence of an anomaly in the subject **12**.

The analyzer **14** may then produce signals representing the at least one property
30 representation of the subject to facilitate analysis of the subject. In some embodiments, the analyzer may produce signals for causing the display **18** to

display a representation of the image representation of the one or more imaging parameter frequency components and/or an image representation of the results of the application of the at least one anomaly criterion.

- 5 In various embodiments, varying an imaging parameter in the ultrasonic signal and knowing of a function characteristic of the variable imaging parameter may allow the analyzer **14** to derive properties of the subject **12** and provide analysis that otherwise would not be possible. In some embodiments, the properties may be derived by applying a function to the time dependent representation of the subject
- 10 **12** wherein the function is defined by the function characteristic or is specific based on the function characteristic. In various embodiments, use of such a particularized property determining function may facilitate generating a representation of the subject **12** that makes properties of the subject **12** discernible, which would otherwise be difficult or impossible to discern using non-
- 15 destructive testing.

Analyzer - Processor Circuit

Referring now to Figure **2**, a schematic view of the analyzer **14** of the system **10** shown in Figure **1** according to various embodiments is shown. The analyzer **14**

20 includes a processor circuit including an analyzer processor **100** and a program memory **102**, a storage memory **104**, and an input/output (I/O) interface **112**, all of which are in communication with the analyzer processor **100**. In various embodiments, the analyzer processor **100** may include one or more processing units, such as for example, a central processing unit (CPU), a graphical processing unit

25 (GPU), and/or a field programmable gate array (FPGA). In some embodiments, any or all of the functionality of the analyzer **14** described herein may be implemented using one or more FPGAs.

The I/O interface **112** includes an interface **120** for communicating with the

30 ultrasound machine **16** and an interface **130** for communicating with the display **18**. In some embodiments, any of the interfaces **120** or **130** may facilitate wireless or

wired communication. In some embodiments, the I/O interface **120** may include an ethernet interface for connecting to the ultrasound machine **16**. In some embodiments, the I/O interface **130** may include an HDMI or another multimedia interface.

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Referring to Figure **2**, in some embodiments, each of the interfaces may include one or more interfaces and/or some or all of the interfaces included in the I/O interface **112** may be implemented as combined interfaces or a single interface.

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In some embodiments, where a device is described herein as receiving or sending information, it may be understood that the device receives signals representing the information via an interface of the device or produces signals representing the information and transmits the signals to the other device via an interface of the device.

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Processor-executable program codes for directing the analyzer processor **100** to carry out various functions are stored in the program memory **102**. Referring to Figure **2**, the program memory **102** includes a block of codes **160** for directing the analyzer **14** to perform subject analysis functions. In this specification, it may be stated that certain encoded entities such as applications or modules perform certain functions. Herein, when an application, module or encoded entity is described as taking an action, as part of, for example, a function or a method, it will be understood that at least one processor (e.g., the analyzer processor **100**) is directed to take the action by way of programmable codes or processor-executable codes or instructions defining or forming part of the application.

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The storage memory **104** includes a plurality of storage locations including location **140** for storing ultrasonic signal definition information, location **142** for storing time dependent representation of the subject **12** information, location **144** for storing pixel specific time dependent information, location **146** for storing discrete Fourier transform (DFT) result information, location **148** for storing frequency specific DFT

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component information, location **150** for storing anomaly criteria information, location **152** for storing anomaly representation data, and location **154** for storing frequency component differentiator data. In various embodiments, the plurality of storage locations may be stored in a database in the storage memory **104**.

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In various embodiments, the blocks of codes included in the program memory **102** may be integrated into a single block of codes and/or may include one or more blocks of code stored in one or more separate locations in program memory **102**. In various embodiments, any or all of the locations in the storage memory **104** may be integrated and/or each may include one or more separate locations in the storage memory **104**.

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In various embodiments, each of the program memory **102** and/or the storage memory **104** may be implemented as one or more storage devices including, for example, random access memory (RAM), a hard disk drive (HDD), a solid-state drive (SSD), a network drive, flash memory, a memory stick or card, any other form of non-transitory computer-readable memory or storage medium, and/or a combination thereof. In some embodiments, the program memory **102**, the storage memory **104**, and/or any portion thereof may be included in a device separate from the analyzer **14** and in communication with the analyzer **14** via a network interface included in the I/O interface **112**, for example.

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Subject analysis

Referring now to Figure **3**, a flowchart depicting blocks of code for directing the analyzer processor **100** shown in Figure **2** to perform subject analysis functions in accordance with various embodiments is shown generally at **200**. The blocks of code included in the flowchart **200** may be included in the block of codes **160** of the program memory **102** shown in Figure **2**, for example.

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In some embodiments, execution of the flowchart **200** by the analyzer processor **100** may be initiated when a user or users of the analyzer **14** wishes to analyze or

characterize the subject **12** or a similar subject, for example, to perform non-destructive testing. For example, in some embodiments, the display **18** shown in Figure **1** may include a touch interface and the user may interact with the display **18** to initiate execution of the flowchart **200**. In some embodiments, the results of the analysis may be used to determine whether the subject **12** is viable for use in an intended application and/or to determine the composition of the subject **12**.

Referring to Figure **1**, in some embodiments, the subject **12** may be an advanced composite part, which may, for example, include a composite material having fibres and in some embodiments, the results of the analysis may be used to identify anomalies or defects, such as, for example, waviness of the fibres or wrinkles in the fibres, and thereby determine whether the subject **12** may be used in an aerospace application, for example. Accordingly, in various embodiments, the flowchart **200** may be initiated during quality assurance testing of the subject **12**. In various embodiments, the subject **12** may be submerged in a water bath container on a table during analysis.

Referring to Figure **3**, the flowchart **200** begins with block **202** which directs the analyzer processor **100** to produce signals for causing a set of outgoing ultrasonic signals to be transmitted to the subject, wherein the set of outgoing ultrasonic signals are defined at least in part by a variable imaging parameter that varies over time in accordance with a variable imaging parameter function, the variable imaging parameter function represented or representable at least in part by a function characteristic. In some embodiments, the set of outgoing ultrasonic signals may be a temporally ordered set of outgoing ultrasonic signals and the variable imaging parameter may vary over the temporally ordered set of outgoing ultrasonic signals.

In some embodiments, the set of outgoing ultrasonic signals may include at least one ultrasonic beam and block **202** may direct the analyzer processor **100** to produce signals for causing the at least one ultrasonic beam to be transmitted to

the subject, the at least one ultrasonic beam defined at least in part by the variable imaging parameter.

In some embodiments, the variable imaging parameter may be a focal depth and block **202** may direct the analyzer processor **100** to transmit to the ultrasound machine **16** shown in Figure **1**, an ultrasound instruction message, a portion of which is shown at **240** in Figure **4**, which may in some embodiments represent computer code, such as, for example C code, for directing the ultrasound machine to cause the transducer **20** to transmit ultrasonic signals to the subject such that the ultrasonic signals have a focal depth that varies over time according to a focal depth function. In various embodiments, the ultrasound machine **16** may include an ultrasound machine with a 1-D linear array transducer with **128** elements.

Referring to Figure **4**, in various embodiments, the ultrasound instruction message **240** includes a focal depth or focal distance function definition **242** that defines a focal depth or focal distance in microns as a function of an index number "i". The ultrasound machine **16** may be configured to transmit a temporally ordered set or sequence of ultrasonic signals indexed by the index number "i" to the subject **12** such that a sequence of images or frames having corresponding indices and representing the reflected or scattered signals can be generated. In some embodiments, the frame rate may be set at a frequency, such as for example, **730** frames per second, and the total number of ultrasonic signals or indices may be set to **128**, for example. In various embodiments, a frame rate of about **730** frames per second may facilitate imaging the subject quickly in a short time period. In various embodiments, capturing **128** frames may allow later analysis, such as analysis using an FFT to be performed accurately.

Accordingly, in some embodiments, the focal depth function definition **242** being a function of i will result in the focal depth function being a function of time. Referring to Figure **4**, in various embodiments, the focal depth function definition **242** of the ultrasound instruction message **240** may represent the following function:

$$\text{Focal depth (in microns)} = D + A \sin(2\pi f \cdot i)$$

where i is the frame index number for each transmitted ultrasonic signal.

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Referring still to Figure 4, in various embodiments, the focal depth function definition **242** of the ultrasound instruction message **240** may be defined in part by respective values stored in a mean focal depth field **244**, an amplitude field **246**, and a focal depth frequency field **248** included in the ultrasound instruction message.

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In various embodiments, the mean focal depth field **244** and the amplitude field **246** may have been previously set, for example, by a user of the analyzer **14**. In some embodiments, the mean focal depth field **244** may be set to a depth that is in the center of the subject **12** being analyzed, which may facilitate more accurate characterization of the subject. In some embodiments, for example, the subject **12** may have a total depth of about 4 cm or 40000 microns and so the mean focal depth field **244** may have been previously set to 20000 microns.

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In some embodiments, the imaging depth for imaging the subject **12** may be set such that a reasonably high resolution for imaging is achieved. For example, for a 5 MHz transducer, 4 cm depth may be reasonable. In some embodiments, lower than that like 1 cm, for example, may degrade beamforming quality and much higher than that like 10 cm, for example, may reduce the imaging resolution. In various embodiments, the subject **12** may be placed generally at the mean focal depth and in various embodiments, a typical focal depth may be about 1 cm to 3 cm for a 4 cm imaging depth.

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The value of the focal depth frequency field **248** of the ultrasound instruction message **240** may have also been previously set, for example, by a user of the analyzer **14**. In some embodiments, the focal depth frequency field **248** may be

chosen such that the focal depth function definition **242** completes **1** period within a sample time period. For example, in some embodiments, a sample time period may include **128** frames, and so the focal depth frequency field **248** may be set to $1/128 = 0.03125$. In various embodiments, based on the frame rate of **730** frames per second, this may result in a frequency of the focal depth function of about **5.7** Hz, hence with **128** frames, one cycle of the sinusoid may be sampled fairly densely and this may facilitate reliably reconstructing the amplitude of the sinusoid.

In various embodiments, the focal depth frequency field **248** may be set to a value such that each period is sampled at about **4** times the Nyquist rate given the imaging frame rate to facilitate reliable reconstruction of the signal in a noisy environment.

In some embodiments, the value stored in the focal depth frequency field **248** may act as an imaging parameter frequency and a function characteristic for the focal depth function defined by the focal depth function definition **242**.

In some embodiments, the ultrasound instruction message **240** may have been previously stored in the location **140** of the storage memory **104** and block **202** may direct the analyzer processor **100** to retrieve the ultrasound instruction message **240** from the location **140** of the storage memory **104** and to send a representation of the ultrasound instruction message **240** to the ultrasound machine **16** via the interface **120** of the I/O interface **112** shown in Figure 2.

After receiving the ultrasound instruction message **240** from the analyzer **14**, the ultrasound machine **16** may cause the transducer **20** to transmit a plurality of outgoing ultrasonic signals to the subject based on the ultrasound instruction message **240**. For example, in various embodiments, the ultrasound machine **16** may receive the ultrasound instruction message **240** shown in Figure 4 and the ultrasound machine **16** may cause the transducer **20** to transmit **128** ultrasonic signals indexed from $i=0$ to $i=127$ at **730** signals/second and each defined at least

in part by a focal depth determined according to the focal depth function definition **242** of the ultrasound instruction message **240**. The transducer **20** then receives reflections of each of the transmitted ultrasonic signals from the subject **12** and the ultrasound machine **16** generates respective images, each representing a reflection of one of the transmitted signals and so corresponding to an index or frame number. For example, in some embodiments, the ultrasound machine **16** may generate **128** images indexed from $i=0$ to $i=127$ representing the subject **12** taken at **730** images/second representing reflections of the ultrasonic signals transmitted to the subject **12**. In various embodiments, the ultrasound machine **16** may transmit the sequence of **128** images, each associated with a respective index number representing time, to the analyzer **14**, for analysis.

For example, in various embodiments, the ultrasound machine **16** may generate and transmit to the analyzer **14** respective image records, an exemplary one of which is shown at **280** in Figure 5. The image record **280** includes an index field **282** for storing an index value representing a time at which the image was taken and an image field **284** for storing an image representation of the reflected ultrasonic signals received at the transducer **20**. In some embodiments, the image information stored in the image field **284** may include a plurality of pixel positions, each associated with a pixel value, wherein the pixel value represents an echo intensity which may represent a change in density, speed of sound and/or acoustic impedance of the subject at the pixel location. In some embodiments, the image information may represent an **8-12** bit image and the pixel values may each be within a range of **0-255** or **0-4095**, for example.

Referring back to Figure 3, block **204** directs the analyzer processor **100** to receive signals representing a time dependent representation of the subject generated from a set of received ultrasonic signal scattered by the subject. In some embodiments, block **204** may direct the analyzer processor **100** to receive a set of **128** image records, each having the same format as the image record **280** shown in Figure 5, from the ultrasound machine **16** via the interface **120** of the I/O

interface **112** shown in Figure **2**. Block **204** may direct the analyzer processor **100** to store the received image records in the location **142** of the storage memory **104** shown in Figure **2**. In various embodiments, the received image records may act as a temporally ordered set of image representations of the subject **12**.

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Block **206** then directs the analyzer processor **100** to determine at least one property representation of the subject **12** based on the function characteristic and the time dependent representation of the subject. In some embodiments, block **206** may direct the analyzer processor **100** to retrieve the set of image records including the image record **280**, together acting as a time dependent representation of the received ultrasonic signals, received at block **204** from the location **142** of storage memory **104** and to retrieve the focal depth frequency value stored in the focal depth frequency field **248**, acting as a function characteristic, from the location **140** of the storage memory **104**. Block **206** may then direct the analyzer processor **100** to determine at least one property representation of the subject based on the set of image records and the focal depth frequency value.

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Referring now to Figure **6**, there is shown a flowchart **290** depicting blocks of code for directing the analyzer processor **100** shown in Figure **2** to perform subject property determining functions in accordance with various embodiments. In various embodiments, the blocks of code included in the flowchart **290** may be included in the block **206** of the flowchart **200** shown in Figure **5**.

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The flowchart **290** begins with block **292** which directs the analyzer processor **100** to identify a sequence of pixel values for a pixel position in the set of images included in the set of image records stored at the location **142** of the storage memory **104**. For example, in some embodiments, block **292** may direct the analyzer processor **100** to read the pixel values for position **(0,0)** in each image of the set of images and generate a pixel value sequence vector, representing the pixel values for position **(0,0)**. Block **292** may direct the analyzer processor **100** to store the pixel value sequence vector in the location **144** of the storage memory **104**.

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For example, referring to Figure 7, there is shown a representation of images **300** that may be included in the image records stored in the location **142** of the storage memory **104**, in accordance with various embodiments. Figure 7 shows a
5 representative pixel **302** at a particular position in the images **300**, which may correspond to a particular position or location in the subject **12**. Figure 7 shows how the pixel value representing echo intensity or material density **304** associated with the pixel **302** changes over time. Block **292** may direct the analyzer processor **100** to generate and store in the location **144** of the storage memory **104**, a pixel
10 value sequence vector representing an echo intensity over time for the first pixel position **(0,0)**.

Block **294** then directs the analyzer processor **100** to apply a discrete Fourier transform (DFT) to the pixel value sequence vector generated at block **292**. In
15 some embodiments, block **294** may direct the analyzer processor **100** to apply a DFT normalized to the frame rate of image acquisition and generate a DFT vector from the application of the DFT, the DFT vector including absolute value components of the computed DFT, each of the absolute value components associated with a frequency. Block **294** may direct the analyzer processor **100**
20 to store the DFT vector in the location **146** of the storage memory **104** shown in Figure 1. In some embodiments, block **294** may direct the analyzer processor **100** to apply a fast Fourier Transform (FFT) to the pixel value sequence vector generated at block **292** to generate the DFT vector.

Referring to Figure 6, block **296** then directs the analyzer processor **100** to identify
25 from the result of the DFT, a component that is associated with the focal depth frequency value stored in the focal depth frequency field **248** of the ultrasound instruction message **240** shown in Figure 4. In some embodiments, the identified component may act as an imaging parameter frequency component since it may
30 be associated with the frequency at which the imaging parameter (i.e., the focal depth in some embodiments) varies. In some embodiments, block **296** may direct

the analyzer processor **100** to identify a component or value from the DFT vector stored in the location **146** of the storage memory **104** as associated with the focal depth frequency. In various embodiments, block **296** may direct the analyzer processor **100** to apply knowledge of the sampling frequency of the signal or frame rate to determine which component of the DFT vector corresponds to the focal depth frequency. For example, in some embodiments, if the focal depth frequency is $f=5.7$ Hz, the period for the focal depth function is $T=1/f=0.1754$ s. In some embodiments, the sampling time may be $t_s=T/128=0.00137$ and the sampling frequency may be $F_s=1/t_s=729.6$ Hz. In various embodiments where **128** frames are used, the second frequency component in FFT corresponds to $1/128 \cdot F_s=5.7$ Hz. Hence, in such embodiments, the amplitude of the second frequency component corresponds to the focal depth frequency of **5.7** Hz.

Block **298** then directs the analyzer processor **100** to associate the identified component with the pixel position being considered. In some embodiments, on a first execution of block **298**, block **298** may direct the analyzer processor **100** to generate a frequency component image and to set a pixel position of the frequency component image corresponding to the pixel position that was considered at block **292** to the component or value identified at block **296** of the flowchart **290**. Block **298** may direct the analyzer processor **100** to store the frequency component image in the location **148** of the storage memory **104**. In various embodiments in subsequent executions of block **298**, block **298** may direct the analyzer processor **100** to modify the frequency component image previously generated and stored in the location **148** of the storage memory **104** to include further pixel values at respective considered pixel positions.

After block **298** has been completed for a particular pixel position, the analyzer processor **100** may be directed to return to block **292** and to consider another pixel position. In various embodiments, blocks **292** to **298** may be repeated for each pixel position included in the images stored in the location **144** of the storage memory **104**. Once every pixel position of the images stored in the location **142**

of the storage memory **104** has been considered during execution of blocks **292** to **298**, the frequency component image stored in the location **148** of the storage memory **104** and each of the pixel values included therein may act as a representation of features or properties of the subject **12**. In some embodiments, deviation of pixel values from a mean pixel value may represent an anomaly or probability of an anomaly in the subject **12** at a particular location in the subject. In various embodiments, once every pixel position has been considered, the frequency component image may be visualized as a color map, which shows the imaging parameter frequency component for each pixel position.

In some embodiments, block **206** may direct the analyzer processor **100** to, for each of the imaging parameter frequency components determined, apply anomaly criteria to the determined component to determine whether the imaging parameter frequency component indicates presence of an anomaly in the subject **12**.

Referring now to Figure **8**, there is shown a flowchart **340** depicting blocks of code for directing the analyzer processor **100** shown in Figure **2** to perform anomaly detection functions in accordance with various embodiments. In various embodiments, the blocks of code included in the flowchart **340** may be included in the block **206** of the flowchart **200** shown in Figure **3** and may be executed after the blocks of code included in the flowchart **290** shown in Figure **6** have been executed.

The flowchart **340** begins with block **342** which directs the analyzer processor **100** to identify an imaging parameter frequency component associated with a particular pixel position. In some embodiments, block **342** may direct the analyzer processor **100** to read the frequency component image from the location **148** of the storage memory **104** and to identify a first imaging parameter frequency component of the frequency component image associated with a first pixel position in the frequency component image.

Block **344** then directs the analyzer processor **100** to apply at least one anomaly criterion to the identified imaging parameter frequency component to determine

whether the imaging parameter frequency component indicates presence of an anomaly in the subject. In some embodiments, expected values for the imaging parameter frequency components may be within a predetermined normal range and so block **344** may direct the analyzer processor **100** to determine whether the
5 imaging parameter frequency component is outside of a predetermined normal range.

For example, in some embodiments, an anomaly range record **360** shown in Figure **9** may have been previously determined or provided and may be stored in
10 the location **150** of the storage memory **104**. Referring to Figure **9**, in various embodiments, the anomaly range record **360** includes a minimum field **362** and a maximum field **364** for storing values defining the predetermined normal range. Block **344** may direct the analyzer processor **100** to compare the first imaging parameter frequency component to the values from the minimum and maximum
15 fields **362** and **364** of the anomaly range record **360** and to determine whether the first imaging parameter frequency component is less than the value stored in the minimum field **362** or greater than the value stored in the maximum field **364**. In some embodiments, there may be no minimum value and so the minimum field **362** may be omitted. In such embodiments, block **344** may direct the analyzer
20 processor **100** to determine whether the first imaging parameter frequency component is greater than the value stored in the maximum field **364**. In some embodiments, the minimum and maximum values may have been previously determined by scanning one or more samples similar to the subject **12** but without anomalies and determining a range of pixel values for frequency component
25 images generated from the samples.

If at block **344** it is determined that the at least one anomaly criterion is met and the imaging parameter frequency component indicates presence of an anomaly in the subject **12**, the analyzer processor is directed to block **346**. For example, if at
30 block **344** it is determined that the first imaging parameter frequency component is

greater than the value stored in the maximum field **364**, block **344** may direct the analyzer processor **100** to proceed to block **346**.

5 Block **346** directs the analyzer processor **100** to associate the pixel position with an anomaly indicator. In some embodiments, block **346** may direct the analyzer processor **100** to set the pixel position identified at block **342** of an anomaly indicating image to an anomaly indicator value. In various embodiments, the anomaly indicating image may be stored in the location **152** of the storage memory **104**. In some embodiments, block **346** may direct the analyzer processor **100** to set the pixel position to an anomaly indicator value that represents an indicator color, such as, for example, red. In various embodiments, by associating the pixel position with an anomaly indicator, anomalies in the imaging parameter frequency components may be easily identified.

15 If at block **344** it is determined that the at least one anomaly criterion is not met and the imaging parameter frequency component does not indicate presence of an anomaly in the subject **12**, the analyzer processor is directed to block **348**. For example, if at block **344** it is determined that the first imaging parameter frequency component is less than the value stored in the maximum field **364** and greater than the value stored in the minimum field **362**, block **344** may direct the analyzer processor **100** to proceed to block **348**.

20 Block **348** may direct the analyzer processor **100** to associate the pixel position with a value that indicates that there is not an anomaly at the pixel position. In some embodiments, block **348** may direct the analyzer processor **100** to associate the pixel position with a value that represents the color blue, for example.

30 After either block **346** or **348** has been executed, the analyzer processor **100** is directed to return to block **342** and to consider another pixel position of the frequency component image retrieved from the location **148** of the storage memory **104**. In various embodiments, blocks **342**, **344**, and **346** or **348** may be executed

for each pixel position in the frequency component image until a complete anomaly indicating image is stored in the location **152** of the storage memory **104**.

Referring to Figure **10**, a representation of an exemplary anomaly indicating image **380** that may be stored in the location **152** of the storage memory **104** after flowchart **340** has been executed is shown beside an image **384** included in one of the image records, for reference. Referring to Figure **10**, the anomaly indicating image **380** includes a region of anomaly which is indicated by the color red (represented in Figure **10** by vertical line hatching), and a normal region which is indicated by the color blue (represented in Figure **10** by horizontal line hatching).

In various embodiments, the anomaly indicating image **380** stored in the location **152** of the storage memory **104** and each of the pixel values included in the anomaly indicating image may act as representations of features or properties of the subject **12**.

Referring to Figure **3**, in some embodiments, block **206** may direct the analyzer processor **100** to determine a representative value from the frequency component image stored in the location **148** of the storage memory **104**. For example, in some embodiments block **206** may direct the analyzer processor **100** to determine a median pixel value from the frequency component image and to store the median pixel value in the location **148** of the storage memory **104**. In various embodiments, the median pixel value may be representative of a level of porosity in the subject **12**. For example, in some embodiments, as the median pixel value increases, this may indicate a higher porosity of the subject **12**.

In some embodiments, blocks **202**, **204**, and **206** of the flowchart **200** may be executed for a plurality of positions on the subject **12**, such that the 3-dimensional subject **12** may be characterized at a plurality of planes. For example, in some embodiments, the system **10** may include a Y-Z stage and the analyzer **14** may be configured to execute blocks **202**, **204**, and **206** of the flowchart **200** shown in

Figure 3 in a first Z position. The system 10 may then move the subject 12 using the Y-Z stage relative to the transducer 20 and then the analyzer 14 may execute blocks 202, 204, and 206 in the next Z-position. For example, in some embodiments, the subject 12 may move about 1 mm at a time. The entire movement procedure may be automated such that the subject 12 moves with increments of 1 mm representing a 1 mm scanning resolution across the entire subject. Accordingly, in various embodiments, the pixels discussed herein may act as a plane of voxels in a larger 3D representation of the subject. Figure 11 shows how an image 390 included in the image records stored in the location 142 of the storage memory 104 may fit as a plane of voxels within a 3D representation 392 of properties of the subject 12. In various embodiments, the frequency component images stored in the location 148 of the storage memory 104 and/or the anomaly indicating images stored in the location 152 of the storage memory 104 may similarly together form respective 3D representations of properties of the subject 12.

In some embodiments, the ultrasound image data stored in the location 142 may be collected in various ways. For example, in some embodiments, the ultrasound image data stored in the location 142 of the storage memory 104 may be collected over equally-sized Regions of Interests (ROI), where the width of each ROI is the half of the probe width (e.g., 1.9 cm) and its depth is equal to the sample's thickness. For each imaging plane, analysis may be performed for 2 ROIs that cover the entire cross section of the subject 12.

Referring back to Figure 3, block 208 directs the analyzer processor 100 to produce signals representing the at least one property representation determined at block 206 to facilitate analysis of the subject 12. In some embodiments, block 208 may direct the analyzer processor 100 to produce signals representing one or more of the frequency component images stored in the location 148 for causing the display 18 shown in Figure 1 to display a representation of the frequency component images. For example, in some embodiments, a 3D representation of

the frequency component images may be displayed. In various embodiments, a user or quality assurance specialist viewing the display **18** may be able to use the display **18** showing the frequency component images to determine whether the subject **12** can be used for a desired application. For example, in various
5 embodiments, the user may determine that the frequency component images include too many high and/or low pixel values that are different from an average or normal pixel value and that therefore the subject **12** has too many imperfections or too high of a porosity to be used in the intended application.

10 In some embodiments, block **208** may direct the analyzer processor **100** to produce signals representing the median pixel value stored in the location **148** of the storage memory **104** for one or more of the frequency component images, for causing the display **18** shown in Figure **1** to display a representation of the median pixel value. In various embodiments, a user or quality assurance specialist viewing
15 the display **18** may be able to use the display **18** showing the median pixel values to determine whether the subject **12** can be used for a desired application. For example, in various embodiments, the user may determine that the median pixel values are too high or too low and therefore has too many imperfections or too high of a level of porosity for the intended application.

20 In some embodiments, block **208** may direct the analyzer processor **100** to produce signals representing one or more of the anomaly indicating images stored in the location **152** for causing the display **18** to display a representation of the one or more anomaly indicating images. For example, in some embodiments, block
25 **208** may direct the analyzer processor **100** to produce signals representing a plurality of anomaly indicating images such that a **3D** view or a top down view of one or more cross sections taken at a pixel position on the x axis may be displayed by the display **18**. In various embodiments, a user or quality assurance specialist viewing the display **18** may be able to use the display **18** showing the anomaly
30 indicating images to determine whether the subject **12** can be used for a desired application. For example, in various embodiments, the user may determine that

the anomaly indicating image includes too many pixel positions that are associated with anomaly indicator values and that therefore the subject **12** has too many imperfections to be used in an aerospace application.

5 Various embodiments

In some embodiments, the variable imaging parameter function may be representable by more than one function characteristic, which may be used to determine the at least one property representation of the subject **12**. For example, in some embodiments, a focal depth function may be used that includes more than one periodic function, each having a different frequency. Accordingly, in various
10 embodiments, an ultrasound instruction message **400** as shown in Figure **12** may be stored in the location **140** of the storage memory **104** and used generally as described above having regard to the ultrasound instruction message **240** shown in Figure **4**.

15 Referring to Figure **12**, the ultrasound instruction message **400** includes a focal depth function definition **402** that includes more than one periodic function, such that the focal depth of the ultrasonic signals transmitted to the subject **12** by the ultrasound machine **16** may vary according to more than one periodic function.
20 Accordingly, referring to Figure **12**, in some embodiments, the focal depth function definition **402** may define a focal depth as follows:

$$Focal\ depth\ (in\ microns) = D + A \sin(2\pi f_1 \cdot i) + B \sin(2\pi f_2 \cdot i)$$

where i is the frame index number for each transmitted ultrasonic signal.

25 Accordingly, in various embodiments, the focal depth function may include a first periodic function $A \cdot \sin(2\pi f_1 \cdot i)$ where f_1 is a first focal depth frequency and a second periodic function $B \cdot \sin(2\pi f_2 \cdot i)$ where f_2 is a second focal depth frequency, wherein f_2 is different from f_1 . In such embodiments, the values for f_1 and f_2 may
30 each act as respective function characteristics for the focal depth function.

In various embodiments, where the ultrasound instruction message **400** is transmitted to the ultrasound machine **16**, block **296** of the flowchart **290** shown in Figure **6** may direct the analyzer processor **100** to identify first and second frequency components of the DFT result, the first and second frequency components associated with the first and second focal depth frequencies. In various embodiments, block **298** of the flowchart **290** shown in Figure **6** may direct the analyzer processor **100** to determine a difference between the first and second frequency components and to associate the pixel position with the difference between the identified first and second frequency components. Block **298** may, for example, direct the analyzer processor **100** to generate a frequency component differentiator image which includes a representation of the difference between frequency component values associated with each pixel position. In various embodiments, the generated frequency component differentiator image may act as a property representation of the subject.

In various embodiments, alternative or additional imaging parameters and imaging parameter functions may be utilized generally as described herein regarding the focal depth acting as an imaging parameter and the focal depth function acting as an imaging parameter function defining how the focal depth varies over time. For example, in some embodiments imaging parameters that may be treated generally as described herein regarding the focal depth, may include focal depth, f-number, apodization window, time gain compensation (TGC), dynamic range, number of active elements, centre frequency of the transducer, shape of the transmitted signal, direction of the transmitted signal (which may be changed using beam steering, for example), length of the transmitted signal, and/or another imaging parameter that affects the point spread function of the imaging system.

For example, in some embodiments, an ultrasound instruction message **420** as shown in Figure **13** may be stored in the location **140** of the storage memory **104** and used generally as described above having regard to the ultrasound instruction message **240** shown in Figure **4**, except the ultrasound instruction message **420**

may cause the ultrasound machine **16** to vary a centre frequency of the transmitted signals based on the ultrasound instruction message **420**. Referring to Figure **13**, the ultrasound instruction message **420** includes a centre frequency function definition **422** for defining the centre frequency in Hz of the ultrasonic signals to be transmitted to the subject **12** by the ultrasound machine **16**, such that the centre frequency may vary according to the centre frequency function definition **422**.

In some embodiments, the centre frequency function may be used on its own generally as described above for the focal depth function. However, in other embodiments, the centre frequency function may be used in conjunction with varying of another imaging parameter, such as, for example, the focal depth. Accordingly, in various embodiments, the flowcharts **200** and **290** shown in Figures **3** and **6** may be executed first as described above using the ultrasound instruction message **240** shown in Figure **5** and then the flowcharts **200** and **290** may be executed generally as described above but using the ultrasound instruction message **420** shown in Figure **13**.

Accordingly, in various embodiments, a focal depth frequency component image and a centre frequency component image for the same planar position in the subject **12** may thus be stored in the location **148** of the storage memory **104**. In some embodiments, when both the focal depth frequency component image and the centre frequency component image are stored in the location **148** of the storage memory **104**, block **206** may direct the analyzer processor **100** to determine, for each pixel position in the images stored in the location **148** of the storage memory **104**, a difference between the pixel values of the focal depth frequency component image and the centre frequency component image. Block **206** may direct the analyzer processor **100** to generate and store a differentiator image representing the differences in pixel values at each pixel position. The differentiator image may be stored in the location **154** of the storage memory **104**, for example.

In some embodiments, block **208** may direct the analyzer processor **100** to produce signals representing the differentiator image stored in the location **154** for causing the display **18** to display a representation of the differentiator image. In various embodiments, a user viewing the differentiator image may be able to
5 determine properties of the subject **12** in view of the differentiator image. For example, in some embodiments, the user may be able to determine a material type from the displayed differentiator image.

10 In some embodiments, a differentiator image may be generated as described above, but using two different functions for the same imaging parameter. For example, in some embodiments, an ultrasound instruction message **440** as shown in Figure **14** may be used as described above instead of the ultrasound instruction message **420** shown in Figure **13**.

15 In some embodiments block **208** of the flowchart **200** shown in Figure **3** may direct the analyzer processor **100** to produce signals representing the at least one property representation of the subject to facilitate analysis of the subject **12** using a neural network. For example, in some embodiments, block **208** may direct the analyzer processor **100** to use the frequency component images and/or the
20 anomaly indicating images stored in the location **148** of the storage memory **104** as inputs into a neural network for analyzing the images.

In some embodiments, block **208** of the flowchart **200** shown in Figure **3** may direct the analyzer processor **100** to transmit signals representing the at least one
25 property representation of the subject to facilitate analysis at another computer of the subject **12**. For example, in some embodiments, the I/O interface **112** may include a network interface and block **208** may direct the analyzer processor **100** to transmit representations of frequency component images and/or the anomaly indicating images stored in the location **148** of the storage memory **104** to another
30 computer via the network interface to facilitate analysis at the other computer.

5 In some embodiments, the ultrasound machine **16** may include **3D** transducers or circular, array transducers which may not require any motion to scan in **3D**. In some embodiments, the ultrasound machine **16** may include more than one transducer, such as, for example, one sending a signal from one side and one receiving a signal from the other side.

10 In various embodiments alternative or additional imaging parameter functions or focal depth functions may be used. For example, in some embodiments, a focal depth function that is not periodic may be used.

15 In various embodiments, block **206** of the flowchart **200** shown in Figure **3** may direct the analyzer processor **100** to, instead of applying the DFT, convolve the focal depth function with the time dependent subject representation (e.g., by convolving the focal depth function with the pixel value sequence vectors) to determine convolution values that may be included in a convolution image which may be treated generally similarly to the frequency component image described herein.

20 In various embodiments, the shape of the focal depth function may include any varying function, such as, for example, a step or a triangle, or a sequence of pulses of varying length or amplitude, or another varying function, such as, for example a function that includes randomly varying elements.

25 In some embodiments, the focal depth function may result in a sequence of ultrasonic or transmit signals being produced that vary the focal point sinusoidally according to an index or time value. However, in some embodiments, the order of firing or transmitting of that sequence of signals to the subject **12** may be scrambled randomly in time, as each backscattered data frame may be considered independent of the subsequent data frame. In such embodiments, block **206** may direct the analyzer processor **100** to first re-sort the received image frames and then to perform an analysis generally as described herein.

30

While various embodiments described herein have been described in connection with the subject **12** being made of a composite material, in various embodiments, the system **10** may facilitate ultrasonic characterization of other subjects for which accurate characterization is required. For example, in some embodiments, the system **10** may be configured to facilitate ultrasonic characterization in biomedical applications, such as for in vivo and ex vivo characterization of biological material, such as, for example, for tissue or organ analysis. For example, in some embodiments, the system **10** may be used to detect cancer, such as, for example prostate cancer and/or breast cancer.

While various embodiments described herein involved the use of a DFT or FFT and selection of components of a result of the DFT or FFT, in various embodiments alternative or additional processing of the time dependent representation of the subject may be used. For example, in some embodiments, block **206** may direct the analyzer processor **100** to more generally apply a band-pass filter to the time dependent representation of the subject **12** received at block **204**, wherein the band-pass filter is configured to pass the focal depth frequency.

In various embodiments, block **206** may process the time dependent representation of the subject **12** using additional or alternative analyses compared to the DFT described above, which may be based on time, frequency, amplitude, statistical, stochastic or a combination thereof. For example, in some embodiments, block **206** may direct the analyzer processor **100** to use a band-pass filter such as a finite impulse response (FIR) filter to filter the time dependent representation, and to use a property of the filtered result, such as the power of the filtered result or its amplitude, for example, to facilitate ultrasonic analysis of a subject. For example, in some embodiments, the power of the filtered result or its amplitude may act as a representation of at least one property of the subject **12**. In some embodiments, the design of the FIR filter may be informed from the variable imaging parameter function. In some embodiments, the FIR filter may

have a passband centered around a frequency of the variable imaging parameter function. For example, if the focal depth variation frequency is **10 Hz**, then the FIR filter may be implemented as a **10 Hz** bandpass filter.

5 In some embodiments, block **206** of the flowchart **200** shown in Figure **3** may direct the analyzer processor **100** to input the time dependent representation of the subject **12** and the function characteristic into a neural network, the neural network having been trained/configured to determine whether the subject **12** has a defect based on the input time dependent representation of the subject **12** and the
10 function characteristic. In some embodiments, the neural network may act as a classifier and may output a determined probability or likelihood that there is a defect in the subject **12**. In such embodiments, the determined probability that there is a defect in the subject **12** may act as the at least one property representation of the subject.

15 In various embodiments, block **208** may then direct the analyzer processor **100** to, if it is determined by the neural network that the subject has a high probability of a defect (e.g., by determining whether the probability of a defect is higher than a threshold probability), produce signals for causing an alert to be provided for a user
20 of the analyzer **14**. For example, in some embodiments, block **208** may direct the analyzer processor **100** to, produce signals for causing the display **18** to provide an alert noting that the subject **12** likely has a defect.

25 In some embodiments, block **206** may direct the analyzer processor **100** to use a deep neural network that is trained to perform DFT and perform an analysis on the result. In some embodiments, block **206** may direct the analyzer processor **100** to use a neural network that is trained to extract a specific frequency component (corresponding to the focal depth frequency, for example) from each of the pixel value sequences without needing to use a full DFT calculation for all frequency
30 components.

While the system **10** shown in Figure **1** includes the ultrasound machine **16** which is shown pictorially as a standard cart-based ultrasound machine, in various embodiments, the system **10** may be implemented in alternative environments, such as, for example, in an assembly line or in a hand held device for use in the field.

In various embodiments, a system **460** shown in Figure **15** that functions generally similarly to the system **10** described herein and shown in Figure **1** may include an ultrasound machine **462** that incorporates an analyzer within the ultrasound machine **462**, the analyzer having generally similar functionality to the analyzer **14** described herein. For example, in various embodiments, a single processor circuit included in the ultrasound **462** may implement functionality of both the ultrasound machine **16** and the analyzer **14** described herein. In various embodiments a display **464** of the system **460** may be used generally as described above regarding the display **18** of the system **10** shown in Figure **1**.

In various embodiments, any or all of the ultrasound machine **16**, transducer **20**, analyzer **14** and/or display **18** may be implemented as a combined single device that incorporates any or all of the functionality described herein.

In various embodiments, time dependent representations and/or functions described herein may be merely variable over time and may, in some embodiments, include random elements.

While specific embodiments of the invention have been described and illustrated, such embodiments should be considered illustrative of the invention only and not as limiting the invention as construed in accordance with the accompanying claims.

CLAIMS:

1. A method of facilitating ultrasonic analysis of a subject, the method comprising:

5 producing signals for causing a set of outgoing ultrasonic signals to be transmitted to the subject, wherein the set of outgoing ultrasonic signals is defined at least in part by a variable imaging parameter that varies over time in accordance with a variable imaging parameter function, the variable imaging parameter function represented or representable at least in part by a function
10 characteristic;

receiving signals representing a time dependent representation of the subject generated from a set of received ultrasonic signals scattered by the subject;

15 determining at least one property representation of the subject based on the function characteristic and the time dependent representation of the subject; and

producing signals representing the at least one property representation of the subject to facilitate analysis of the subject.

2. The method of claim 1 wherein the set of outgoing ultrasonic signals is a
20 temporally ordered set of outgoing ultrasonic signals and wherein the variable imaging parameter varies over the temporally ordered set of outgoing ultrasonic signals.

3. The method of claim 1 or 2 wherein the set of outgoing ultrasonic signals includes at least one ultrasonic beam and wherein producing the signals for
25 causing the set of outgoing ultrasonic signals to be transmitted to the subject comprises producing signals for causing the at least one ultrasonic

beam to be transmitted to the subject, said at least one ultrasonic beam defined at least in part by the variable imaging parameter.

4. The method of claim **3** wherein the variable imaging parameter is a focal depth of the at least one ultrasonic beam and wherein producing the signals for causing the at least one ultrasonic beam to be transmitted to the subject comprises producing signals for causing the focal depth of the at least one ultrasonic beam to vary over time according to the variable imaging parameter function.
5. The method of any one of claims **1** to **4** wherein the variable imaging parameter function includes a periodic function that varies over time at an imaging parameter frequency and wherein the function characteristic includes the imaging parameter frequency.
6. The method of claim **5** wherein determining the at least one property representation of the subject comprises applying a band-pass filter to the time dependent representation of the subject, the band-pass filter configured to pass the imaging parameter frequency.
7. The method of claim **5** or **6** wherein determining the at least one property representation of the subject comprises applying a discrete Fourier transform to the time dependent representation of the subject to determine one or more imaging parameter frequency components, each of the one or more imaging parameter frequency components associated with the imaging parameter frequency.
8. The method of claim **7** further comprising, for each of the one or more imaging parameter frequency components, applying at least one anomaly criterion to the imaging parameter frequency component to determine whether the imaging parameter frequency component indicates presence of an anomaly in the subject.

9. The method of claim **8** wherein applying the at least one anomaly criterion comprises determining whether the imaging parameter frequency component is outside of a predetermined normal range.
- 5 10. The method of claim **9** wherein producing the signals representing the at least one property representation of the subject comprises producing signals for causing at least one display to display a representation of the subject including indicators identifying the one or more imaging parameter frequency components determined to be outside of the predetermined normal range.
- 10 11. The method of claim **7** wherein producing the signals representing the at least one property representation of the subject comprises producing signals for causing at least one display to display a representation of the one or more imaging parameter frequency components.
12. The method of claim any one of claims **5** to **11** wherein:
- 15 the periodic function is a first periodic function and the imaging parameter frequency is a first imaging parameter frequency;
- the variable imaging parameter function includes a second periodic function that varies over time at a second imaging parameter frequency, different from the first imaging parameter frequency, such
- 20 that the variable imaging parameter function is represented or representable at least in part by the second imaging parameter frequency; and
- determining the at least one property representation of the subject based on the function characteristic and the time dependent
- 25 representation of the subject comprises determining the at least one property representation of the subject based on the first imaging

parameter frequency, the second imaging parameter frequency, and the time dependent representation of the subject.

13. The method of any one of claims **1** to **12** wherein:

5 the set of outgoing ultrasonic signals is a first set of outgoing ultrasonic signals;

the variable imaging parameter is a first variable imaging parameter;

the variable imaging parameter function is a first variable imaging parameter function;

the function characteristic is a first function characteristic;

10 the method further comprises:

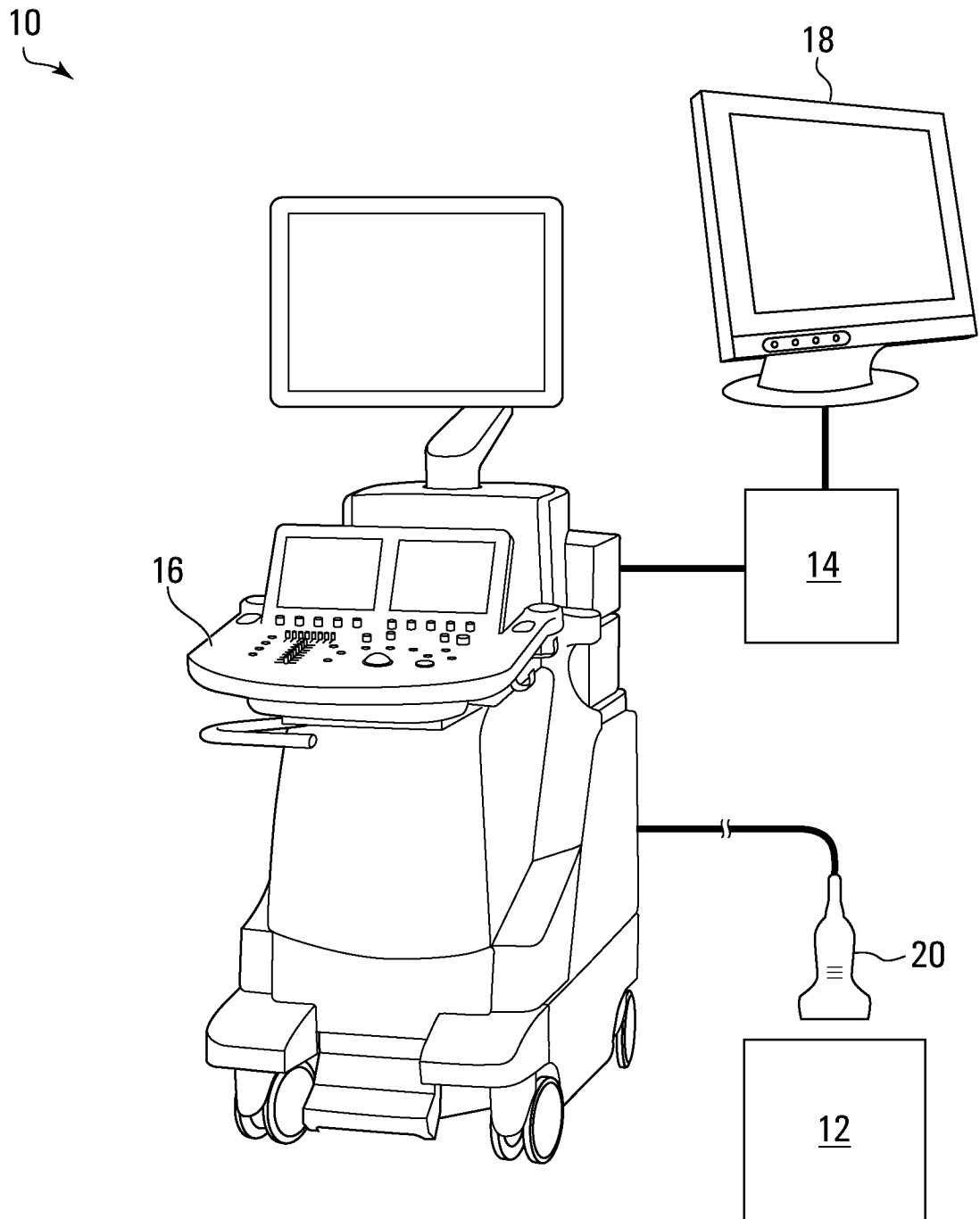
15 producing signals for causing a second set of outgoing ultrasonic signals to be transmitted to the subject, wherein the second set of outgoing ultrasonic signals is defined at least in part by a second variable imaging parameter that varies over time in accordance with a second variable imaging parameter function, the second variable imaging parameter function represented or representable at least in part by a second function characteristic; and

20 receiving signals representing a second time dependent representation of the subject generated from a second set of received ultrasonic signals scattered by the subject; and

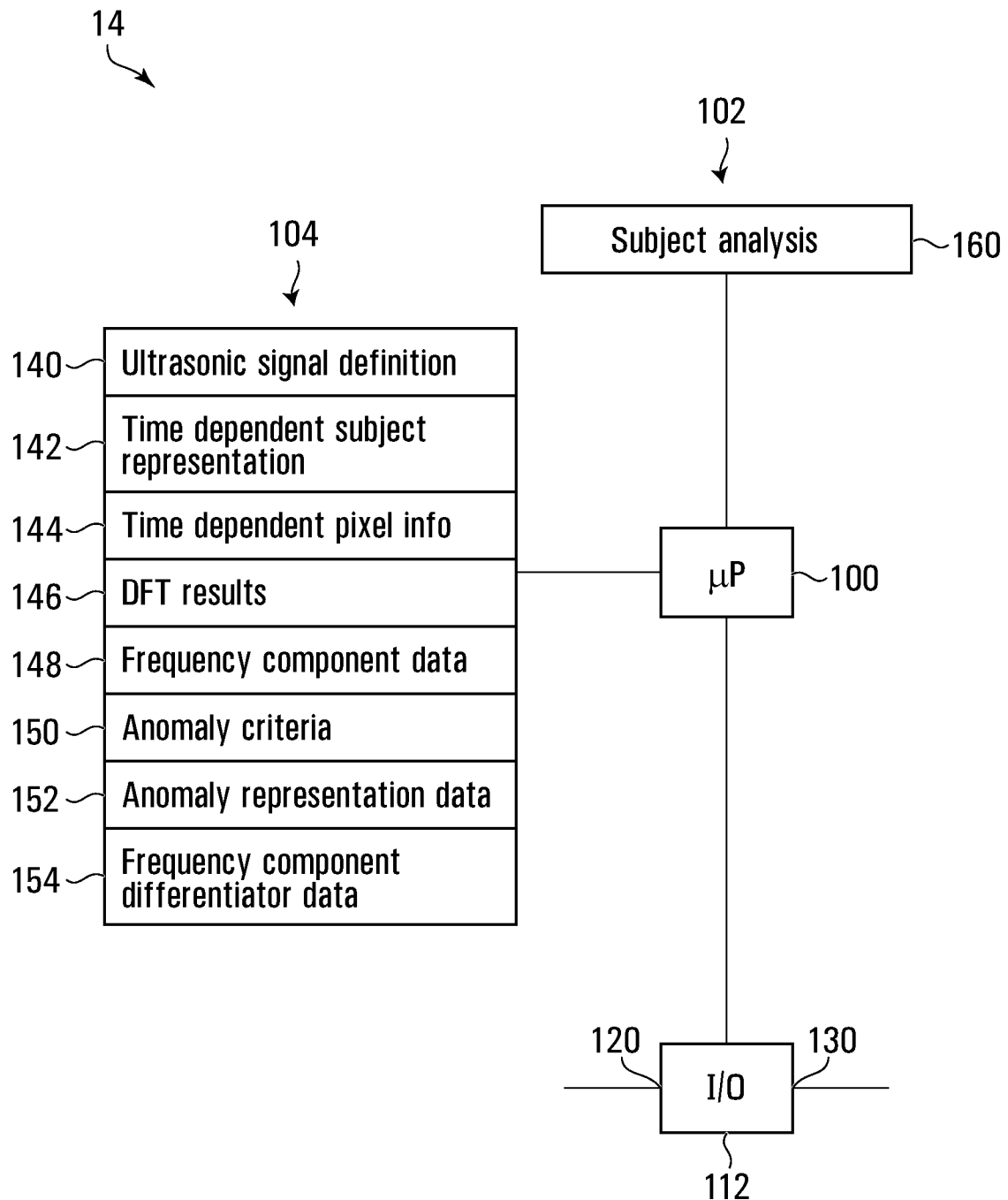
25 determining the at least one property representation of the subject comprises determining the at least one property representation of the subject based on the first function characteristic, the second function characteristic, and the time dependent representation of the subject.

14. The method of any one of claims **1** to **13** wherein the subject is a composite material.
15. A system for facilitating ultrasonic analysis of a subject comprising at least one processor configured to perform the method of any one of claims **1** to
- 5 **14**.
16. A non-transitory computer readable medium having stored thereon codes which when executed by at least one processor cause the at least one processor to perform the method of any one of claims **1** to **14**.

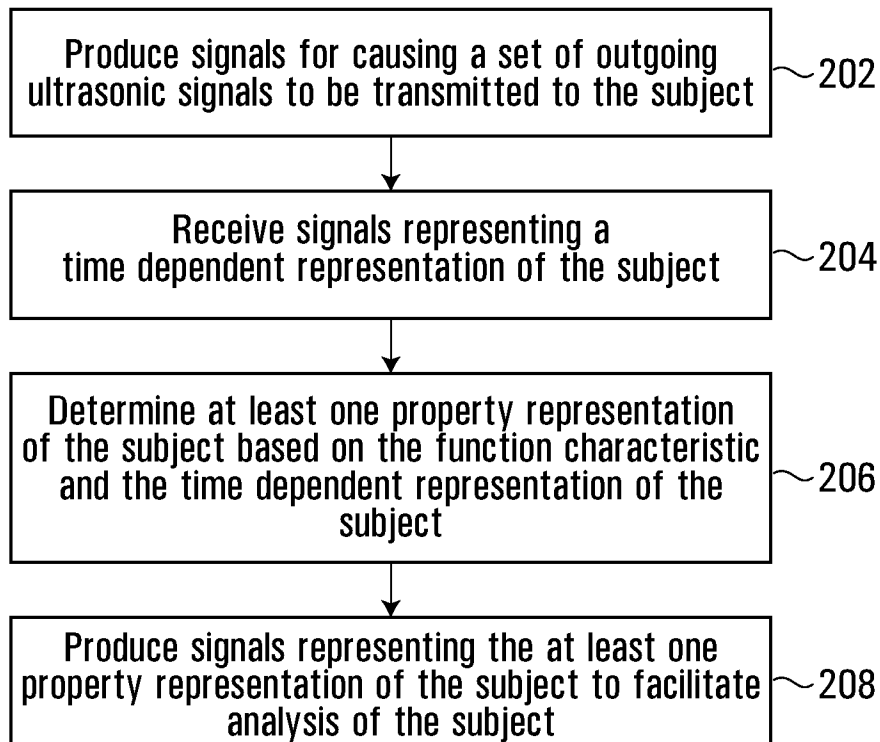
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**FIG. 1**

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**FIG. 2**

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200
**FIG. 3**

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240


Ultrasound instruction message

⋮

244 ~ $D = 20000$ 246 ~ $A = 5000$ 248 ~ $f = 0.03125$ 242 ~ $\text{focusDistance} = D + A \cdot \sin(2\pi \cdot f \cdot i)$

⋮

FIG. 4

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280
↙

Image record

282 ~ Index no.
284 ~ Image

0

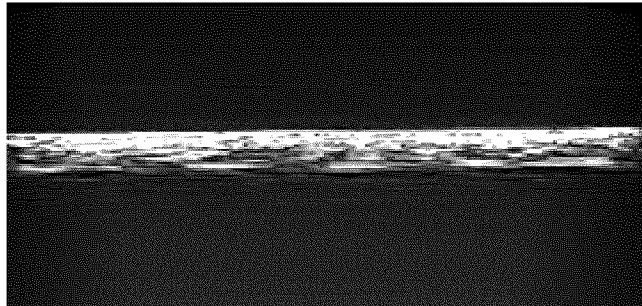
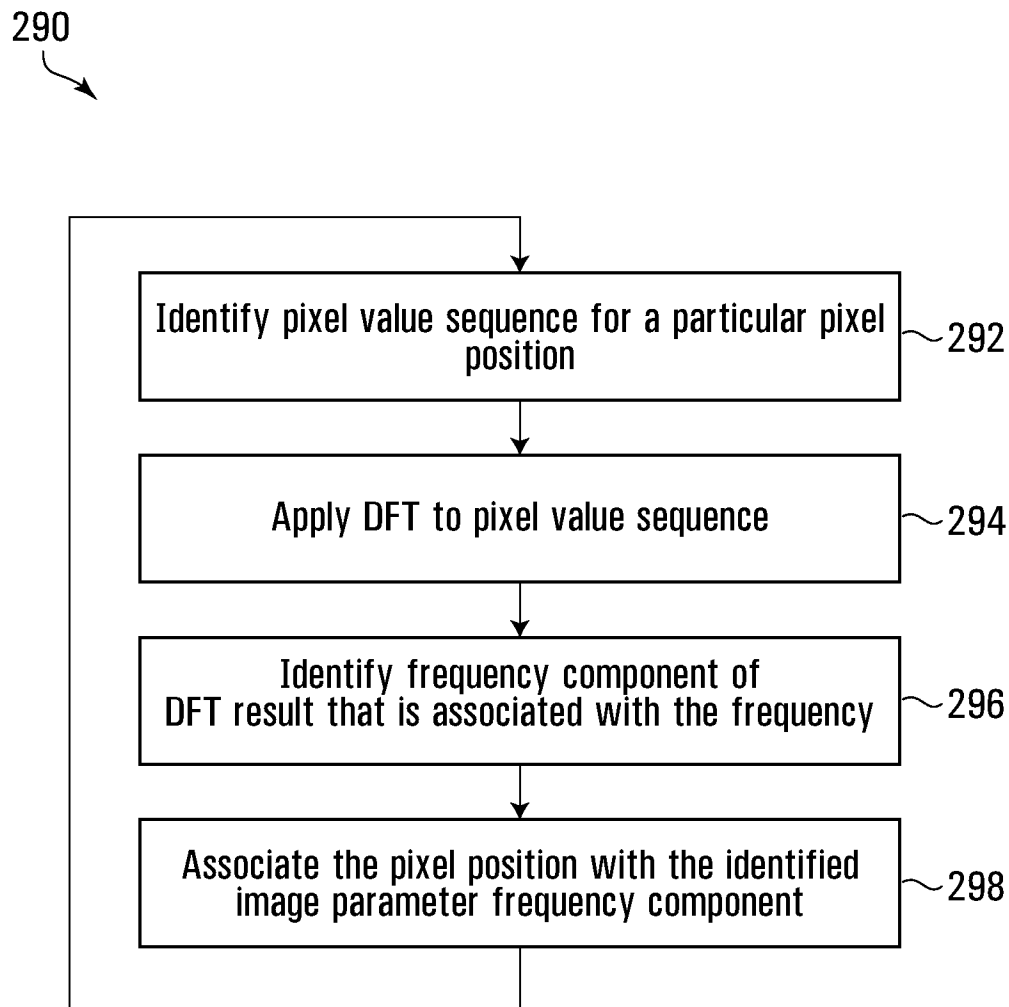


FIG. 5

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**FIG. 6**

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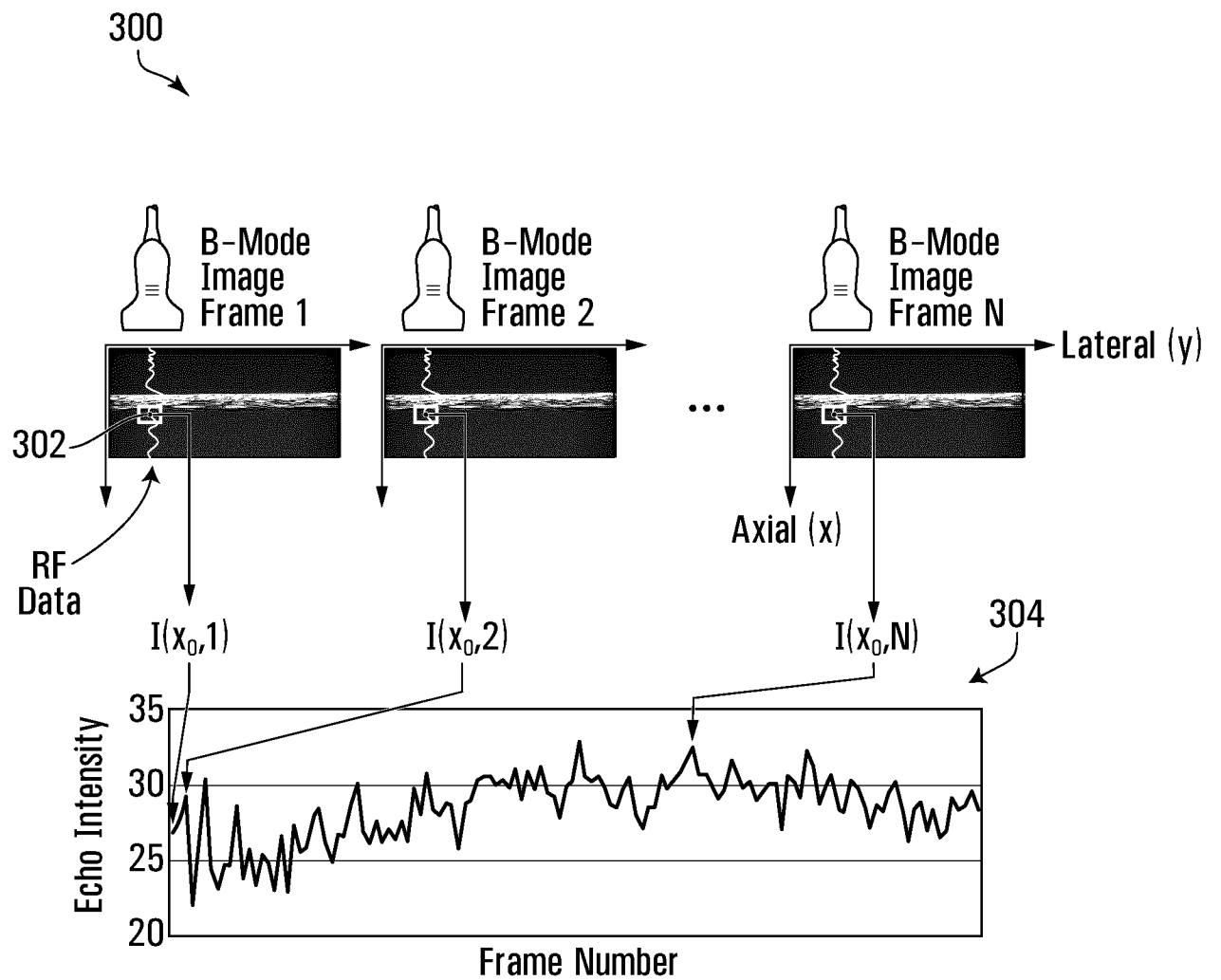
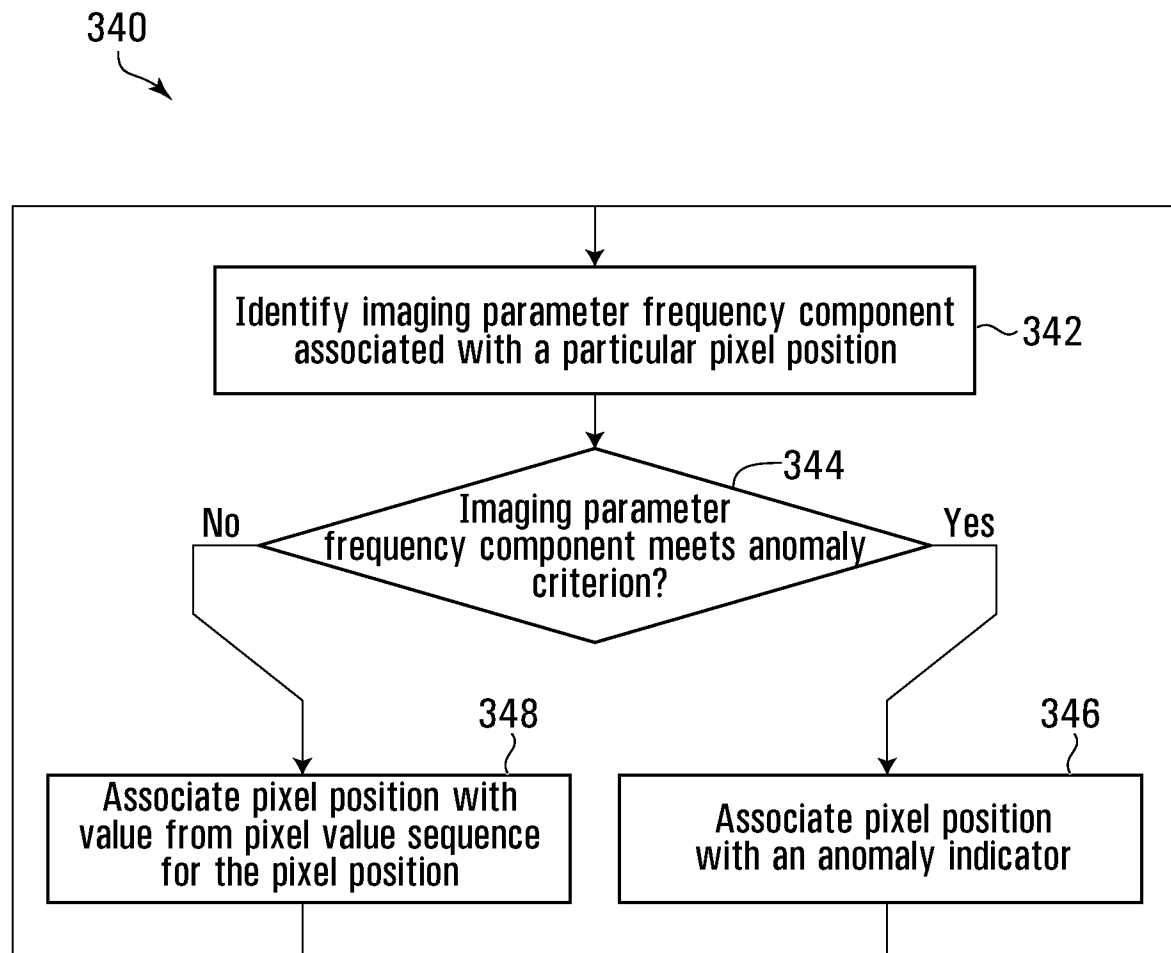


FIG. 7

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**FIG. 8**

*9/15*360
**Anomaly range record**

362 ~ Minimum	0
364 ~ Maximum	15000

FIG. 9

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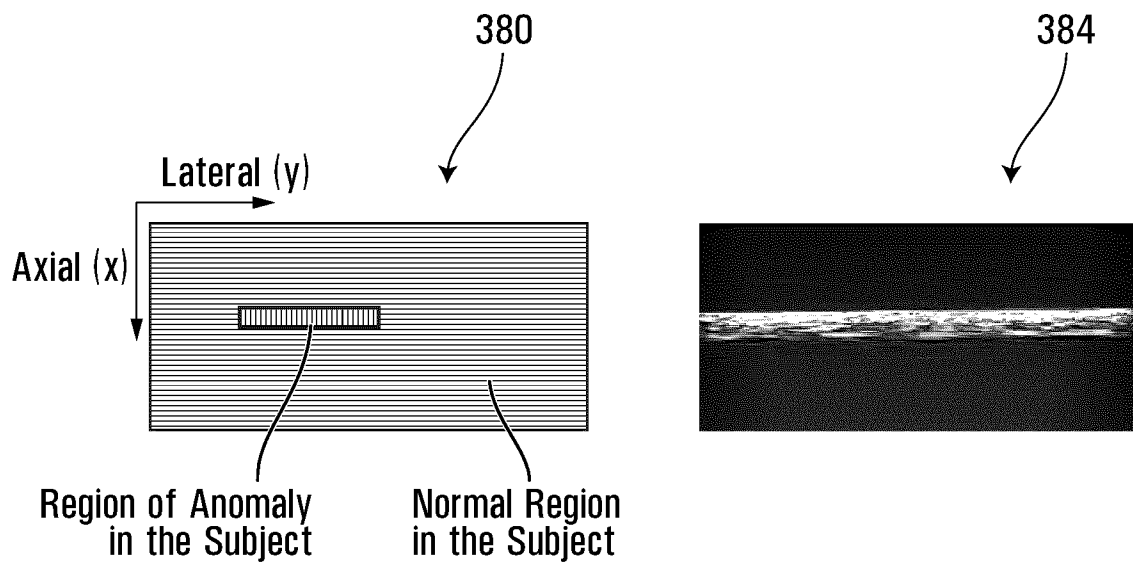
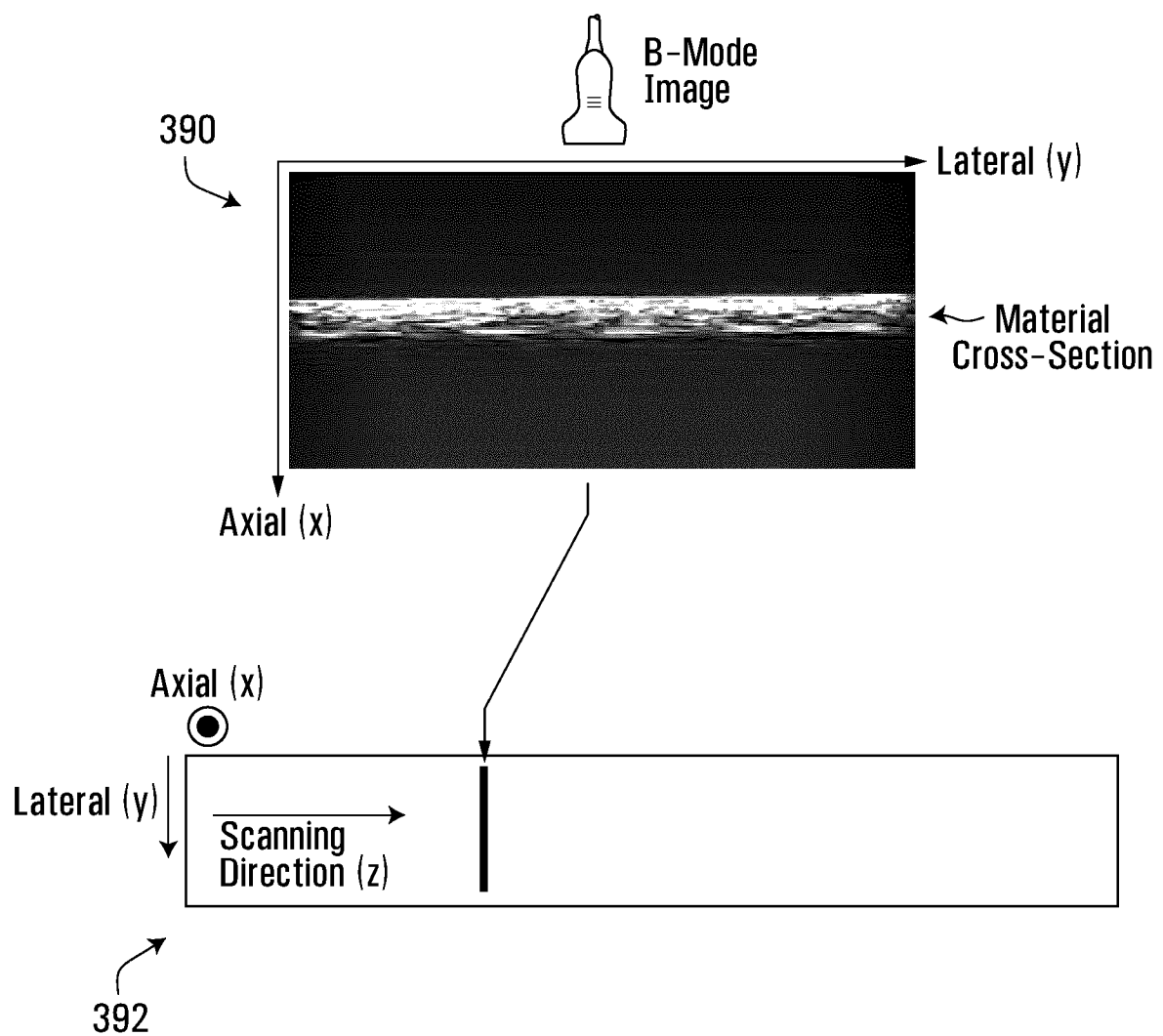


FIG. 10

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**FIG. 11**

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400



Ultrasound instruction message

⋮

 $D = 20000$ $A = 5000$ $B = 5000$ $f_1 = 0.03125$ $f_2 = 0.025$ 402 ~ $\text{focusDistance} = D + A \cdot \sin(2\pi \cdot f_1 \cdot i) + B \cdot \sin(2\pi \cdot f_2 \cdot i)$

⋮

FIG. 12

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Ultrasound instruction message

⋮

 $D2 = 5000000$ $B = 50000$ $f2 = 0.025$ 422 ~ $\text{centreFrequency} = D2 + B \cdot \sin(2\pi \cdot f2 \cdot i)$

⋮

FIG. 13

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440



Ultrasound instruction message

⋮

$D1 = 20000$

$B = 5000$

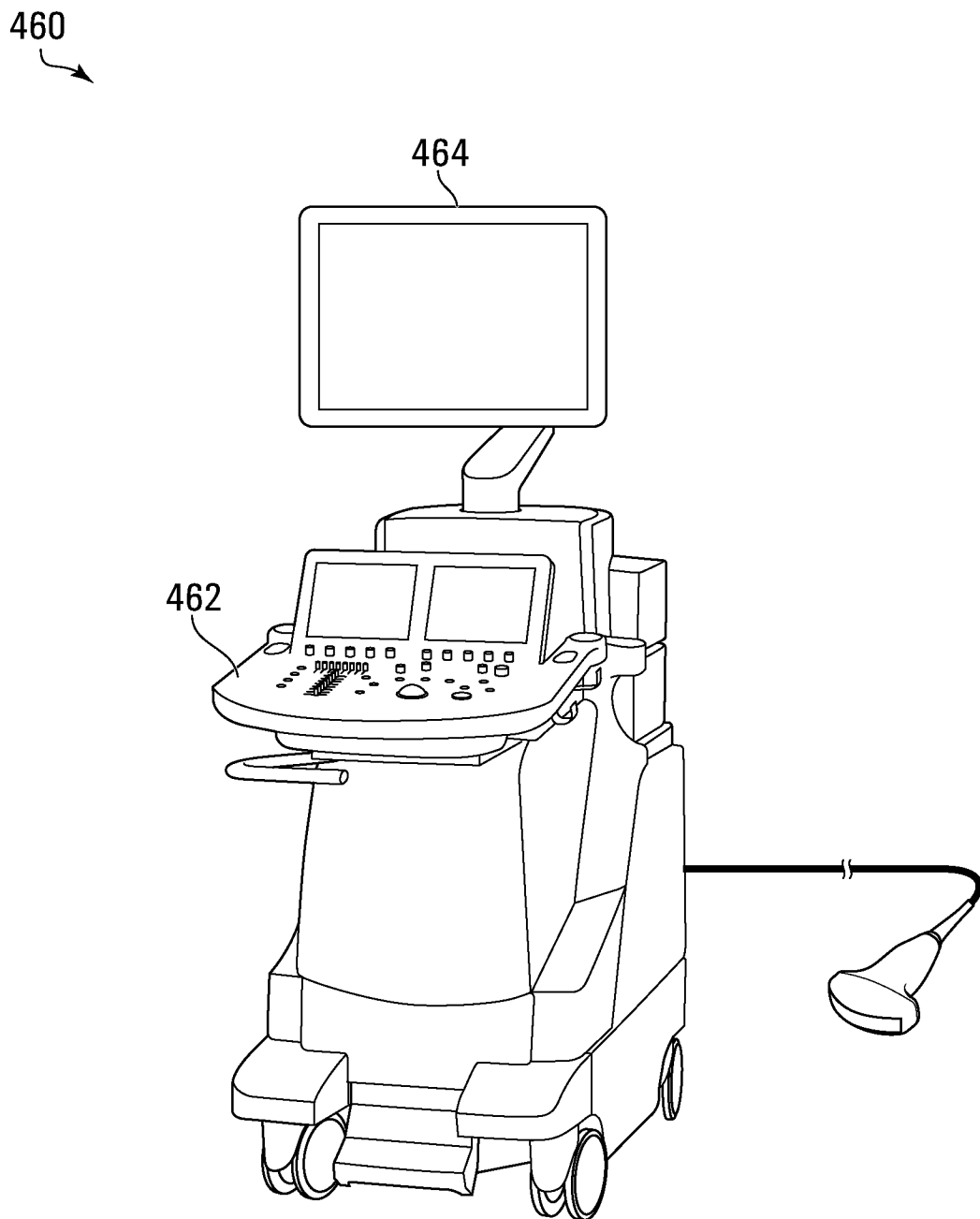
$f2 = 0.02$

$\text{focusDistance} = D + B \cdot \sin(2\pi \cdot f2 \cdot i)$

⋮

FIG. 14

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**FIG. 15**

INTERNATIONAL SEARCH REPORT

International application No.

PCT/CA2019/051314

A. CLASSIFICATION OF SUBJECT MATTER

IPC: **G01N 29/06** (2006.01), **A61B 8/08** (2006.01), **A61B 8/14** (2006.01), **G01N 29/42** (2006.01)

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC(2006.01): G01N, A61B

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

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

Questel Orbit, Google Scholar: (Keywords: non-destructive testing; ultrasonic analysis; ultrasonic signals; variable imaging parameter; function; scatter; determine property)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 2006/0287596 A1 (JOHNSON et al.) 21 December 2006 (21-12-2006) * Whole document *	1-16
A	EP 3 239 706 A1 (OSMAN et al.) 01 November 2017 (01-11-2017) * Whole document *	1-16

☐ Further documents are listed in the continuation of Box C.☒ See patent family annex.

* Special categories of cited documents:	"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"A" document defining the general state of the art which is not considered to be of particular relevance	"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"D" document cited by the applicant in the international application	"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"E" earlier application or patent but published on or after the international filing date	"&" document member of the same patent family
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)	
"O" document referring to an oral disclosure, use, exhibition or other means	
"P" document published prior to the international filing date but later than the priority date claimed	

Date of the actual completion of the international search

01 November 2019 (01-11-2019)

Date of mailing of the international search report

18 November 2019 (18-11-2019)

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INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.
PCT/CA2019/051314

Patent Document Cited in Search Report	Publication Date	Patent Family Member(s)	Publication Date
US2006287596A1	21 December 2006 (21-12-2006)	US2006287596A1 AU4169497A US6005916A US6636584B2 US2004034307A1 US2007282200A1 US2006084859A1 US7841982B2 WO9812667A2	21 December 2006 (21-12-2006) 14 April 1998 (14-04-1998) 21 December 1999 (21-12-1999) 21 October 2003 (21-10-2003) 19 February 2004 (19-02-2004) 06 December 2007 (06-12-2007) 20 April 2006 (20-04-2006) 30 November 2010 (30-11-2010) 26 March 1998 (26-03-1998)
EP3239706A1	01 November 2017 (01-11-2017)	None	