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Digital watermarking of acoustic data

Abstract

Examples described herein include adding a digital watermark into acoustic data. For example, the digital watermark data can be embedded using a key such that the watermark data is spread across a spectrum of the acoustic data. Thus, the data for the digital watermark may have no or minimal visible impact in the images generated using the marked acoustic data. The digital watermark may provide improved security and privacy. Moreover, the digital watermark may be incorporated into the reconstruction process of images.

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Background/Summary

CROSS-REFERENCE TO RELATED APPLICATION (1) This application claims the benefit of priority to U.S. Provisional Patent Application Ser. No. 63/139,127, filed Jan. 19, 2021, the contents of which are incorporated herein by reference.

TECHNICAL FIELD
(1) The present disclosure generally relates to embedding digital watermarks into data, such as acoustic data.
BACKGROUND
(2) Ultrasonic inspection can be a useful inspection technique for a variety of structures. Inhomogeneities on or within the structure under test can generate scattered or reflected acoustic signals in response to a transmitted acoustic pulse. Such acoustic "echoes" can be received and

processed. The processing can include reconstruction of an image corresponding to a region of the structure under test, for review by an inspector or for archival.

(3) Processing of received acoustic echo signals to form images can involve various techniques. In one approach, a technique called a "total focusing method" (TFM) can be used, which can involve a full-matrix capture (FMC) acquisition scheme where focus can be achieved across a broad spatial region on or within a structure under test. The TFM images or FMC data, for example, can be relatively unprotected, meaning that they can be corrupted, intentionally or accidentally, or copied by others without being traceable. Thus, the integrity of the data can be compromised by improper data copying.

Description

BRIEF DESCRIPTION OF THE DRAWINGS

(1) Various ones of the appended drawings merely illustrate example implementations of the present disclosure and should not be considered as limiting its scope.

(2) FIG. **1** illustrates an inspection system, according to an example of the present subject matter.

(3) FIG. **2** illustrates an inspection process, according to an example of the present subject matter.

(4) FIG. **3** illustrates a process to embed a digital watermark into acoustic data, according to an example of the present subject matter.

(5) FIG. **4** illustrates a process to extract a digital watermark from marked acoustic data, according to an example of the present subject matter.

(6) FIG. **5** illustrates three sample embedded TFM images and corresponding decoded digital watermarks with varying values of the strength coefficient, according to an example of the present subject matter.

(7) FIG. **6**A illustrates a flow diagram of a method for embedding a digital watermark, according to an example of the present subject matter.

(8) FIG. **6**B illustrates a flow diagram of a method for extracting an embedded digital watermark, according to an example of the present subject matter.

(9) FIG. **7** illustrates a block diagram of an example comprising a machine upon which any one or more of the techniques (e.g., methodologies) discussed herein may be performed.

DETAILED DESCRIPTION

(10) The inventor has recognized, among other things, a need in the art for techniques to embed a digital watermark into acoustic data without significantly impacting images generated from the acoustic data. Examples described herein include adding a digital watermark into acoustic data. For example, the digital watermark data can be embedded using a key such that the watermark data is spread across a spectrum of the acoustic data. Thus, the data for the digital watermark may not be visible in the images generated using the marked acoustic data. The digital watermark may provide improved security and privacy. Moreover, the digital watermark may be incorporated into the reconstruction process of images. For example, the digital watermark may include comments that may be needed to reconstruct images from the marked acoustic data.

(11) This document describes a method comprising: arranging acoustic data into a first volume of slices; for each of a set of slices: transforming a respective slice into a frequency domain representation using a discrete transform to obtain a respective transformed slice, embedding a portion of a digital watermark into the transformed slice, wherein the digital watermark is based on a key, and applying an inverted form of the discrete transform to the transformed slice with the embedded portion of the digital watermark to generate a respective marked slice; arranging respective marked slices with respective embedded portions of the digital watermark into a second volume of marked slices; and generating an image based on the second volume of marked slices.

(12) This document describes a method comprising: receiving acoustic echo data comprising time-

series representations of acoustic echo signals obtained using an acoustic transducer array; aggregating the received acoustic data into a first three-dimensional matrix of echo data samples; for each of a set of two-dimensional slices from the first matrix: transforming a respective slice into a frequency domain representation using a discrete transform to obtain a respective transformed slice, embedding a portion of a digital watermark into the transformed slice, the digital watermark based on a key, and applying an inverted form of the discrete transform to the transformed slice with the embedded portion of the digital watermark to generate a respective marked slice; arranging respective marked slices with respective embedded portions of the digital watermark into a second three-dimensional matrix of echo data samples; and generating an image based on the second matrix.

(13) This document further describes a system with one or more processors of a machine. The system also includes a memory storing instructions that, when executed by the one or more processors, cause the machine to perform operations comprising: arranging acoustic data into a first volume of slices; for each of a set of slices: transforming a respective slice into a frequency domain representation using a discrete transform to obtain a respective transformed slice, embedding a portion of a digital watermark into the transformed slice, wherein the digital watermark is based on a key, and applying an inverted form of the discrete transform to the transformed slice with the embedded portion of the digital watermark to generate a respective marked slice; arranging respective marked slices with respective embedded portions of the digital watermark into a second volume of marked slices; and generating an image based on the second volume of marked slices.

(14) FIG. **1** illustrates generally an example comprising an acoustic inspection system **100**, such as can be used to perform one or more techniques showed and described elsewhere herein. The inspection system **100** can include a test instrument **140**, such as a hand-held or portable assembly. The test instrument **140** can be electrically coupled to a probe assembly, such as using a multi-conductor interconnect **130**. The probe assembly **150** can include one or more electroacoustic transducers, such as a transducer array **152** including respective transducers **154**A through **154**N. The transducers array can follow a linear or curved contour or can include an array of elements extending in two axes, such as providing a matrix of transducer elements. The elements need not be square in footprint or arranged along a straight-line axis. Element size and pitch can be varied according to the inspection application.

(15) A modular probe assembly **150** configuration can be used, such as to allow a test instrument **140** to be used with different probe assemblies **150**. Generally, the transducer array **152** includes piezoelectric transducers, such as can be acoustically coupled to a target **158** (e.g., an object under test) through a coupling medium **156**. The coupling medium can include a fluid or gel or a solid membrane (e.g., an elastomer or other polymer material), or a combination of fluid, gel, or solid structures. For example, an acoustic transducer assembly can include a transducer array coupled to a wedge structure comprising a rigid thermoset polymer having known acoustic propagation characteristics (for example, Rexolite® available from C-Lec Plastics Inc.), and water can be injected between the wedge and the structure under test as a coupling medium **156** during testing.

(16) The test instrument **140** can include digital and analog circuitry, such as a front end-circuit **122** including one or more transmit signal chains, receive signal chains, or switching circuitry (e.g., transmit/receive switching circuitry). The transmit signal chain can include amplifier and filter circuitry, such as to provide transmit pulses for delivery through an interconnect **130** to a probe assembly **150** for insonification of the target **158**, such as to image or otherwise detect a flaw **160** on or within the target **158** structure by receiving scattered or reflected acoustic energy elicited in response to the insonification.

(17) While FIG. **1** shows a single probe assembly **150** and a single transducer array **152**, other configurations can be used, such as multiple probe assemblies connected to a single test instrument **140**, or multiple transducer arrays **152** used with a single or multiple probe assemblies **150** for tandem inspection. Similarly, a test protocol can be performed using coordination between multiple

test instruments **140**, such as in response to an overall test scheme established from a master test instrument **140**, or established by another remote system such as a compute facility **108** or general purpose computing device such as a laptop **132**, tablet, smart-phone, desktop computer, or the like. The test scheme may be established according to a published standard or regulatory requirement and may be performed upon initial fabrication or on a recurring basis for ongoing surveillance, as illustrative examples.

(18) The receive signal chain of the front-end circuit **122** can include one or more filters or amplifier circuits, along with an analog-to-digital conversion facility, such as to digitize echo signals received using the probe assembly **150**. Digitization can be performed coherently, such as to provide multiple channels of digitized data aligned or referenced to each other in time or phase. The front-end circuit **122** can be coupled to and controlled by one or more processor circuits, such as a processor circuit **102** included as a portion of the test instrument **140**. The processor circuit can be coupled to a memory circuit, such as to execute instructions that cause the test instrument **140** to perform one or more of acoustic transmission, acoustic acquisition, processing, or storage of data relating to an acoustic inspection, or to otherwise perform techniques as shown and described herein. The test instrument **140** can be communicatively coupled to other portions of the system **100**, such as using a wired or wireless communication interface **120**.

(19) For example, performance of one or more techniques as shown and described herein can be accomplished on-board the test instrument **140** or using other processing or storage facilities such as using a compute facility **108** or a general-purpose computing device such as a laptop **132**, tablet, smart-phone, desktop computer, or the like. For example, processing tasks that would be undesirably slow if performed on-board the test instrument **140** or beyond the capabilities of the test instrument **140** can be performed remotely (e.g., on a separate system), such as in response to a request from the test instrument **140**. Similarly, storage of imaging data or intermediate data such as A-scan matrices of time-series data can be accomplished using remote facilities communicatively coupled to the test instrument **140**. The test instrument can include a display **110**, such as for presentation of configuration information or results, and an input device **112** such as including one or more of a keyboard, trackball, function keys or soft keys, mouse-interface, touch-screen, stylus, or the like, for receiving operator commands, configuration information, or responses to queries.

(20) FIG. **2** illustrates an inspection process, according to an example of the subject matter. Using an inspection probe **202**, as described above, a scan may be performed on an object **204**. In this example, the object **204** is illustrated as a block (e.g., steel) with a plurality of side drilled holes **206**. The inspection probe **202** may include a plurality of transducer elements (e.g., transducer array). In this example, the inspection probe **202** may include N transmitting elements (N=32) and M receiving elements (M=32). The inspection probe **202** may capture acoustic data **208**, which may include A-scan time-series representations of acoustic echo signals. The acoustic data **208** captured by the inspection probe **202** may be in the form of FMC data, for example. Here, the acoustic data **208** (e.g., FMC data) may include 1024 columns (N×M, which in this example is 32×32) with each column including approximately 3000 samples; each column may represent an A-scan. The acoustic data **208** may be then used to generate an image **210**, such as a TFM image. Here, the image **210** illustrates echo representations of the side drilled holes **206** in the object **204**.

(21) Next, techniques to embed a digital watermark in acoustic data will be described. The digital watermark may have no or minimal impact on the final image(s) generated using the acoustic data.

(22) FIG. **3** illustrates a process to embed a digital watermark into acoustic data, according to an example of the present subject matter. First, acoustic data **208**, which may be in the form of FMC data, or may be rearranged into a 3D arrangement, such as a 3D matrix of echo data samples (3D FMC data **302**). The value of the data may be the same but rearranged in a 3D representation. In an example, the acoustic data **208** may undergo pre-processing, such as data enhancement. The 3D FMC data **302** may be provided as a plurality of 2D slices (3000 slices which may correspond to

the number of samples). In this example, each slice is 32×32, where 32 represents the number of transmitting and receiving elements (N×M) of the inspection probe used to capture the acoustic data. Other transmitting and receiving element configurations may also be used.

(23) A digital watermark may be embedded and distributed across the slices. In one example, the digital watermark may be distributed across all the slices in the 3D FMC data **302**. In another example, the digital watermark may be distributed across a select set of slices, and not all slices. In this example, portions of the digital watermark may be added to each of the selected slices.

(24) Each slice **304** of the selected set may be transformed from the time domain to the frequency domain. For example, a 2D discrete cosine transform (DCT) may be applied to the slice **304** to generate a transformed slice **306** as a frequency domain representation. Other transform functions, such as Fourier, wavelet, etc., may also be used.

(25) A portion of a digital watermark **308** may be embedded into the transformed slice **306**. For example, a pixel of the digital watermark **308** (e.g., bitmap "Logo") may be embedded into the transformed slice **306**. To insert the pixel of digital watermark **308**, a key **310** may be used. The key **310** may be the same size as the transformed slice **306**, N×M (e.g., 32×32). The key **310** may include an image representation of randomly generated numbers or digits (e.g., +1, 0, −1), such as a bitmap representation of a random pattern or random pixel values. For example, a +1 digit may be represented by a black pixel, a −1 digit may be represented by a white pixel, and a 0 digit may be represented by a gray pixel. Other color pixels and pixel values may also be used. For example, the key may be represented by other values between 0 and 1, where its value may reflect the visibility of the mark. In another example, the key may be represented by values ranging from −x to +x, where x is an integer.

(26) The key **310** may be defined in a manner to lessen its impact on the acoustic data. For example, in a transformed slice (e.g., **306**), the upper left pixels may include relatively low-frequency information and the bottom right pixels may include relatively high-frequency information. Therefore, the key **310** may be defined to lower its impact in the upper left pixels, which include relatively low-frequency information. For example, the key **310** may concentrate "0" values (e.g., gray pixels) in the upper left pixels to reduce the impact of embedding the key **310** on the acoustic data. Conversely, the key **310** may include more robust key information in the bottom right pixels, which may include relatively high-frequency information.

(27) The key **310** may be multiplied by a strength coefficient (a) **312**. In an example, the strength coefficient **312** may be pre-set. In another example, the strength coefficient **312** may be programmed or set based on the acoustic data. A signal-to-noise ratio or other indicium of quality of a recovered digital watermark may be related to the strength coefficient **312**; for example, the visibility of the digital watermark may be related to the strength coefficient **312**. A relatively higher strength coefficient **312** may correspond to a more clearly discernable (e.g., more visible) recovered digital watermark and a relatively lower strength coefficient **312** may correspond to a comparatively noisier digital watermark (e.g., less visible). In one example, the value of the strength coefficient **312** may be adjusted based on the content of the respective slice **304**. For example, for certain slices, such as those with more relevant acoustic data, a relatively lower strength coefficient **312** may be applied, and for other slices, such as those with less relevant acoustic data, a relatively higher strength coefficient **312** may be applied. Energy of the slice may be measured, and based on the measured energy, the value of the strength coefficient **312** for that respective slice may be set.

(28) The key **312** may then be combined with the transformed slice. For example, the key **312** may be added or subtracted from the transformed slice **306** based on the portion of the digital watermark **308** to be added to the respective slice. For instance, if the portion of the digital watermark **308** corresponds to a white pixel (e.g., white pixel in "Logo" bitmap), then the key **312** may be added to the transformed slice **306**. Conversely, if the portion of the digital watermark **308** to the slice **304** corresponds to a black pixel (e.g., black pixel in "Logo" bitmap), then the key **312** may be

subtracted from the transformed slice **306**.

(29) After the key **312** has been inserted into the transformed slice **306** based on the respective portion of the digital watermark **306**, the transformed slice **306** may then transformed back from the frequency domain into the time domain using an inverse function of the function used to transform the slice **304** to generate a marked slice **314**. For example, if a 2D DCT was applied, then an inverse DCT (IDCT) may be applied to generate the marked slice. The marked slice **304** may include information regarding the added portion of the digital watermark **308** based on the key **310**.

(30) This process may be repeated for the set of slices in the 3D FMC data **302** until the digital watermark **308** is completely added to generate marked 3D FMC data **316**. In one example, as described above, portions of the digital watermark **308** may be added using key **310** (with strength coefficient **312**) to all slices of the 3D FMC data **302**. If the 3D FMC data **302** includes 3000 samples and information of one pixel of the digital watermark **308** can be embedded into each slice, then a 3000-pixel mark may be embedded.

(31) Alternatively, information regarding the digital watermark **308** may be embedded into a selected set of slices of the 3D FMC data **302**. The slices to be marked may be selected based on their acoustic data content. For example, slices with less relevant acoustic data may be selected for digital watermarking while slices with more relevant acoustic data may not be selected for digital watermarking. Relevancy of the acoustic data may be determined using different techniques. Energy of the slice may be measured, and based on the measured energy, the slice may be selected for watermark embedding. In one example, the last set of samples of 3D FMC data **302** may not be used to generate a TFM image; therefore, the digital watermark information may be embedded in those last set of samples.

(32) In any event, the digital watermark **308** may be distributed across a frequency spectrum to make minimal visible impact in image(s) generated using the marked acoustic data. The marked 3D FMC data **316** may be then used to generate an image **318**, such as a TFM image. The image **318** may display the echo representations in the acoustic and may include information regarding the embedded digital watermark **308**, but that watermark information may have no or minimal visible impact on the display of the echo representations.

(33) Next, techniques to extract and decode a digital watermark will be described. FIG. **4** illustrates a process to extract a digital watermark from marked acoustic data, according to an example of the present subject matter. For extraction, the marked acoustic data such as marked 3D FMC data **316** may be provided. Each slice **402** of the marked 3D FMC data **316** of the selected set may be transformed from the time domain representation to frequency domain representation. The same transform function used to embed the digital watermark, as described above with reference to FIG. **3**, may be used here in the extraction process. For example, a 2D discrete cosine transform (DCT) may be applied to the slice **402** to generate a transformed slice **404**. Other transform functions, such as Fourier, wavelet, etc., may also be used.

(34) Each transformed slice **404** may then be applied to a correlation function **406** with the key **310** (the same key used for embedding the digital watermark). The correlation function **406** may determine a degree of correlation between the transformed slice **404** and the key **310**. Based on the result of the correlation function **406** (e.g., degree of correlation), the portion of the digital watermark **308** embedded in the respective transformed slice **404** may be established. Consider the example described above: for white pixels of the digital watermark **308**, the key **310** was added to the respective transformed slices **306**; for black pixels of the digital watermark **308**, the key **310** was subtracted from the respective transformed slices **306**. In this example, if the result of the correlation function **406** is positive (greater than zero), it may correspond to a white pixel for the digital watermark; if the result of the correlation function **406** is negative (less than zero), it may correspond to a black pixel for the digital watermark. This correlation procedure may be performed for all embedded slices and the results may be aggregated so that the embedded digital watermark may then be decoded and reconstructed accordingly.

(35) As mentioned above, the strength coefficient (a) of the key used to embed the digital watermark may impact the visibility of the embedded information and the clarity of the decoded watermark. There can be a tradeoff between the clarity of the decoded digital watermark and the visible impact of the watermark. FIG. **5** illustrates three sample embedded TFM images and corresponding decoded digital watermarks with varying values of the strength coefficient. The first sample TFM image **502.1** was embedded with the digital watermark information with the strength coefficient set at 0.1. Here, the relatively low strength coefficient shows minimal to no visible impact to the TFM image **502.1**, but the clarity of the decoded digital watermark **502.2** is low. This is because decoding a relatively low-strength embedded watermark may be more prone to error. For example, here the logo error was measured to be about 16.6% and the Peak Signal to Noise Ratio (PSNR) was measured to be about 120.8 dB.

(36) The second sample TFM image **504.1** was embedded with the digital watermark information with the strength coefficient set at 1. Here, the set strength coefficient shows minimal to no visible impact to the TFM image **504.1** (like the first sample TFM image), but, unlike the first sample TFM image, the clarity of the decoded digital watermark **504.2** is high. Indeed, the measured logo error measured to be about 0% and the PSNR was measured to be about 100.6 dB.

(37) The third sample TFM image **506.1** was embedded with the digital watermark information with the strength coefficient set at 10. Here, the clarity of the decoded digital watermark **506.2** is high. The measured logo error measured to be about 0% and the PSNR was measured to be about 100.6 dB. But appreciable visible impact to the TFM image **506.1** can be seen. This shows the tradeoff of using high strength coefficients when embedding the digital watermark using the techniques described herein.

(38) As mentioned above, the value of the strength coefficient (a) may be varied or adjusted during the embedding process. For example, the energy of each transformed slice to be embedded may be measured, and based on the measured amount of energy, the value of the strength coefficient may be adjusted. For slices with relatively higher amounts of energy, the strength coefficient may set to a relatively lower value, and for slices with relatively lower amounts of energy, the strength coefficient may be set to a relatively higher value.

(39) The digital watermark may be provided in different forms. For example, the digital watermark may be provided as a bitmap (e.g., binary image of "Logo"). In another example, the digital watermark may be a photograph or an image. The digital watermark may also be provided as text or code represented as a binary signal. For example, an ASCII character may be coded to 8 bits, i.e., 8 pixels (e.g., 0=black and 1=white).

(40) In addition to providing security, the digital watermark may also include information related to constructing an image (e.g., TFM image) from the acoustic data. For example, the digital watermark may include metadata information encoded for storage as a portion of a digital watermark, such as representing number of elements used in inspection, a test configuration, etc. The metadata may include traceability information relating to specific site conditions, or data relating to an object-under-test such as physical coordinates or other identifying data indicative of a test location. Metadata may be used to construct an image from the marked acoustic data or to modify such construction of an image. In this example, the embedded digital watermark may be extracted and decoded first, and then the extracted information from the embedded digital watermark may be used to construct an image from the marked acoustic data.

(41) FIG. **6**A illustrates a flow diagram of a method **600** for embedding a digital watermark, according to an example of the present subject matter. At **605**, acoustic data obtained using an acoustic transducer array may be received. The acoustic data may include time-series representations of acoustic echo signals obtained using an acoustic transducer array, such as FMC data. In an example, the acoustic data may undergo pre-processing, such as data enhancement. At **610**, the received acoustic data may be arranged into a first volume of slices. For example, the received acoustic data into a three-dimensional volume matrix of echo data samples. For each of a

set of two-dimensional slices of the first volume: at **615**, a respective slice may be transformed into a frequency domain representation using a discrete transform to obtain a respective transformed slice; at **620**, a portion of a digital watermark may be embedded into the transformed slice, the digital watermark may be based on a key; and at **625**, an inverted form of the discrete transform may be applied to the transformed slice with the embedded portion of the digital watermark to generate a respective marked slice. At **630**, the respective marked slices with respective embedded portions of the digital watermark may be arranged into a second volume of marked slices. For example, exampled the marked slices may be arranged into second three-dimensional matrix of echo data samples. At **635**, an image may be generated based on the second volume of marked slices (e.g., second matrix of echo data samples).

(42) FIG. **6**B illustrates a flow diagram of a method **650** for extracting an embedded digital watermark, according to an example of the present subject matter. At **660**, the second volume of marked slices (e.g., second matrix of echo data samples) may be received. For each marked slice: at **665**, a respective marked slice may be transformed into a frequency domain representation using a discrete transform to obtain a respective transformed marked slice; at **670**, a degree of correlation between the transformed marked slice and the key used to embed the digital watermark may be determined; and at **675**, based on the degree of correlation, a value of a portion of the digital watermark for the respective slice may be established. Correlation may be a statistic method (e.g., sum of product) that measures the degree of similarity between to items (e.g., signal, image). In an example, the result of the correlation may fall between 0 and +1. At **680**, the established values of portions of the digital watermark may be aggregated. At **685**, a visual representation of the digital watermark may be generated based on the aggregated established values.

(43) The techniques shown and described in this document can be performed using a portion or an entirety of an inspection system **100** as shown in FIG. **1** or otherwise using a machine **700** as discussed below in relation to FIG. **7**. FIG. **7** illustrates a block diagram of an example comprising a machine **700** upon which any one or more of the techniques (e.g., methodologies) discussed herein may be performed. In various examples, the machine **700** may operate as a standalone device or may be connected (e.g., networked) to other machines. In a networked deployment, the machine **700** may operate in the capacity of a server machine, a client machine, or both in server-client network environments. In an example, the machine **700** may act as a peer machine in peer-to-peer (P2P) (or other distributed) network environment. The machine **700** may be a personal computer (PC), a tablet device, a set-top box (STB), a personal digital assistant (PDA), a mobile telephone, a web appliance, a network router, switch or bridge, or any machine capable of executing instructions (sequential or otherwise) that specify actions to be taken by that machine. Further, while only a single machine is illustrated, the term "machine" shall also be taken to include any collection of machines that individually or jointly execute a set (or multiple sets) of instructions to perform any one or more of the methodologies discussed herein, such as cloud computing, software as a service (SaaS), other computer cluster configurations.

(44) Examples, as described herein, may include, or may operate by, logic or a number of components, or mechanisms. Circuitry is a collection of circuits implemented in tangible entities that include hardware (e.g., simple circuits, gates, logic, etc.). Circuitry membership may be flexible over time and underlying hardware variability. Circuitries include members that may, alone or in combination, perform specified operations when operating. In an example, hardware of the circuitry may be immutably designed to carry out a specific operation (e.g., hardwired). In an example, the hardware comprising the circuitry may include variably connected physical components (e.g., execution units, transistors, simple circuits, etc.) including a computer readable medium physically modified (e.g., magnetically, electrically, such as via a change in physical state or transformation of another physical characteristic, etc.) to encode instructions of the specific operation. In connecting the physical components, the underlying electrical properties of a hardware constituent may be changed, for example, from an insulating characteristic to a

conductive characteristic or vice versa. The instructions enable embedded hardware (e.g., the execution units or a loading mechanism) to create members of the circuitry in hardware via the variable connections to carry out portions of the specific operation when in operation. Accordingly, the computer readable medium is communicatively coupled to the other components of the circuitry when the device is operating. In an example, any of the physical components may be used in more than one member of more than one circuitry. For example, under operation, execution units may be used in a first circuit of a first circuitry at one point in time and reused by a second circuit in the first circuitry, or by a third circuit in a second circuitry at a different time.

(45) Machine (e.g., computer system) **700** may include a hardware processor **702** (e.g., a central processing unit (CPU), a graphics processing unit (GPU), a hardware processor core, or any combination thereof), a main memory **704** and a static memory **706**, some or all of which may communicate with each other via an interlink (e.g., bus) **708**. The machine **700** may further include a display unit **720**, an alphanumeric input device **722** (e.g., a keyboard), and a user interface (UI) navigation device **724** (e.g., a mouse). In an example, the display unit **720**, input device **722** and UI navigation device **724** may be a touch screen display. The machine **700** may additionally include a storage device (e.g., drive unit) **726**, a signal generation device **728** (e.g., a speaker), a network interface device **720**, and one or more sensors **722**, such as a global positioning system (GPS) sensor, compass, accelerometer, or other sensor. The machine **700** may include an output controller **728**, such as a serial (e.g., universal serial bus (USB), parallel, or other wired or wireless (e.g., infrared (IR), near field communication (NFC), etc.) connection to communicate or control one or more peripheral devices (e.g., a printer, card reader, etc.).

(46) The storage device **726** may include a machine readable medium **722** on which is stored one or more sets of data structures or instructions **724** (e.g., software) embodying or utilized by any one or more of the techniques or functions described herein. The instructions **724** may also reside, completely or at least partially, within the main memory **704**, within static memory **706**, or within the hardware processor **702** during execution thereof by the machine **700**. In an example, one or any combination of the hardware processor **702**, the main memory **704**, the static memory **707**, or the storage device **726** may constitute machine readable media.

(47) While the machine readable medium **722** is illustrated as a single medium, the term "machine readable medium" may include a single medium or multiple media (e.g., a centralized or distributed database, and/or associated caches and servers) configured to store the one or more instructions **724**.

(48) The term "machine readable medium" may include any medium that is capable of storing, encoding, or carrying instructions for execution by the machine **700** and that cause the machine **700** to perform any one or more of the techniques of the present disclosure, or that is capable of storing, encoding or carrying data structures used by or associated with such instructions. Non-limiting machine-readable medium examples may include solid-state memories, and optical and magnetic media. Accordingly, machine-readable media are not transitory propagating signals. Specific examples of massed machine readable media may include: non-volatile memory, such as semiconductor memory devices (e.g., Electrically Programmable Read-Only Memory (EPROM), Electrically Erasable Programmable Read-Only Memory (EEPROM)) and flash memory devices; magnetic or other phase-change or state-change memory circuits; magnetic disks, such as internal hard disks and removable disks; magneto-optical disks; and CD-ROM and DVD-ROM disks.

(49) The instructions **724** may further be transmitted or received over a communications network **726** using a transmission medium via the network interface device **720** utilizing any one of a number of transfer protocols (e.g., frame relay, internet protocol (IP), transmission control protocol (TCP), user datagram protocol (UDP), hypertext transfer protocol (HTTP), etc.). Example communication networks may include a local area network (LAN), a wide area network (WAN), a packet data network (e.g., the Internet), mobile telephone networks (e.g., cellular networks), Plain Old Telephone (POTS) networks, and wireless data networks (e.g., Institute of Electrical and

Electronics Engineers (IEEE) 802.22 family of standards known as Wi-Fi®, IEEE 802.26 family of standards known as WiMax®), IEEE 802.25.4 family of standards, peer-to-peer (P2P) networks, among others. In an example, the network interface device **720** may include one or more physical jacks (e.g., Ethernet, coaxial, or phone jacks) or one or more antennas to connect to the communications network **726**. In an example, the network interface device **720** may include a plurality of antennas to wirelessly communicate using at least one of single-input multiple-output (SIMO), multiple-input multiple-output (MIMO), or multiple-input single-output (MISO) techniques. The term "transmission medium" shall be taken to include any intangible medium that is capable of storing, encoding or carrying instructions for execution by the machine **700**, and includes digital or analog communications signals or other intangible medium to facilitate communication of such software.

Various Notes

(50) Each of the non-limiting aspects above can stand on its own or can be combined in various permutations or combinations with one or more of the other aspects or other subject matter described in this document.

(51) The above detailed description includes references to the accompanying drawings, which form a part of the detailed description. The drawings show, by way of illustration, specific implementations in which the invention can be practiced. These implementations are also referred to generally as "examples." Such examples can include elements in addition to those shown or described. However, the present inventors also contemplate examples in which only those elements shown or described are provided. Moreover, the present inventors also contemplate examples using any combination or permutation of those elements shown or described (or one or more aspects thereof), either with respect to a particular example (or one or more aspects thereof), or with respect to other examples (or one or more aspects thereof) shown or described herein.

(52) In the event of inconsistent usages between this document and any documents so incorporated by reference, the usage in this document controls.

(53) In this document, the terms "a" or "an" are used, as is common in patent documents, to include one or more than one, independent of any other instances or usages of "at least one" or "one or more." In this document, the term "or" is used to refer to a nonexclusive or, such that "A or B" includes "A but not B," "B but not A," and "A and B," unless otherwise indicated. In this document, the terms "including" and "in which" are used as the plain-English equivalents of the respective terms "comprising" and "wherein." Also, in the following claims, the terms "including" and "comprising" are open-ended, that is, a system, device, article, composition, formulation, or process that includes elements in addition to those listed after such a term in a claim are still deemed to fall within the scope of that claim. Moreover, in the following claims, the terms "first," "second," and "third," etc. are used merely as labels, and are not intended to impose numerical requirements on their objects.

(54) Method examples described herein can be machine or computer-implemented at least in part. Some examples can include a computer-readable medium or machine-readable medium encoded with instructions operable to configure an electronic device to perform methods as described in the above examples. An implementation of such methods can include code, such as microcode, assembly language code, a higher-level language code, or the like. Such code can include computer readable instructions for performing various methods. The code may form portions of computer program products. Further, in an example, the code can be tangibly stored on one or more volatile, non-transitory, or non-volatile tangible computer-readable media, such as during execution or at other times. Examples of these tangible computer-readable media can include, but are not limited to, hard disks, removable magnetic disks, removable optical disks (e.g., compact disks and digital video disks), magnetic cassettes, memory cards or sticks, random access memories (RAMs), read only memories (ROMs), and the like.

(55) The above description is intended to be illustrative, and not restrictive. For example, the

above-described examples (or one or more aspects thereof) may be used in combination with each other. Other implementations can be used, such as by one of ordinary skill in the art upon reviewing the above description. The Abstract is provided to allow the reader to quickly ascertain the nature of the technical disclosure. It is submitted with the understanding that it will not be used to interpret or limit the scope or meaning of the claims. Also, in the above Detailed Description, various features may be grouped together to streamline the disclosure. This should not be interpreted as intending that an unclaimed disclosed feature is essential to any claim. Rather, inventive subject matter may lie in less than all features of a particular disclosed implementation. Thus, the following claims are hereby incorporated into the Detailed Description as examples or implementations, with each claim standing on its own as a separate implementation, and it is contemplated that such implementations can be combined with each other in various combinations or permutations. The scope of the invention should be determined with reference to the appended claims, along with the full scope of equivalents to which such claims are entitled.

Claims

1. A method comprising: providing acoustic data comprising time-series representation of acoustic echo signals from an object under inspection using an acoustic transducer array, the acoustic data being arranged in a 3D arrangement; generating a first volume of slices based on the acoustic data, the first volume slices comprising 2D slices, wherein a parameter of the 2D slices is based on a number of elements of the acoustic transducer array; for each of the first volume of slices: transforming a respective slice into a frequency domain representation using a discrete transform to obtain a respective transformed slice, embedding a portion of a digital watermark into the transformed slice, wherein the digital watermark is based on a key, the embedding comprising: determining an energy level of the transformed slice, and setting a strength coefficient for application of the key for the transformed slice based on the energy level of the transformed slice, and applying an inverted form of the discrete transform to the transformed slice with the embedded portion of the digital watermark to generate a respective marked slice; arranging respective marked slices with respective embedded portions of the digital watermark into a second volume of marked slices; and generating an image based on the second volume of marked slices, wherein the image illustrates echo representations from the object.
2. The method of claim 1, further comprises: extracting the embedded digital watermark from the second volume of marked slices to generate a visual representation of the digital watermark.
3. The method of claim 2, wherein extracting the embedded digital watermark includes for each of a set of marked slices: transforming a respective marked slice into the frequency domain representation to obtain a respective transformed marked slice, determining a degree of correlation between the transformed marked slice and the key to generate a correlation result, and based on the degree of correlation, establish a value of the portion of the recovered digital watermark; aggregating the respective established values of portions of the recovered digital watermark; and generating a visual representation of the recovered digital watermark based on the aggregated established values.
4. The method of claim 1, wherein embedding the portion of the digital watermark into the transformed slice comprises: based on a value of the portion of the digital watermark, combining the key with the transformed slice.
5. The method of claim 4, further comprising: based on the value of the portion of the digital watermark being a first type, adding the key to the transformed slice; and based on the value of the portion of the digital watermark being a second type, subtracting the key from the transformed slice.
6. The method of claim 1, wherein the key includes a bitmap representation.
7. The method of claim 6, wherein the bitmap representation comprises at least one of a random

pattern or random pixel values.

8. The method of claim 1, wherein the digital watermark is a binary bitmap.

9. A method comprising: providing acoustic echo data comprising time-series representations of acoustic echo signals from an object under inspection obtained using an acoustic transducer array; aggregating the received acoustic data into a first three-dimensional matrix of echo data samples; generating a set of two-dimensional slices from the matrix, wherein a parameter of the two-dimensional slices is based on a number of elements of the acoustic transducer array; for each of the set of two-dimensional slices from the first matrix: transforming a respective slice into a frequency domain representation using a discrete transform to obtain a respective transformed slice, embedding a portion of a digital watermark into the transformed slice, the digital watermark based on a key, the embedding comprising: determining an energy level of the transformed slice, and setting a strength coefficient for application of the key for the transformed slice based on the energy level of the transformed slice, and applying an inverted form of the discrete transform to the transformed slice with the embedded portion of the digital watermark to generate a respective marked slice; arranging respective marked slices with respective embedded portions of the digital watermark into a second three-dimensional matrix of echo data samples; and generating an image based on the second matrix, wherein the image illustrates echo representations from the object.

10. The method of claim 9, wherein the matrix of echo data sample comprises a matrix of A-scan time-series representations of received acoustic echo data.

11. The method of claim 9, wherein the generating the image comprises applying a total focusing method (TFM) imaging technique to the second volume of marked slices to generate the image.

12. The method of claim 9, further comprises extracting the embedded portions of the digital watermark from the second matrix to generate a visual representation of the digital watermark.

13. A system comprising: one or more processors of a machine; and a memory storing instructions that, when executed by the one or more processors, cause the machine to perform operations comprising: providing acoustic data comprising time-series representation of acoustic echo signals from an object under inspection using an acoustic transducer array, the acoustic data being arranged in a 3D arrangement; generating a first volume of slices based on the acoustic data, the first volume slices comprising 2D slices, wherein a parameter of the 2D slices is based on a number of elements of the acoustic transducer array; for each of the first volume of slices: transforming a respective slice into a frequency domain representation using a discrete transform to obtain a respective transformed slice, embedding a portion of a digital watermark into the transformed slice, wherein the digital watermark is based on a key, the embedding comprising: determining an energy level of the transformed slice, and setting a strength coefficient for application of the key for the transformed slice based on the energy level of the transformed slice, and applying an inverted form of the discrete transform to the transformed slice with the embedded portion of the digital watermark to generate a respective marked slice; arranging respective marked slices with respective embedded portions of the digital watermark into a second volume of marked slices; and generating an image based on the second volume of marked slices, wherein the image illustrates echo representations from the object.

14. The system of claim 13, the operations further comprises: extracting the embedded digital watermark from the second volume of marked slices to generate a visual representation of the digital watermark.

15. The system of claim 14, wherein extracting the embedded digital watermark includes for each of a set of marked slices: transforming a respective marked slice into the frequency domain representation to obtain a respective transformed marked slice, determining a degree of correlation between the transformed marked slice and the key to generate a correlation result, and based on the degree of correlation, establish a value of the portion of the recovered digital watermark; aggregating the respective established values of portions of the recovered digital watermark; and generating a visual representation of the recovered digital watermark based on the aggregated

established values.

16. The system of claim 13, wherein embedding the portion of the digital watermark into the transformed slice comprises: based on a value of the portion of the digital watermark, combining the key with the transformed slice.

17. The system of claim 16, the operations further comprising: based on the value of the portion of the digital watermark being a first type, adding the key to the transformed slice; and based on the value of the portion of the digital watermark being a second type, subtracting the key from the transformed slice.

18. The system of claim 13, wherein the key includes a bitmap representation.

19. The system of claim 18, wherein the bitmap representation comprises at least one of a random pattern or random pixel values.

20. The system of claim 13, wherein the digital watermark is a binary bitmap.