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(54) **SYSTEM AND METHOD FOR ULTRASONIC  
DETECTION AND IMAGING**

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(57) **ABSTRACT**

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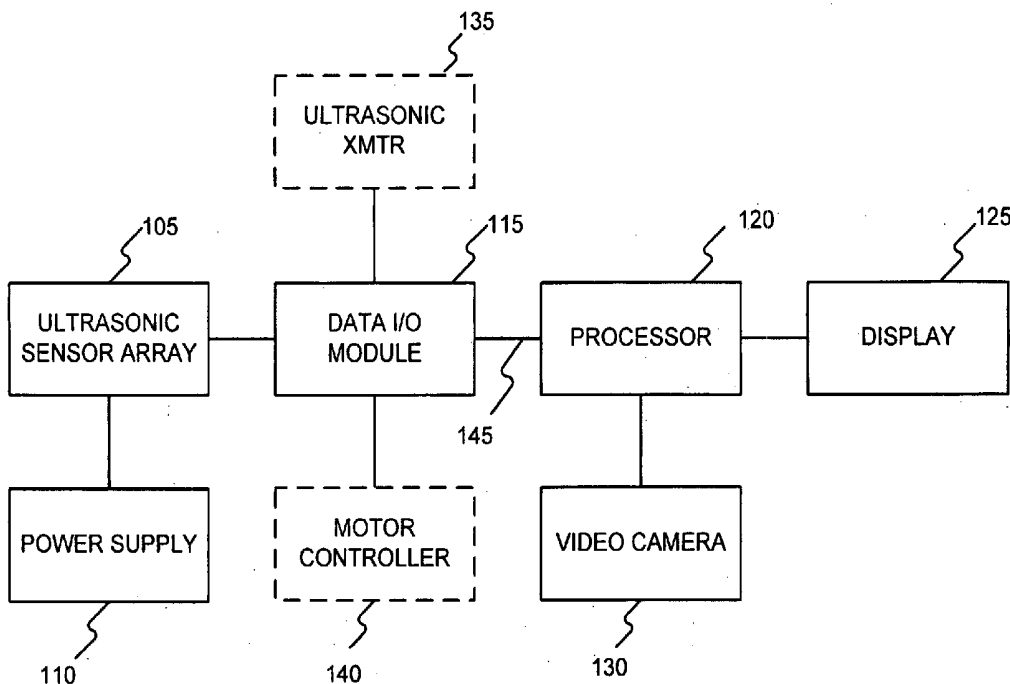
Systems and Methods are disclosed for the detection and imaging of ultrasonic energy. Embodiments of the invention utilize an array of ultrasonic sensors where data from each of the sensors are processed by RMS-to-DC conversion. In addition, embodiments of the invention output a contour map based on detected ultrasonic energy and blend at least one feature of the contour map with a feature of a visible image so that a blended image can be displayed to an operator. Furthermore, embodiments of the invention provide a system and method for repositioning an array of ultrasonic sensors with respect to target area or Unit Under Test (UUT) to facilitate a thorough and repeatable test.

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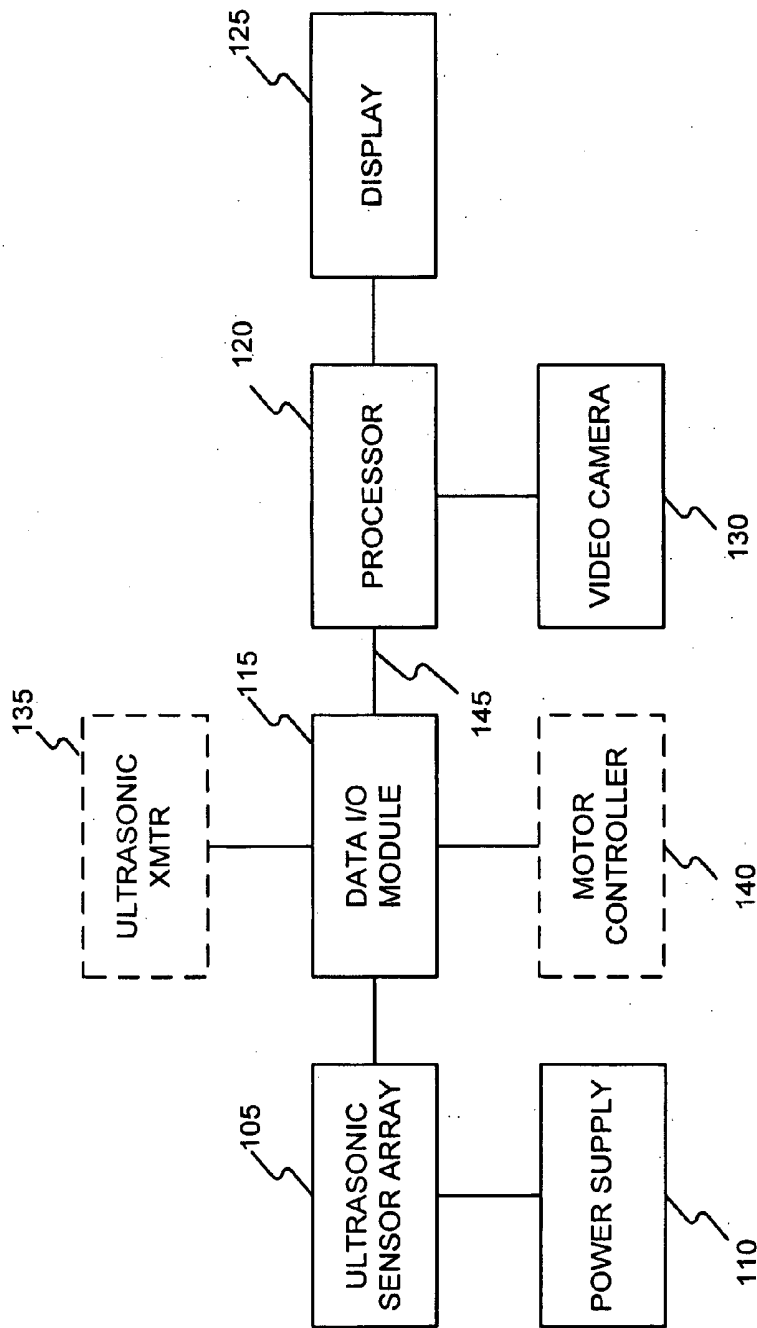


FIG. 1

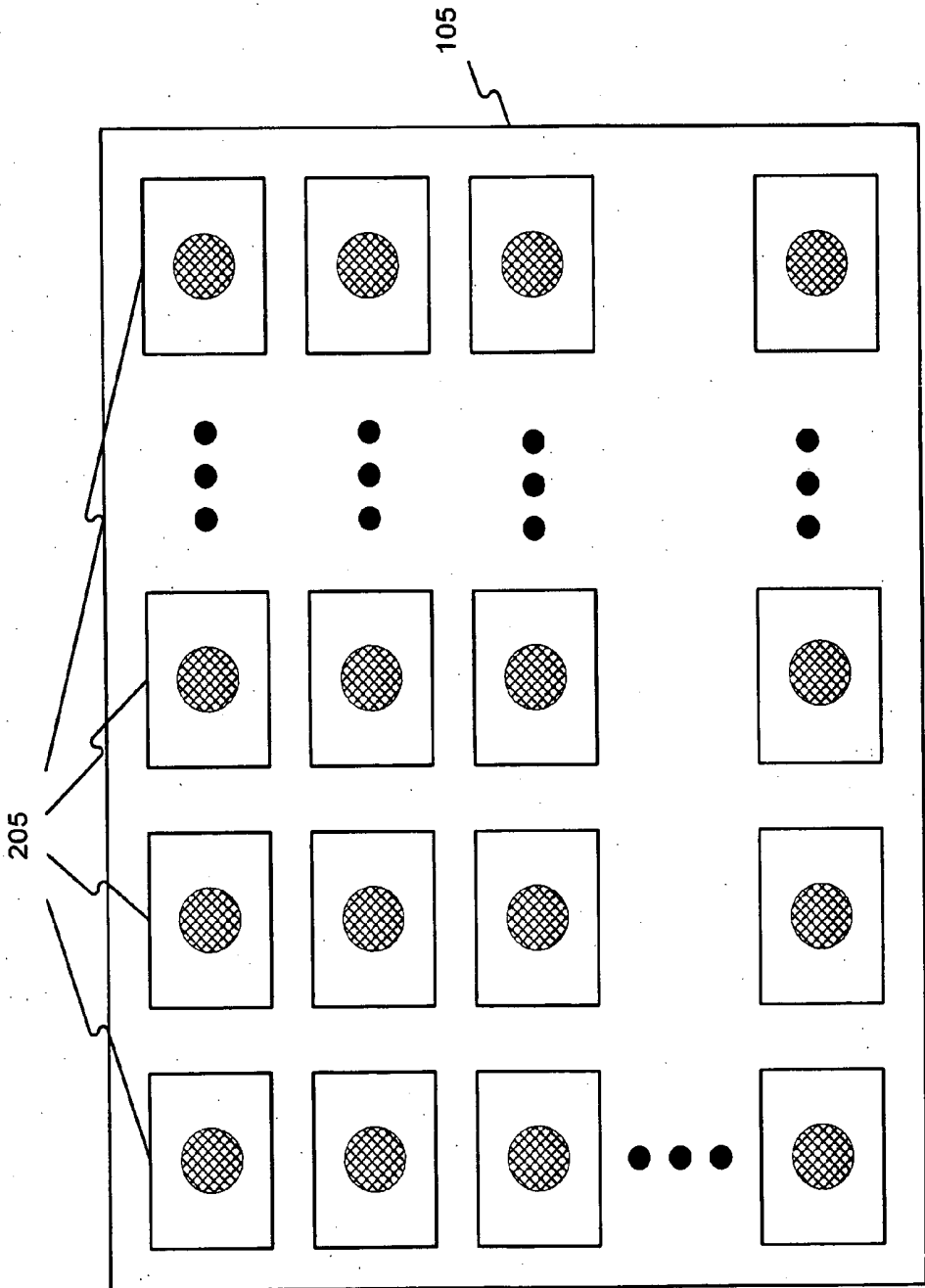


FIG. 2

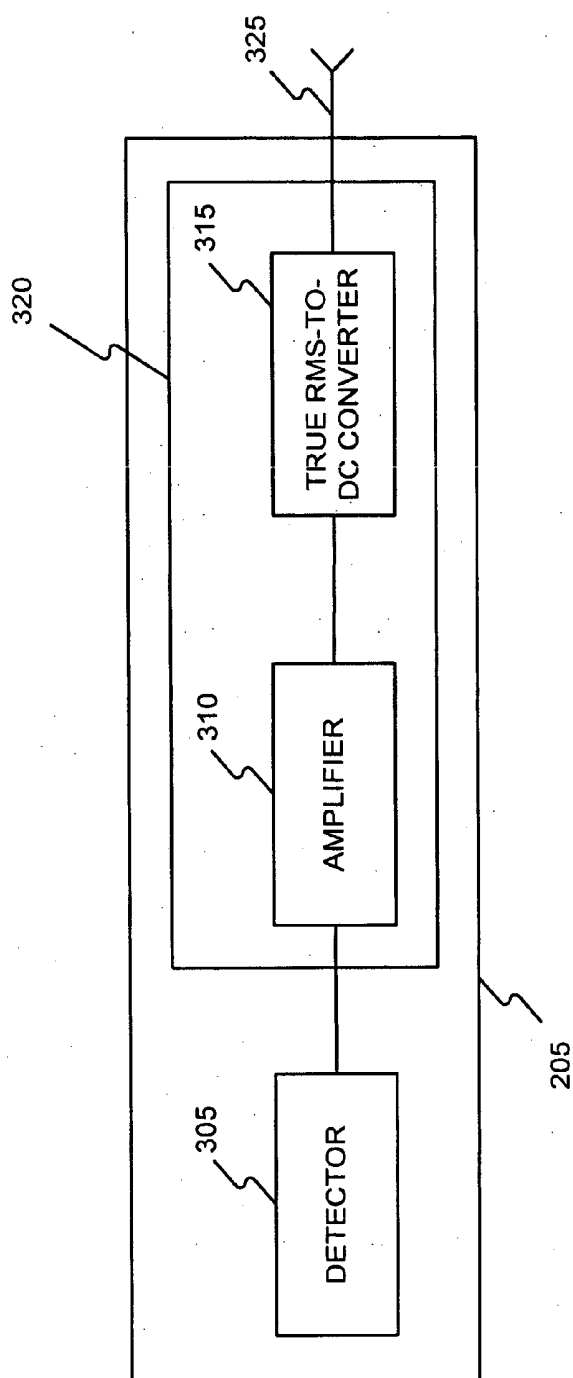


FIG. 3

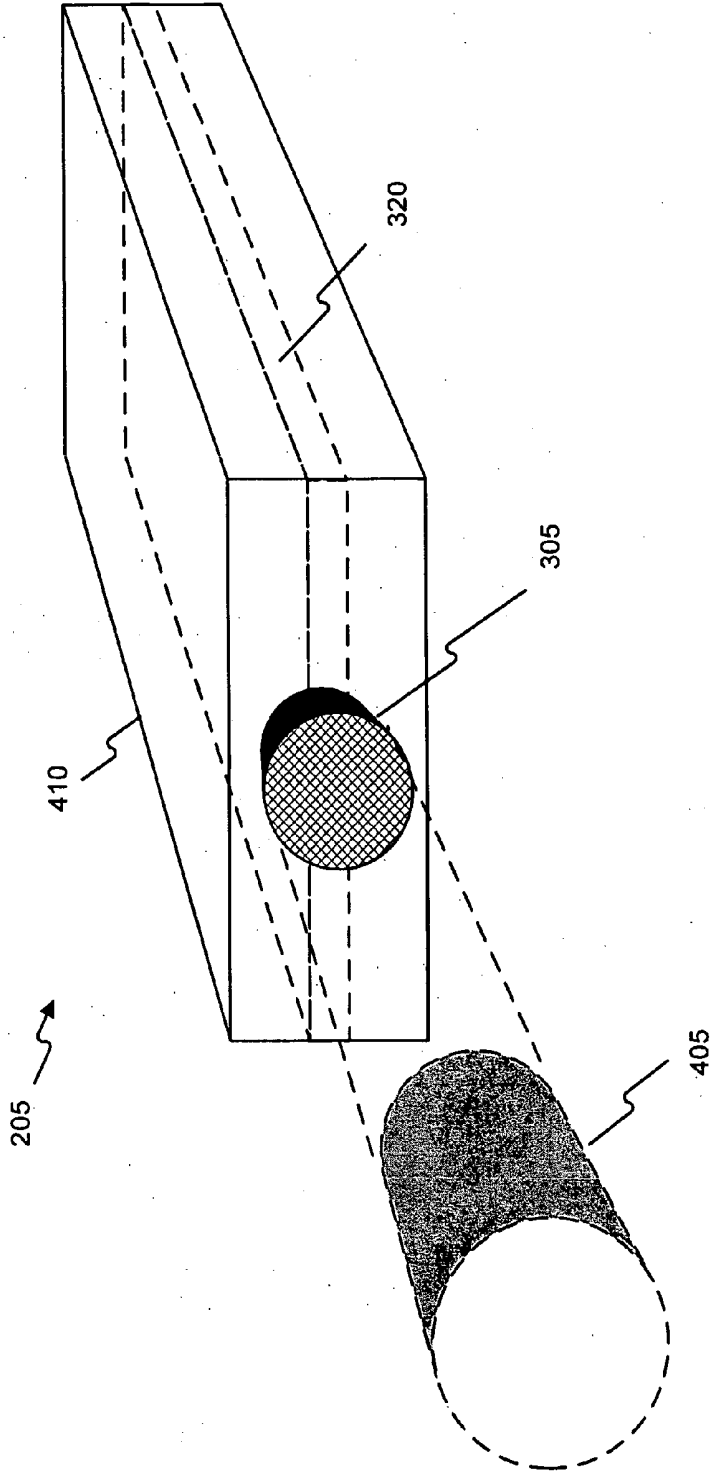


FIG. 4

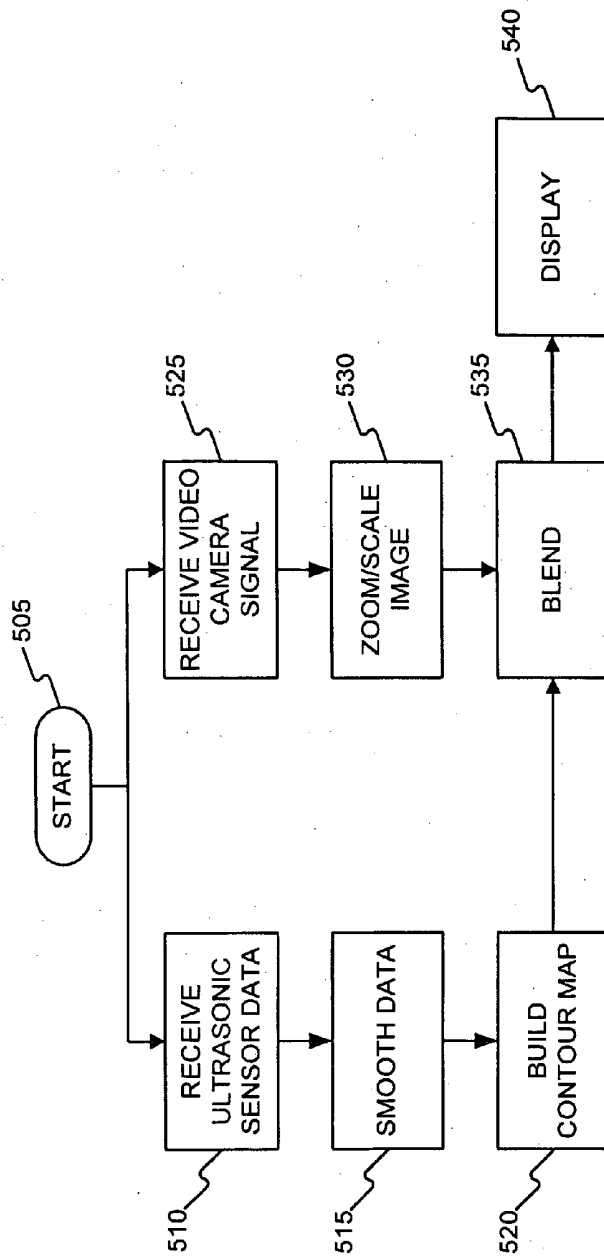


FIG. 5A

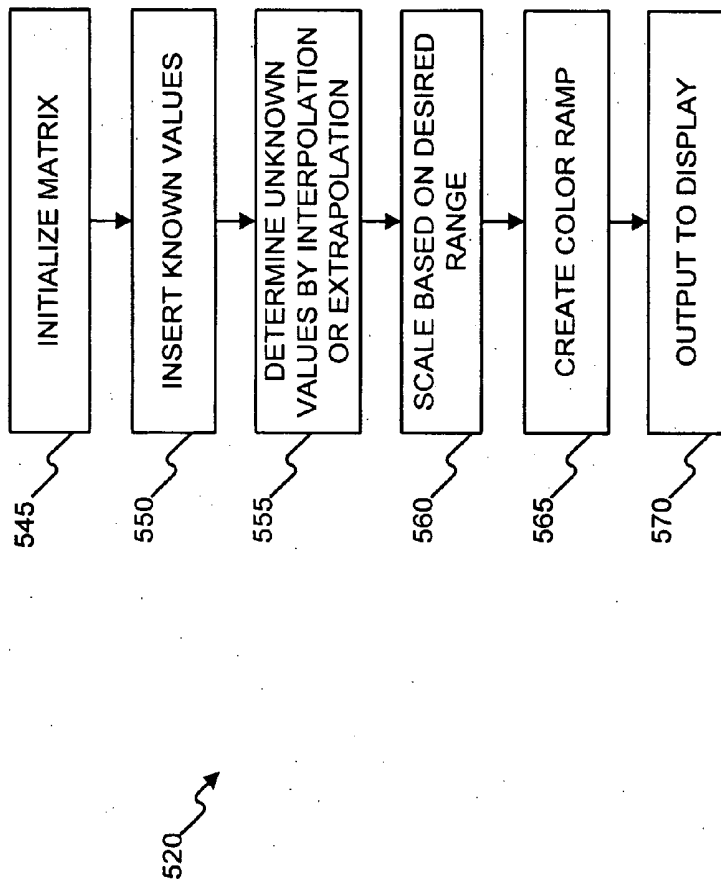
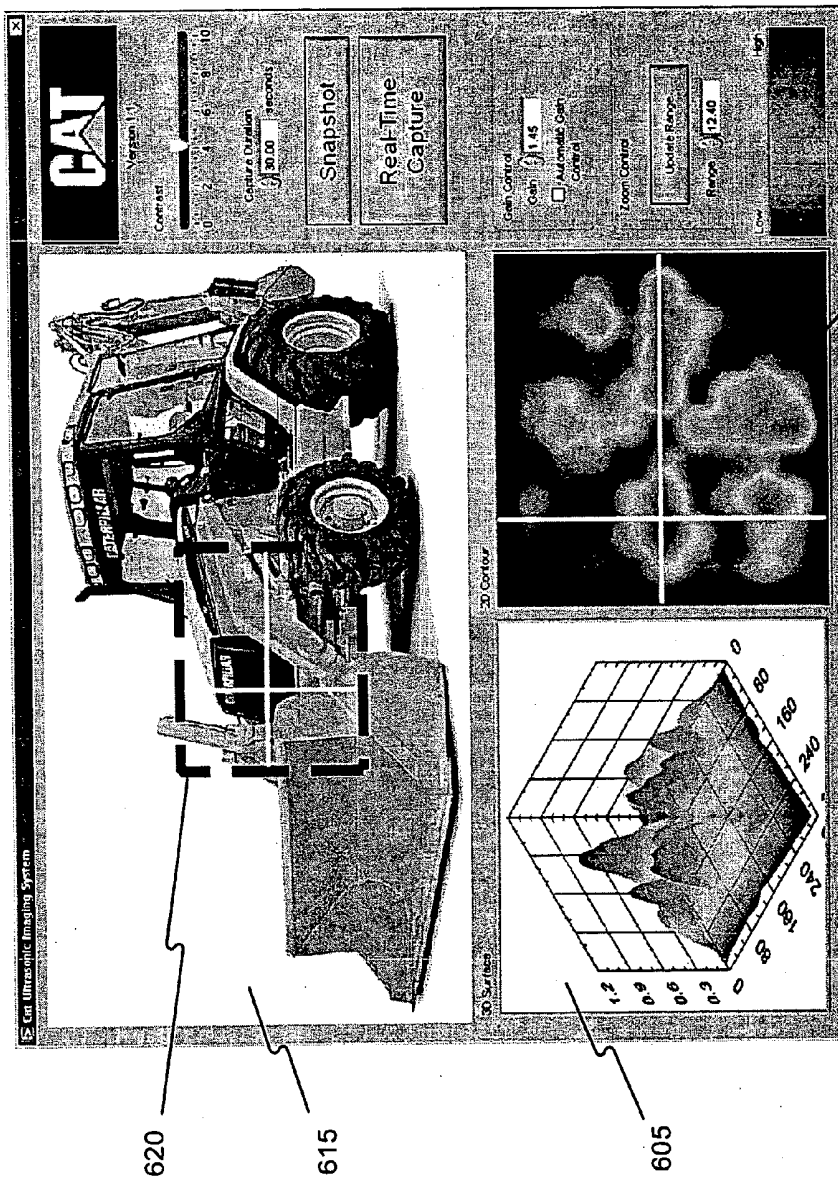


FIG. 5B



610

FIG. 6

620

615

605

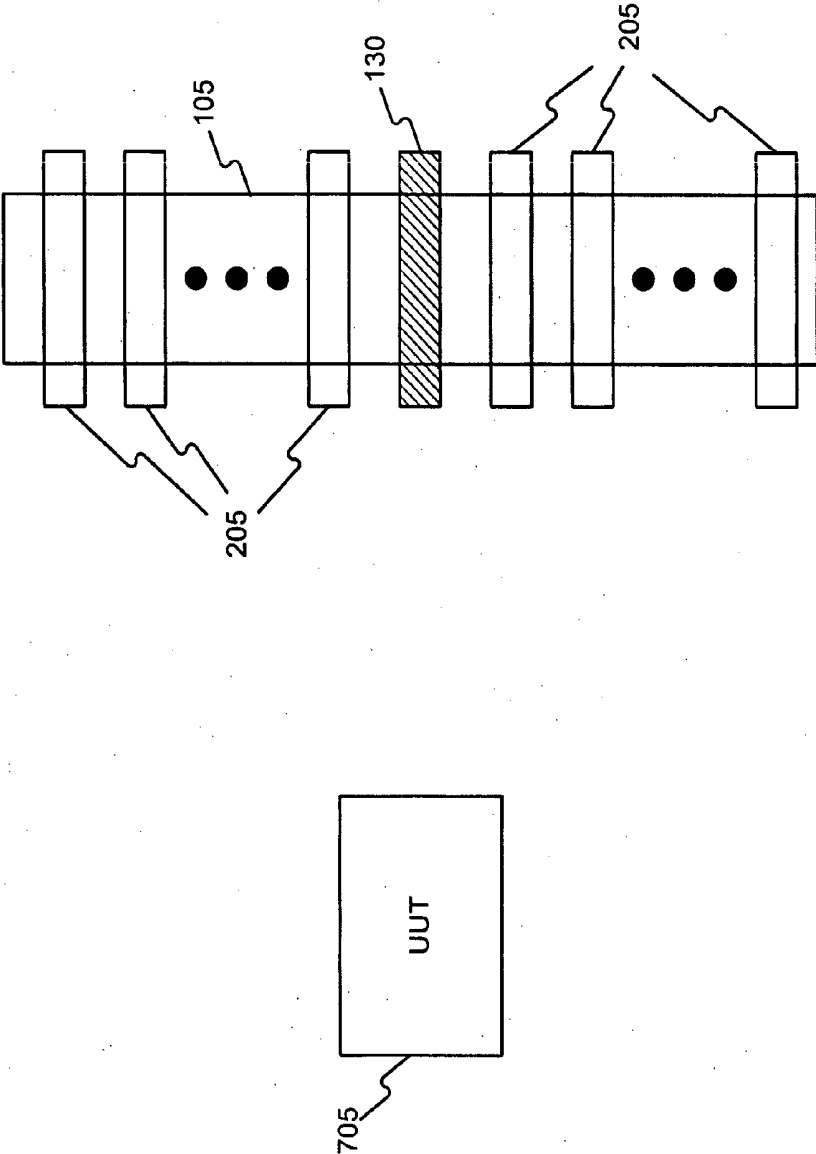


FIG. 7

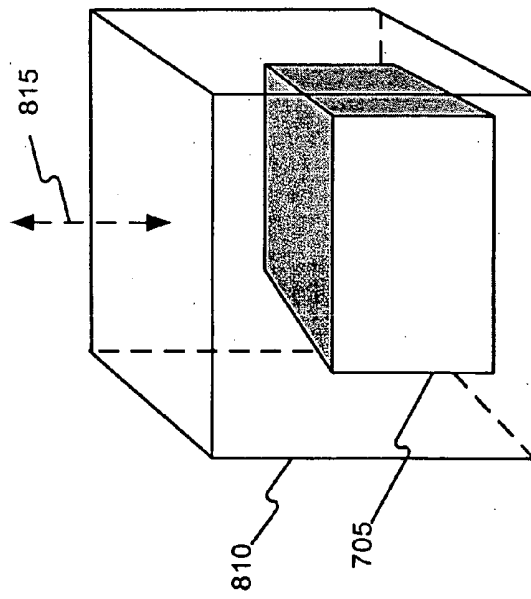


FIG. 8A

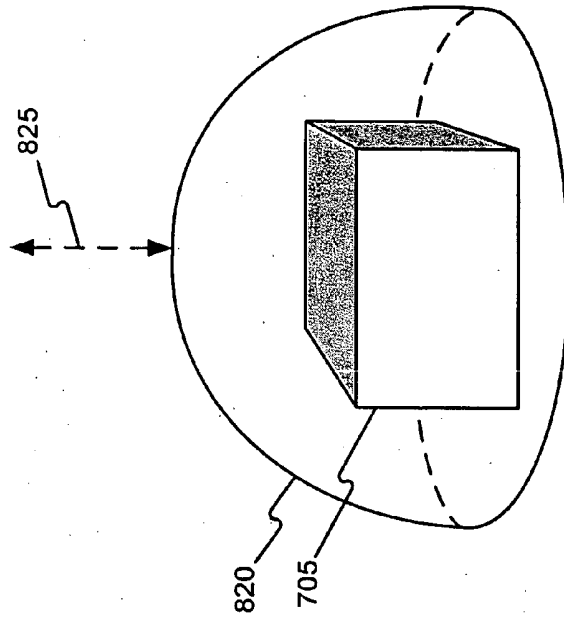


FIG. 8B

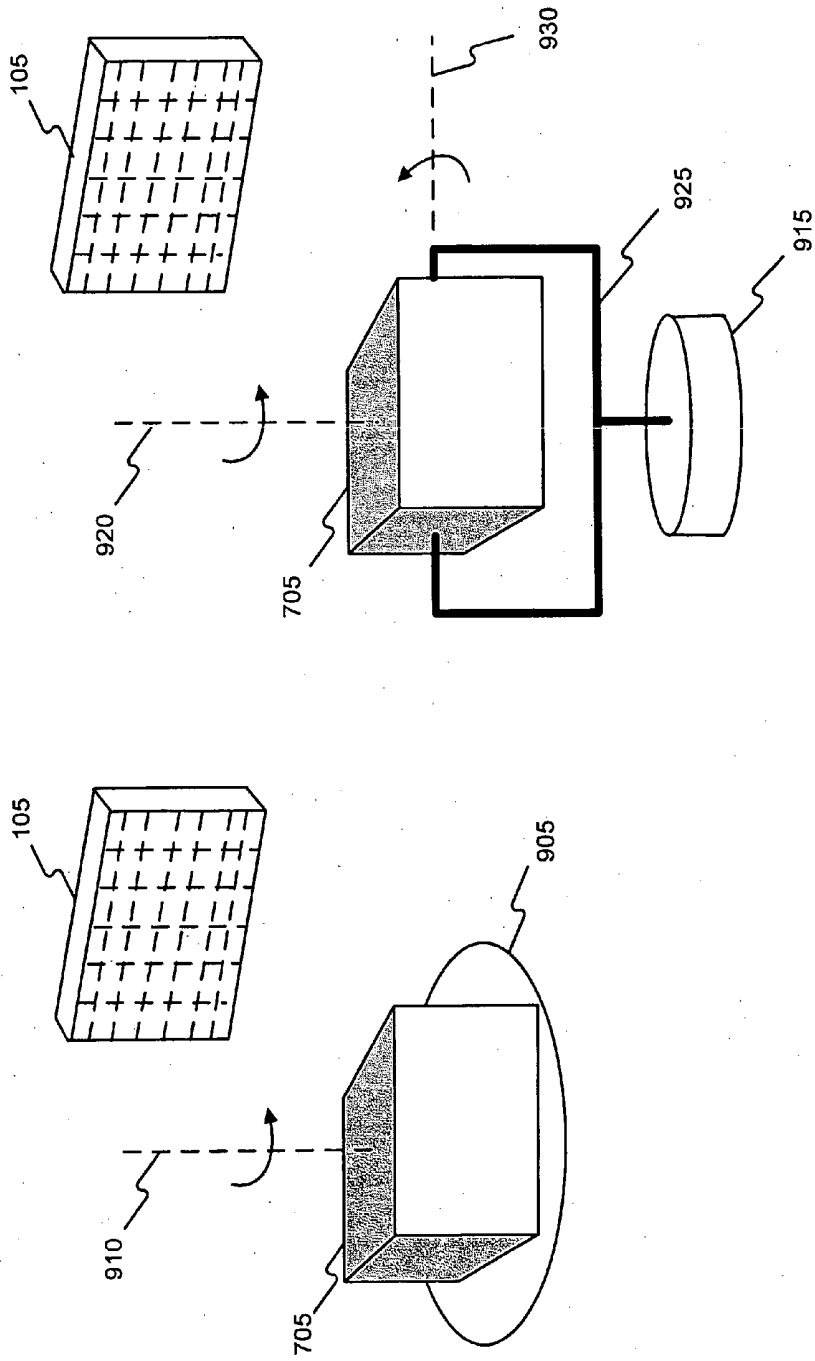


FIG. 9A

FIG. 9B

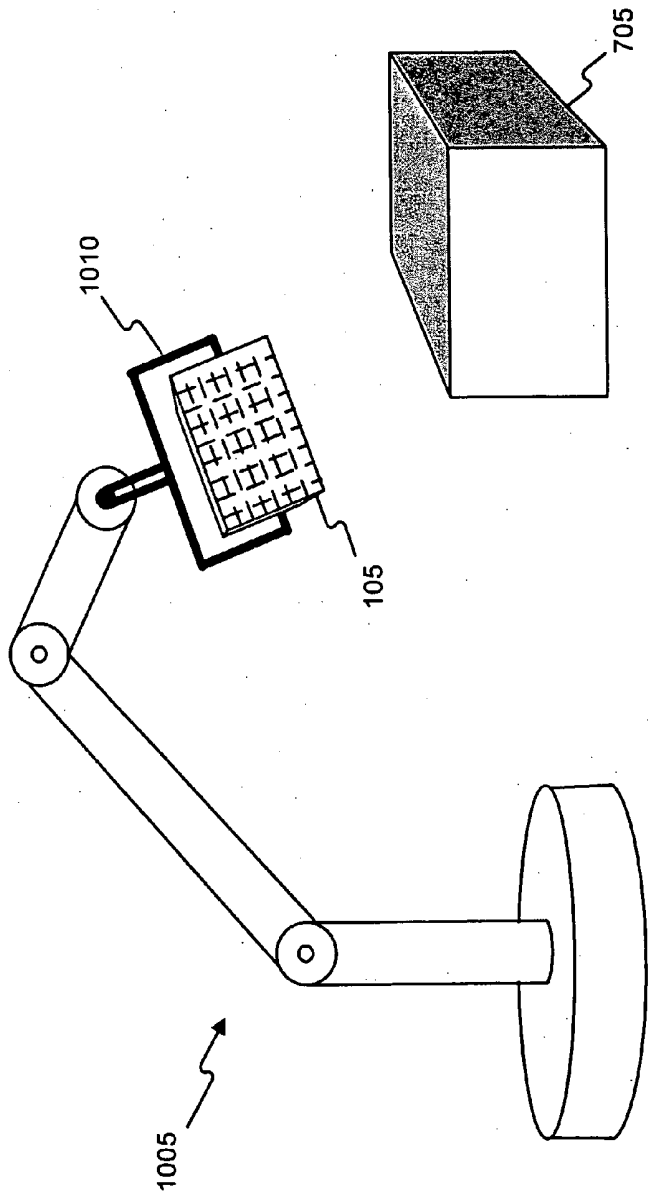


FIG. 10

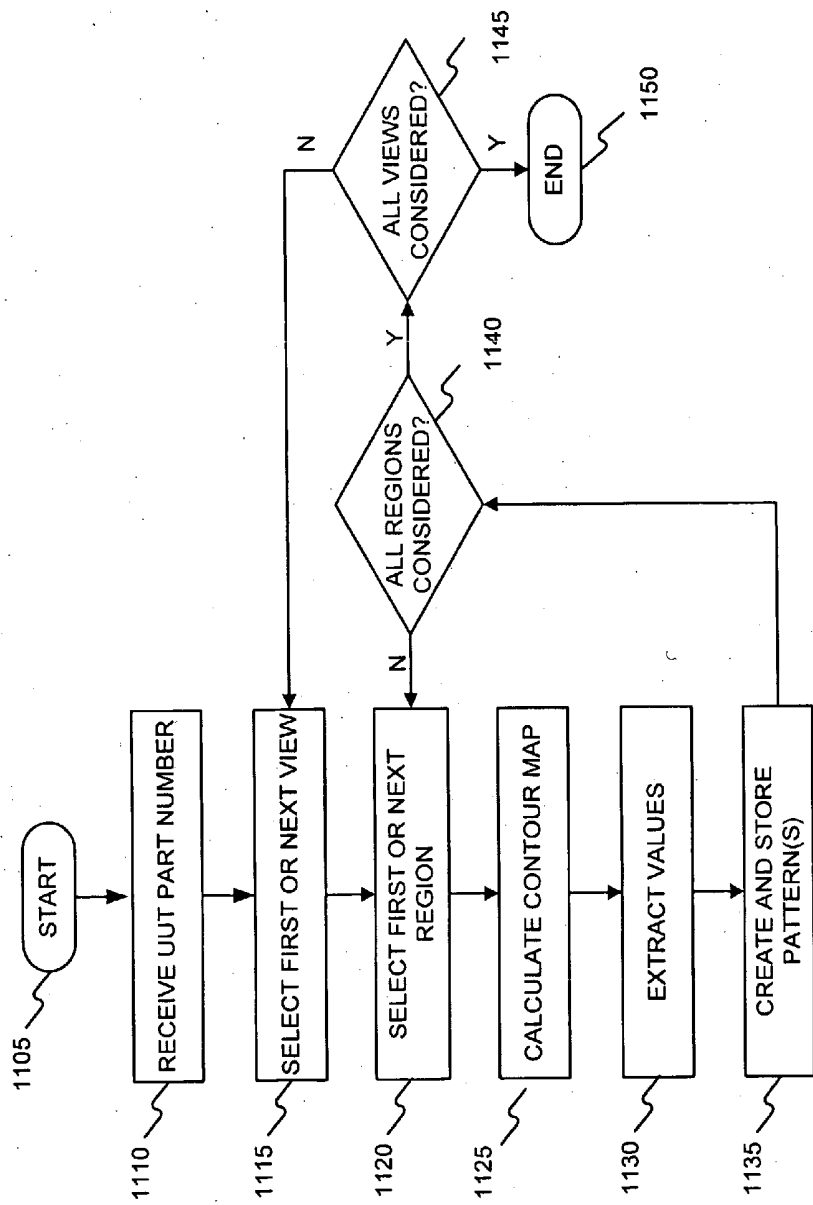


FIG. 11A

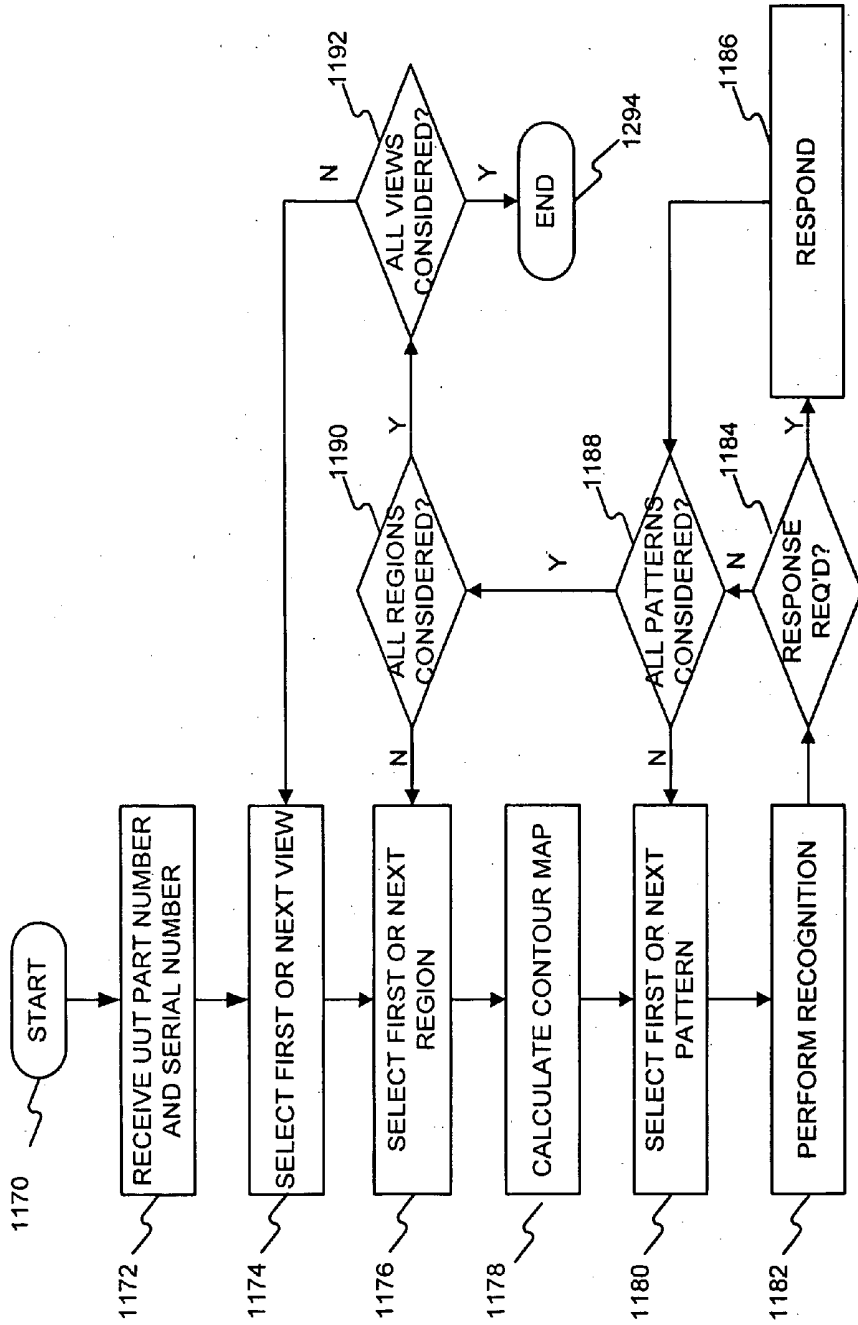


FIG. 11B

## SYSTEM AND METHOD FOR ULTRASONIC DETECTION AND IMAGING

### TECHNICAL FIELD

[0001] This disclosure relates generally to data processing systems and methods, and more particularly, but without limitation, to systems and methods related to detection, imaging, and/or other processing associated with ultrasonic energy.

### BACKGROUND

[0002] A practical application for the detection and imaging of ultrasonic energy is to locate, by inference, ultrasonic energy sources. Such sources may be, for instance, a gas or fluid escaping from a pressurized container (in other words, a leak). Alternatively, ultrasonic energy may be caused by a mechanical vibration, such as that caused by an excessively-worn bearing or by missing teeth on a gear drive assembly.

[0003] Piezoelectric and other detectors are known for detecting ultrasonic energy emissions. Known systems and methods utilizing such detectors have many disadvantages, however. For instance, because of the signal frequencies involved, known systems may utilize very high-speed sampling rates that increase the expense of data acquisition hardware. Furthermore, known detection systems do not provide user-friendly outputs. For example, such systems may not support imaging at all. And known systems that do provide imaging of the ultrasonic energy may not sufficiently relate the detected source of ultrasonic energy to the surrounding environment in a way that allows for a targeted response to the detection event. Moreover, known detection systems and methods may be limited to a narrow Field-Of-View (FOV) without a structured way to fully screen a Unit Under Test (UUT) that occupies an area that is many times the size of the detector's FOV. Known hand-held detection systems and methods are exemplary of this latter problem, relying on an operator to wave the hand-held detection system with respect to the UUT in an effort to provide an effective screen.

[0004] What is needed are systems and methods for detecting ultrasonic energy that reduce the cost of data acquisition, provide more useful outputs to a test operator, and enable more complete and repeatable ultrasonic energy detection over a broad target area.

### SUMMARY OF THE INVENTION

[0005] Embodiments of the invention seek to overcome one or more of the disadvantages described above. For example, embodiments of the invention utilize an array of ultrasonic sensors where data from each sensor in the array are processed by RMS-to-DC conversion. An advantage of this approach is that it may eliminate the need for high-speed analog-to-digital conversion (ADC) hardware as part of the data collection channel. In addition, embodiments of the invention output a contour map based on detected ultrasonic energy and blend at least one feature of the contour map with a feature of a visible or other image so that a blended image can be displayed to an operator. Such a system and method may be more intuitive and useful to a user than a system that merely outputs an image based upon the ultrasonic energy alone. Furthermore, embodiments of the invention provide a system and method for repositioning an array of ultrasonic

sensors with respect to target area or Unit Under Test (UUT) to facilitate a thorough and repeatable test. As used herein, ultrasonic energy refers generally to vibrations in the ultrasonic frequency range, for example at frequencies greater than about 20 kHz.

[0006] Embodiments of the invention provide a system configured to detect ultrasonic energy including: an ultrasonic sensor array, the ultrasonic sensor array including a plurality of ultrasonic sensors; a processor operably coupled to the ultrasonic sensor array; and a visible image detector module operably coupled to the processor, the system configured to calculate a Root-Mean-Square (RMS) value associated with each of the plurality of ultrasonic sensors.

[0007] Embodiments of the invention provide a method for graphically displaying ultrasonic energy including: receiving data from each of a plurality of ultrasonic sensors, the data based on Root-Mean-Square (RMS) calculation; building a contour map based on the received data; receiving a camera image; and blending at least one feature of the contour map with at least one feature of the received camera image.

[0008] Embodiments of the invention provide a processor-readable medium having stored thereon instructions for a method of generating a graphical user interface (GUI), the method including: receiving data from each of a plurality of ultrasonic sensors, the data based on Root-Mean-Square (RMS) calculation; building a contour map based on the received data; receiving a visual camera image; blending at least one feature of the contour map with at least one feature associated with the received visual camera image to create a blended image; and displaying the blended image in a first portion of a display screen.

[0009] Embodiments of the invention provide a method for testing including: selecting a first view of a unit under test, the first view associated with a relative position between a first ultrasonic sensor array and the unit under test; selecting a first region, the first region being associated with a portion of the first view; calculating a contour map based on the first region; and recognizing at least one feature of the contour map.

[0010] The invention will now be described with respect to exemplary embodiments illustrated in the drawings and discussed in the detailed description.

### BRIEF DESCRIPTION OF THE DRAWINGS

[0011] FIG. 1 is a block diagram of a functional architecture for an ultrasonic energy detection system, according to an embodiment of the invention;

[0012] FIG. 2 is an illustration of the ultrasonic sensor array depicted in FIG. 1, according to an embodiment of the invention;

[0013] FIG. 3 is a block diagram of a functional architecture for the ultrasonic sensor assembly 205, according to an embodiment of the invention;

[0014] FIG. 4 is a perspective drawing of the ultrasonic sensor assembly 205, according to an embodiment of the invention;

[0015] FIG. 5A is a flow diagram for a graphical display method, according to an embodiment of the invention;

[0016] FIG. 5B is a flow diagram of a method for building a contour map, according to an embodiment of the invention;

[0017] FIG. 6 is an illustration of a graphical user interface (GUI), according to an embodiment of the invention;

[0018] FIG. 7 is an illustration of an ultrasonic sensor array positioned with respect to a Unit Under Test (UUT), according to an embodiment of the invention;

[0019] FIG. 8A is an illustration of a test environment, according to a first embodiment of the invention;

[0020] FIG. 8B is an illustration of a test environment, according to a second embodiment of the invention;

[0021] FIG. 9A is an illustration of a test environment, according to a third embodiment of the invention;

[0022] FIG. 9B is an illustration of a test environment, according to a fourth embodiment of the invention;

[0023] FIG. 10 is an illustration of a test environment, according to a fifth embodiment of the invention;

[0024] FIG. 11A is a flow diagram of a pattern generation method, according to an embodiment of the invention; and

[0025] FIG. 11B is a flow diagram of a testing method, according to an embodiment of the invention.

#### DETAILED DESCRIPTION

[0026] FIG. 1 is a block diagram of a functional architecture for an ultrasonic energy detection system, according to an embodiment of the invention. In the illustrated embodiment, an ultrasonic sensor array 105 is coupled to the power supply 110 and a data I/O module 115. The data I/O module 115 is coupled to an ultrasonic transmitter 135, a motor controller 140, and a processor 120. The processor 120 may be or include a personal computer, microcomputer, microcontroller, or other processing element. Link 145 may be a Universal Serial Bus (USB) port, although other communication protocols may also be used. The processor 120 is coupled to video camera 130 and display 125. IOtech Personal Daq/50 Series USB Data Acquisition Modules are suitable hardware choices for the data I/O module 115. The architecture may further include memory (not shown) coupled to the processor 120, the memory being configured to store data and/or software that is executable by the processor 120.

[0027] Variations to the illustrated functional architecture are possible. For example, as indicated by dashed lines, the ultrasonic transmitter 135 and the motor controller 140 are optional. In addition, in some embodiments, the video camera 130 may be coupled to the data I/O module 115. Further, the video camera 130 could be adapted to capture still images (“snapshots”) instead of, or in addition to, video images. Moreover, the functional architecture illustrated in FIG. 1 may further include a laser or other range finder (not shown) coupled to the processor 120. Further, the functional architecture may include multiple instances of any of the illustrated functional blocks. For instance, some embodiments may include multiple ultrasonic sensor arrays 105, multiple data I/O modules 115, multiple processors 120, and/or multiple motor controllers 140. The couplings between functional blocks illustrated in FIG. 1 may be

accomplished with any suitable wired or wireless interconnection protocol, according to design choice.

[0028] In operation, the ultrasonic sensor array 105 detects ultrasonic energy in response to ultrasonic energy sources (not shown) from a target area or Unit Under Test (UUT). The ultrasonic sensor array 105 may include signal processing modules (not shown) powered by the power supply 110. Processed ultrasonic data is coupled from the ultrasonic sensor array 105 to the processor 120 via the data I/O module 115. Video Camera 130 may be positioned to have a similar view of the ultrasonic source (not shown) as the ultrasonic sensor array 105. The processor 120 may be configured to further process the data received from the ultrasonic sensor array 105 and/or the video camera 130. The processor 120 may be adapted to display data derived from the ultrasonic sensor array 105, the video camera 130, or some combination or combinations thereof via the display 125.

[0029] In embodiments lacking a natural ultrasonic source, the ultrasonic transmitter 135 may be applied. For example, to facilitate the detection of defects, such as cracks or holes in the UUT, the ultrasonic transmitter 135 may be positioned inside of, or behind, the UUT so that ultrasonic energy from the ultrasonic transmitter 135 passing through the defect is detected by the ultrasonic sensor array 105.

[0030] In some instances, it may be desirable to change a relative position between the UUT and the ultrasonic sensor array 105. In this respect, it may be advantageous to move the position of the UUT. In other embodiments, it may be advantageous to move the ultrasonic sensor array. To reposition either the UUT or the ultrasonic sensor array 105, the motor controller 140 may receive commands from the processor 120, for instance to drive a stepper motor associated with tooling in the test environment. Exemplary embodiments of such repositioning will be described in further detail with respect to FIGS. 9A, 9B, and 10.

[0031] FIG. 2 is an illustration of the ultrasonic sensor array depicted in FIG. 1, according to an embodiment of the invention. In the illustrated embodiment, an ultrasonic sensor array 105 may be or include a two-dimensional rectangular array of ultrasonic sensor assemblies 205 arranged in  $n$  rows by  $m$  columns, where  $n$  and  $m$  are any positive integer, where each row includes the same number of sensor assemblies 205 as other rows and where each column includes the same number of sensor assemblies 205 as other columns. The ultrasonic sensor array 105 could include only a single row or a single column of sensor assemblies 205, thus forming a one-dimensional array.

[0032] The number of ultrasonic sensor assemblies 205, and relative positioning with respect to each other, may be varied according to design choice. For example, in an alternative embodiment, a circular pattern or other two or three dimensional arrangement of sensor assemblies 205 could be utilized.

[0033] In alternative embodiments, one or more sensor assemblies 205 in the ultrasonic sensor array 105 are sensitive to energy at other than ultrasonic frequencies.

[0034] FIG. 3 is a block diagram of a functional architecture for the ultrasonic sensor assembly 205, according to an embodiment of the invention. In the illustrated embodiment, the ultrasonic sensor assembly 205 includes a detector 305

coupled to a Circuit Card Assembly (CCA) 320. The detector 305 may be sensitive to a particular range of ultrasonic energy, for example a frequency range of approximately 38 to 42 KHz, and may be a piezoelectric device. The detector 305 could also be sensitive to a broader frequency range, and filters (not shown) could optionally be applied to detect ultrasonic energy over a narrower frequency range.

[0035] The CCA 320 may include an amplifier 310 coupled to a true RMS-to-DC converter 315. The output 325 of the true RMS-to-DC converter 315 may be coupled to the processor 120 via the data I/O module 115.

[0036] In operation, the detector 305 detects ultrasonic energy, providing an analog signal (a varying voltage) to the amplifier 310. The amplifier 310 amplifies the analog signal from the detector 305 and provides the amplified signal to the true RMS-to-DC converter 315.

[0037] Roughly stated, Root Mean Square (RMS) transformation ("transformation" being used interchangeably herein with "conversion" or "calculation") produces a Direct Current (DC) equivalent of an Alternating Current (AC) voltage. True RMS-to-DC conversion is a statistical measure (the quadratic mean) of the magnitude of a varying quantity. For N measured voltages ( $v_1, v_2, \dots, v_N$ ), the true RMS voltage ( $v_{RMS}$ ) is given by:

$$v_{RMS} = \sqrt{1/N(v_1^2 + v_2^2 + \dots + v_N^2)}$$

In practical application, the N measurements must be taken rapidly enough (as compared to the frequency of the signal) and over a meaningful window of time.

[0038] In alternative embodiments, approximations of the true RMS may be used. For example, a common approximation of the RMS value for a sinusoidal signal is:

$$v_{RMS} = (0.707)(v_{peak}), \text{ where } v_{peak} = \text{the peak voltage of an AC signal.}$$

[0039] Other RMS approximations, such as the arithmetic mean or arithmetic median of the N measurements could also be used, although such approximated RMS-to-DC transformations would likely lead to less accurate results than the true RMS-to-DC conversion described above.

[0040] Preferably, RMS-to-DC conversions are performed for signals associated with each of the ultrasonic sensor assemblies over the same time interval. An output 325 associated with each of the ultrasonic sensor assemblies 205 provides a DC equivalent voltage to the data I/O module 115. Analog Devices AD536A is a suitable true RMS-to-DC converter.

[0041] Other embodiments of the CCA 320 may include multiple amplifier stages. For example, the amplifier 320 may include a front-end preamplifier (not shown) and a variable-gain amplifier (not shown). One or more National Semiconductor LM386 low-voltage power amplifiers are suitable for the amplifier 310.

[0042] CCA 320 may include additional signal conditioning devices according to design choice. Furthermore, the system could be partitioned so that the true RMS-to-DC converter 315 and/or the amplifier 310 is included with the data I/O module 115 instead of the ultrasonic sensor assemblies 205.

[0043] FIG. 4 is a perspective drawing of the ultrasonic sensor assembly 205, according to an embodiment of the

invention. In the illustrated embodiment, the ultrasonic sensor assembly 205 includes a cylindrical shroud 405 to encase the detector 305. The detector 305 and shroud 405 may be affixed to a chassis 410, and CCA 320 may be mounted inside the chassis 410 and electronically coupled to the detector 305.

[0044] Other form factors for the shroud 405, chassis 410, and CCA 320 are possible. For example, the shroud 405 may be of a hyperbolic, conical, hemispherical, or other shape that would facilitate focusing, filtering, or other conditioning of ultrasonic signals received by the detector 305. The use of a shroud 405 is optional.

[0045] In an alternative embodiment, a single cylindrical, hyperbolic, conical, hemispherical, or other shroud (not shown) is adapted to focus, filter, or otherwise condition ultrasonic energy with respect to the entire ultrasonic sensor array 105 rather than being present on each of the ultrasonic sensor assemblies 205.

[0046] FIG. 5A is a flow diagram for a graphical display method, according to an embodiment of the invention. In the illustrated embodiment, after initialization step 505, the process advances to step 510 to receive the ultrasonic sensor data, and also to step 525 to receive a video camera signal. As described with reference to FIG. 3 above, the ultrasonic sensor data may be based on a true RMS-to-DC conversion of the signal output by the ultrasonic detector 305 or an approximation thereof.

[0047] After receiving the ultrasonic sensor data in step 510, the process advances to step 515 to smooth data. The purpose of smoothing step 515 is to reduce the effect of transient noise in the detection frequency range. In one embodiment, smoothing step 515 is performed via a simple moving average calculation on the received data values. For example, smoothing step 515 may add the five most recent data values, then divide by five. Alternatively, a low-pass filter (LPF) (not shown), which may be implemented in hardware or software, could be utilized to perform smoothing step 515.

[0048] Next, the process advances to step 520 to build a contour map. An embodiment of step 520 is described below with reference to FIG. 5B.

[0049] Meanwhile, subsequent to receiving the video camera signal in step 525, the process advances to step 530 to zoom or scale (zoom/scale) an image associated with the video camera. The purpose of zooming/scaling step 530 is to scale the Field Of View (FOV) of the video camera to the contour map so that corresponding pixel locations on the video camera image and the contour map relate to the same physical locations of the UUT. The FOV of the video camera may be adjusted optically or via software. In addition, zooming/scaling step 530 may be performed manually or automatically. In automatic operation, step 530 may be informed of the distance between the video camera and the UUT by a ultrasonic range-finder, a laser range-finder, or other range-finder. A transfer function may then be used to convert the distance data to a video camera zoom value.

[0050] In step 535, the process blends data output from steps 520 and 530. For example, one or more features of the contour map resulting from step 520 may be overlaid with one or more features of the scaled image resulting from step 530. An example of such a blended image is provided in the

blended display window **615** of FIG. 6. Finally, in step **540**, the blended image may be displayed. In sum, FIG. 5A illustrates that ultrasonic data and video data may be separately processed before at least one feature of the processed ultrasonic data and the processed video data are blended. An advantage of a producing a blended image is that the source of the ultrasonic energy is spatially located with respect to the broader context of a target test area or UUT.

[**0051**] Variations to the process illustrated in FIG. 5A are possible. For example, instead of or in addition to receiving a video camera signal in step **525**, the process could receive a signal from an infrared (IR) camera (not shown) or other detector (not shown). In addition, in some embodiments, it may not be necessary to adjust the zoom in step **530** (for example where the sensor array and video camera are always at a fixed distance from the UUT). Moreover, smoothing data step **515** may be omitted according to application demands.

[**0052**] FIG. 5B is a flow diagram of a method for building a contour map, according to an embodiment of the invention. The illustrated process is an embodiment of building a contour map step **520** that is shown in FIG. 5A. In the illustrated embodiment, the process begins by initializing a two-dimensional (2D) matrix in step **545**. Step **545** is informed by a desired resolution that translates to a first value (representing a number of x positions) and a second value (representing a number of y positions) in the matrix.

[**0053**] Next, in step **550**, known data (z values) associated with the true RMS-to-DC conversion (or approximation thereof) from each sensor assembly are associated with corresponding positions on the initialized 2D matrix. Then, in step **555**, the process determines unknown values, for example by mathematical interpolation or extrapolation, which are also added to the initialized matrix. Interpolation/extrapolation step **555** can take into account the fact that the FOV of individual sensor assemblies may overlap at the UUT. Next, in step **560**, the matrix is scaled based on a desired range of data in each dimension of the three dimensional matrix. For example, the scaling may be set for one or more of the x, y, and z axes.

[**0054**] In step **565**, a color ramp is created for data ranges of the z axis in the matrix. For instance, where the z-axis scale varies from 0.0 to 1.0, a color ramp may specify that values between 0.0 and 0.7 are blue, values at 0.8 and 0.9 are yellow and orange, respectively, and values at 1.0 are red. In step **570**, the matrix may be colored according to the color ramp created in step **565** and then output to a display in step **570**.

[**0055**] Variations to the illustrated process are possible. For example, in some embodiments, the determining unknown values step **555** may be omitted where resolution requirements do not require additional matrix data values. Scaling step **560** may likewise be omitted if not required by the application. Moreover, in some embodiments, pre-existing color ramps may be used, eliminating the need to create a color map in step **565**.

[**0056**] FIG. 6 is an illustration of a graphical user interface (GUI), according to an embodiment of the invention. In the illustrated embodiment, a contour map window **605** illustrates relative intensity of detected ultrasonic energy, peak intensity window **610** displays a peak intensity location on

a plan view of the contour map, and a blended display window **615** includes a feature of the contour map (in this case, cross-hairs **620** associated with peak ultrasonic intensity) overlaid onto a color or gray-scale image from the video camera **130**.

[**0057**] In an alternative embodiment (not shown) a blended window could include a blended image that includes a complete contour map (optionally at least partially transparent) overlaid onto a video camera image. Other blended variants are also possible.

[**0058**] FIG. 7 is an illustration of an ultrasonic sensor array positioned with respect to a Unit Under Test (UUT), according to an embodiment of the invention. As illustrated therein, an ultrasonic sensor array **105**, shown in a profile view, includes multiple ultrasonic sensor assemblies **205** and may also include the video camera **130** positioned on the ultrasonic sensor array **105**. The advantage of co-locating the video camera **130** on the ultrasonic sensor array **105** is to provide similar perspective in the sensor array **105** and the video camera **130** with respect to the UUT **705**. Each of the sensor assemblies **205** may have a FOV of, for example, twelve (12) degrees. Accordingly, the fields of view of two or more sensor assemblies **205** may overlap at the UUT **705**.

[**0059**] In embodiments of the invention, a laser or other range finder (not shown) may also be mounted to the sensor array **105** to measure a distance to the UUT **705**. Resulting distance information may be used, for example, to facilitate focusing the video camera **130** or performing zooming/scaling step **530** as discussed with reference to FIG. 5A.

[**0060**] The systems and methods described above with reference to FIGS. 1-7 may be used together with any of the test environments discussed below with respect to FIGS. 8A, 8B, 9A, 9B, or 10.

[**0061**] FIG. 8A is an illustration of a test environment, according to a first embodiment of the invention. As shown therein, a hollow cubic cover **810** having one open end may be raised or lowered in a vertical direction **815** over a UUT **705** to enclose the UUT **705** during test. One or more ultrasonic sensor arrays **105** may be attached to one or more interior surfaces of the cubic cover **810**. Accordingly, the UUT **705** can be inspected from one or more perspectives during a test procedure. Moreover, a benefit of the cubic cover **810** is that it shields background noise, thereby improving signal-to-noise ratio (SNR) at the one or more ultrasonic sensor arrays **105**.

[**0062**] FIG. 8B is an illustration of a test environment, according to a second embodiment of the invention. As shown therein, a hemispherical cover **820** may be positioned over the UUT **705** along a vertical axis **815**. An inner surface of the hemispherical cover **820** may include one or more ultrasonic sensor arrays **105**. Like cubic cover **810**, the hemispherical cover **820** shields the UUT **705** from background noise during test, thereby improving signal-to-noise ratio (SNR) at the one or more ultrasonic sensor arrays **105**.

[**0063**] As described above with reference to FIGS. 8A and 8B, a test environment may utilize more than one ultrasonic sensor array **105**. Systems utilizing multiple sensor arrays **105** may be configured to switch between one or more of the multiple sensor arrays **105** during test. Moreover, where multiple sensor arrays **105** are implemented, one or more of

the sensor arrays **105** could be sensitive to energy outside of the ultrasonic frequency range.

[0064] In embodiments of the invention, it may be advantageous to change the position of the UUT **705** with respect to the ultrasonic sensor array **105**. Exemplary material handling devices for accomplishing this are illustrated in FIGS. **9A**, **9B**, and **10**.

[0065] FIG. **9A** is an illustration of a test environment, according to a third embodiment of the invention. As illustrated therein, a UUT **705** may be rotated about a vertical axis **910** using a carousel **905**. Carousel **905** may be driven by a stepper motor (not shown), which may be controlled by motor controller **140**. The benefit of such repositioning is that different views of the UUT **705** may be presented to the fixed sensor array **705**. Moreover, such changing views are under precise and repeatable control.

[0066] FIG. **9B** is an illustration of a test environment, according to a fourth embodiment of the invention. As shown therein, a UUT **705** is coupled to a gimbal mount **925** having a base **915**. The gimbal mount **925** facilitates the positioning of the UUT about a vertical axis **920** and a horizontal axis **930** to change the position of the UUT **705** with respect to a stationary ultrasonic sensor array **105**. The gimbal mount **925** may be under the control of the motor controller **140**.

[0067] FIG. **10** is an illustration of a test environment, according to a fifth embodiment of the invention. As illustrated, an articulated arm **1005** may include end effector **1010** adapted to position the ultrasonic sensor array **105** with respect to the UUT **705**. For example, the articulated arm **1005** may allow for six (6) degree freedom of motion (x, y, z, roll, pitch, yaw) in changing the position of the ultrasonic sensor array **105** with respect to the UUT **705**. Either of the embodiments illustrated in FIG. **9A** or **9B** may be used in combination with the embodiment shown in FIG. **10**. In addition, a conveyor system may be used as a material handling device to change the relative position of a UUT with respect to one or more ultrasonic sensor arrays **105** in the alternative or in combination with any of the embodiments described with reference to FIGS. **9A**, **9B**, or **10** above.

[0068] The methods discussed next with reference to FIGS. **11A** and **11B** can be used separately or together to enable a test environment.

[0069] FIG. **11A** is a flow diagram of a pattern generation method, according to an embodiment of the invention. After initialization step **1105**, the process receives a UUT part number in step **1110**. The UUT part number may be received in step **1110** based on manual input from an operator. In other embodiments, step **1110** may be based on automated input, for example a bar code scan, optical character recognition (OCR) scan, or other automated input.

[0070] Next, the process selects a first view (for example a predetermined plan or perspective view of the UUT) in step **1115**, then selects a first region (portion of the view) in step **1120**. The process then calculates at least one contour map in step **1125**, for example using the process described above with reference to FIG. **5B**. In step **1130**, the process extracts values from the one or more contour maps. In embodiments of the invention, step **1130** may include manipulation of the extracted values, for instance selection

of peak values or calculation of average values from the one or more contour maps. Patterns are created and stored in step **1135** based on the values extracted in step **1130**. In conditional step **1140** the process determines whether all predetermined regions have been considered.

[0071] Where the result of conditional step **1140** is in the affirmative, the process advances to conditional step **1145** to determine whether all predetermined views have been considered. Where the result of conditional step **1140** is in the negative, the process selects a next region in step **1120**.

[0072] Where the result of conditional step **1145** is in the negative, the process selects a next predetermined view in step **1115**. Where the result of conditional step **1145** is in the affirmative, the process terminates in step **1150**. Upon completion of the process illustrated in FIG. **11A**, one or more patterns have been created for a particular UUT part number. The pattern generation process described above could be repeated for one or more known good units and/or for one or more known defective units.

[0073] Variations to the process illustrated in FIG. **11A** are possible. For example, some applications may only review a single view or only a single region within any one or more views. In addition, in alternative embodiments, calculation step **1125** may be eliminated where, for example, extraction step **1130** is based on a bit map image from the video camera. Data from other sensors, such as digital thermometers and/or digital hygrometers may also be used in extraction step **1130**. In addition, human intelligence can be added to the patterns generated by the process in FIG. **11A**. For example, different portions of the patterns can be associated with part descriptors. Moreover, known "leaky" regions, such as portions of the UUT that utilize temporary plugs during assembly and test operations, can inform one or more patterns of the UUT created in step **1135**.

[0074] FIG. **11B** is a flow diagram of a testing method, according to an embodiment of the invention. After initialization step **1170**, the process receives a UUT part number in step **1172**. The UUT part number may be received in step **1172** based on manual input from an operator. In other embodiments, step **1172** may be based on automated input, for example a bar code scan, optical character recognition (OCR) scan, pattern recognition, or other automated process.

[0075] Next, the process selects a first view (for example a predetermined plan or perspective view of the UUT part number) in step **1174**, then selects a first region (portion of the view) in step **1176**. Views and regions selected in steps **1172** and **1174** correspond to views and regions selected in steps **1115** and **1120**, respectively. The process then calculates at least one contour map in step **1178**, for example using the process described above with reference to FIG. **5B**.

[0076] Then, in step **1180**, the process selects a first pattern (including reading the first pattern from memory) and performs a recognition task in step **1182**. Recognition task **1182** may be or include artificial intelligence and/or neural network approaches for analyzing data derived from sensors. Such data may be analyzed on its own (in which case selection step **1180** is not needed), or by comparison to one or more stored patterns. In a simple form, recognition step **1182** may simply compare one or more peak measured values to a predetermined threshold value. The result of

recognition step **1182** may be or include, for example, the identification of a leak, the precise location of a leak (by coordinates or with reference to a descriptive feature), an assessment of the flow rate and/or direction of a leak, and/or an estimate of the size of a hole in a pressurized UUT.

[**0077**] The process then advances to conditional step **1184** to determine whether a response is required. Where the result of conditional step **1184** is in the affirmative, the process advances to response step **1186**, which may include, for example, logging or saving the results of recognition step **1182** by UUT part number and serial number, notifying an operator, and/or facilitating indicated rework or repair operations (not shown). Subsequent to step **1186**, and where the result of conditional step **1184** is in the negative, the process is promoted to conditional step **1188** to determine whether all relevant patterns have been considered.

[**0078**] Where the result of conditional step **1188** is in the negative, the process selects a next pattern in step **1180**. Where the result of conditional step **1188** is in the affirmative, the process advances to conditional step **1190** to determine whether all regions have been considered. Where the result of conditional step **1190** is in the negative, the process selects a next region in step **1176**. Where the result of conditional step **1190** is in the affirmative, the process advances to conditional step **1192** to determine whether all views have been considered. Where the result of conditional step **1192** is in the negative, the process selects a next predetermined view in step **1174**. Where the result of conditional step **1192** is in the affirmative, the process terminates in step **1294**.

[**0079**] Variations to the process illustrated in FIG. **11B** are possible. For example, some applications may only review a single view or only a single region within any one or more views. In addition, in alternative embodiments, recognition step **1182** may be further informed by primitive image or other comparisons to one or more stored bit map images. Alternatively, or in combination, recognition step **1182** may be based on a combination of more than one pattern, more than one region, and/or more than one view.

[**0080**] The system described with reference to FIGS. **1-4** may be configured to perform one or more of the methods described with reference to FIGS. **5A, 5B, 11A, and 11B**. In addition, any one of the methods described with reference to FIGS. **5A, 5B, 11A, and 11B** may be performed in hardware, software, or a combination of hardware and software. Moreover, the methods described with reference to FIGS. **5A, 5B, 11A, and 11B**, or any portion thereof, may be implemented by instructions that are stored on computer-readable medium so that the instructions can be read and executed by the processor **120**.

#### INDUSTRIAL APPLICABILITY

[**0081**] The disclosed systems and method may be applicable to a wide variety of applications where it may be advantageous to detect, display or otherwise process data associated with ultrasonic energy. As described above, an ultrasonic signature may be associated with certain types of defects. Moreover, an ultrasonic source may be used in a testing or diagnostic mode to uncover certain holes, cracks, voids, or other defects indicated by mechanical vibrations of mechanical components or systems in the ultrasonic frequency range.

[**0082**] Accordingly, the systems and/or methods described herein may be applicable for testing or diagnostics associated with, for instance: cylinders, transmissions, engine blocks, fuel tanks, fittings, valves, flanges, vehicles cabs, pump cavitations, missing gear teeth gear boxes, line blockage, steam traps, compressors, motors, pipes, flow direction, underground leaks, vacuum leaks, welds, substations, heat exchangers, seals, pump tanks, air brakes, gaskets, pressure leaks, electrical arcs, caulking, and/or junction boxes.

[**0083**] It will be apparent to those skilled in the art that various modifications and variations can be made to the disclosed systems and methods. For instance, systems and/or methods could be implemented using arithmetic mean, arithmetic average, or other approximation instead of the true RMS-to-DC translations described herein. In addition, combinations of the disclosed embodiments not specifically described are also possible, for example those that utilize other sensor types instead of, or in combination with, sensor types described herein. Accordingly, other embodiments will be apparent to those skilled in the art from consideration of the specification and practice of the disclosed system and methods. It is intended that the specification and examples be considered as exemplary only, with a true scope being indicated by the following claims and their equivalents.

We claim:

1. A system configured to detect ultrasonic energy comprising:
  - an ultrasonic sensor array, the ultrasonic sensor array including a plurality of ultrasonic sensors;
  - a processor operably coupled to the ultrasonic sensor array; and
  - a visible image detector module operably coupled to the processor, the system configured to calculate a Root-Mean-Square (RMS) value associated with each of the plurality of ultrasonic sensors.
2. The system of claim 1 wherein the ultrasonic sensor array includes a two dimensional array of sensors, the two dimensional array of sensors having n rows and m columns.
3. The system of claim 1 wherein the processor is configured to build a contour map based on a plurality of signals received from the ultrasonic sensor array, the contour map associated with an intensity of the ultrasonic energy detected by the ultrasonic sensor array.
4. The system of claim 3 wherein the processor is configured to blend at least one feature of the contour map with at least one feature associated with a signal output from the visible image detector module to create a blended display image.
5. The system of claim 1 wherein the visible image detector module includes a camera.
6. The system of claim 5 wherein the camera includes a video camera.
7. The system of claim 5 wherein the camera includes an infrared camera.
8. The system of claim 1 wherein the RMS value is a true RMS value.
9. The system of claim 1 wherein each of the plurality of sensors includes a RMS converter configured to calculate the RMS value.
10. The system of claim 9 wherein the RMS value is a true RMS value.

11. The system of claim 9 wherein each of the plurality of sensors includes a detector and an amplifier.

12. The system of claim 11 wherein the detector is a piezoelectric device.

13. The system of claim 11 wherein the amplifier has at least two stages of amplification.

14. The system of claim 1 further including a data I/O module operably coupled between the ultrasonic sensor array and the processor.

15. The system of claim 14 further including an ultrasonic transmitter operably coupled to the data I/O module, the ultrasonic transmitter responsive to a command signal from the processor to emit ultrasonic energy.

16. The system of claim 14 further including a range finder operably coupled to the data I/O module, the range finder in communication with the processor.

17. The system of claim 14 further including a motor controller operably coupled to the data I/O module, the motor controller responsive to a command signal from the processor.

18. The system of claim 17 further including at least one material handling device coupled to the motor controller and configured to reposition the ultrasonic sensor array with respect to a unit under test.

19. The system of claim 1 further including a second ultrasonic sensor array coupled to the processor, the second ultrasonic sensor array including a second plurality of ultrasonic sensors.

20. A method for graphically displaying ultrasonic energy comprising:

receiving data from each of a plurality of ultrasonic sensors, the data based on Root-Mean-Square (RMS) calculation;

building a contour map based on the received data;

receiving a camera image; and

blending at least one feature of the contour map with at least one feature of the received camera image.

21. The method of claim 20 further including smoothing the received data prior to the building.

22. The method of claim 20 further including scaling the camera image prior to the blending.

23. The method of claim 20 wherein building the contour map includes:

initializing a matrix;

inserting each of a plurality of known data values at positions in the matrix to create a contour map, each of the plurality of known data values associated with a Root-Mean-Square (RMS) calculation;

scaling the contour map; and

colorizing the contour map based on a color ramp.

24. The method of claim 23 further including:

determining additional data values via interpolation; and inserting the additional data values in the contour map prior to scaling the contour map.

25. A processor-readable medium having stored thereon instructions for a method of generating a graphical user interface (GUI), the method comprising:

receiving data from each of a plurality of ultrasonic sensors, the data based on Root-Mean-Square (RMS) calculation;

building a contour map based on the received data;

receiving a visual camera image;

blending at least one feature of the contour map with at least one feature associated with the received visual camera image to create a blended image; and

displaying the blended image in a first portion of a display screen.

26. The processor-readable medium of claim 25, the method further including displaying the contour map in a second portion of the display screen.

27. The processor-readable medium of claim 25 wherein the at least one feature of the contour map is associated with a highest intensity on the contour map, the highest intensity related to a highest RMS calculation value.

28. A method for testing comprising:

selecting a first view of a unit under test, the first view associated with a relative position between a first ultrasonic sensor array and the unit under test;

selecting a first region, the first region being associated with a portion of the first view;

calculating a contour map based on RMS-to-DC conversion data associated with the first region; and

recognizing at least one feature of the contour map.

29. The method of claim 28 wherein the recognizing includes comparing a measured peak value of the contour map to a predetermined threshold value.

30. The method of claim 28 wherein the recognizing includes comparing the contour map to a stored pattern.

31. The method of claim 30 wherein the stored pattern is based on a known good unit.

32. The method of claim 30 wherein the stored pattern is based on a known bad unit.

\* \* \* \* \*

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摘要(译)

公开了用于超声能量的检测和成像的系统和方法。本发明的实施例利用超声波传感器阵列，其中来自每个传感器的数据通过RMS-DC转换来处理。另外，本发明的实施例基于检测到的超声能量输出轮廓图，并且将轮廓图的至少一个特征与可见图像的特征混合，使得可以向操作者显示混合图像。此外，本发明的实施例提供了一种系统和方法，用于相对于目标区域或被测单元 (UUT) 重新定位超声波传感器阵列，以便于彻底和可重复的测试。

