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(54) TRIANGULATION WITH CO-LOCATED SENSORS

TRIANGULATION MIT KOLOKALISIERTEN SENSOREN

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Description

BACKGROUND OF THE INVENTION

[0001] The determination of near precise location of an object, feature or event is obligatory in various applications, including for radar, sonar, wireless technologies, damage detection, structural health monitoring, positioning or mapping systems, and the like, to perform their function. A common location sensing scheme known as triangulation involves the measurement of distance to an event from a reference point. For triangulation, sensors are placed in at least three separate locales to determine the location of an object situated at a point between the sensors.

[0002] Location sensing is particularly useful for damage detection and structural health monitoring (SHM) methods. SHM involves the incorporation of non-destructive test methods into a structure to provide continuous remote monitoring for damage. SHM systems are systems with the ability to detect and interpret adverse changes in a structure, such as an airplane or other aircraft, automobiles, and naval applications, for example. Simple SHM systems that have been implemented in diverse industries generally include the adhesion of strain gauges or thermocouples to monitor changes in strain, frequency and temperature. A common form of SHM that provides minimal data is a "black-box" on aircraft that collect critical flight data.

[0003] The invention relates to the in-plane location triangulation of remote objects, features, events or damage using sensors positioned in substantially close proximity to each other. The sensors are configured to detect objects, features, events or damage that is located at a position outside of the perimeter formed by the sensors. [0004] According to the invention, there is provided a method of detecting an event in a mechanical structure using sensors and at least one actuator. The method includes generating an excited signal in the structure using the at least one actuator, detecting a reflected signal from the event using each of three of more of the sensors, the three or more of the sensors being positioned around a circle having a central axis, and the sensors and the at least one actuator being positioned concentrically with respect to the central axis, determining respective durations of time for which the reflected signals travel from the event to each of the sensors, and calculating a location of the event by using differences in the respective durations of time for which the reflected signal travels from the event to each of the sensors to determine an angle and a distance at which the event is positioned.

[0005] Implementations of the invention may include one or more of the following features. The event may comprise one of an impact event, physical damage or a feature in the structure. The sensors may be positioned at even intervals around a circle. A method of detecting a position of a feature in a structure using a device having sensors and at least one actuator can include detecting an acoustic event, returning a reflected wave signal from the event to each of the sensors in the device, determining a respective duration of time for which the signal travels from the event to each of the sensors, and calculating

- ⁵ a location of the event by using differences in the respective durations of time for which the signal travels from the event to each of the sensors to determine an angle and a distance at which the event is positioned.
- [0006] It is also known from US2005/0228597 A1 to provide a device for detecting an event in a mechanical structure. The device includes at least one actuator and at least three sensors being positioned around a circle having a central axis, the at least one actuator and the sensors being positioned concentrically around the cen-
- ¹⁵ tral axis, wherein the device is configured to determine the location of the event by using the at least one actuator to generate an excited signal in the structure and using each of the at least three sensors to detect a reflected signal from the event.
- 20 [0007] Implementations of the invention may include one or more of the following features. The actuator can surround the at least three sensors. The actuator can be positioned in plane with the at least three sensors. The at least three sensors can surround the at least one ac-
- ²⁵ tuator. An arrangement of the at least three sensors and an arrangement of the at least one actuator can be concentrically aligned. The at least three sensors can be positioned at even intervals around the circle. The at least one actuator used to generate the excited signal can be
- ³⁰ a separate component from the at least three sensors used to detect the reflected signal. The event can comprise one of an impact event, physical damage or a feature in the structure. The at least one actuator and the at least three sensors may be co-planar.
- ³⁵ [0008] The invention provides one or more of the following capabilities. Co-located sensors can be used actively to replace phased array methods. Location of an event can be determined within approximately 2 degrees of accuracy. Location of an event can be determined with-
- 40 in better than 2 degrees of accuracy. "Halo effect" and "blackout" regions found in traditional phased array can be substantially eliminated. Co-located sensors can be used to replace larger, denser sensor triangulation arrays. The method can be broadly defused in aerospace,
- ⁴⁵ automotive, naval and civil applications, or in other fields. Fewer sensors can accomplish detection without limiting the range over which detecting is desired. Co-located sensors can be used in large or in small applications requiring differing power to obtain the desired range and
 ⁵⁰ resolution. Embodiments of the invention can use an array of actuator and sensor components, including but not limited to piezoelectric wafers, strain gauges, fiber optics or MEMS devices. A set of sensors in a node can be used passively to determine the location of an impact
 ⁵⁵ event using acoustic emission. A set of sensors in a node can actively locate the position (e.g., angle and radius)

to a damage feature using Lamb waves or other common

ultrasound techniques.

[0009] Other capabilities will be apparent upon a review of the Figures and Detailed Description that follows.

BRIEF DESCRIPTION OF THE DRAWINGS

[0010]

FIG. 1 is a top perspective view of co-located sensors used in a damage detection device fabricated by laser cutting a PZT-5A wafer, for example.

FIG. 2 is a schematic of exemplary alternative sensor/actuator configurations.

FIG. 3A is a schematic of a measurement of distance and angle to an event using co-located sensors.

FIG. 3B is a graph of experimental results comparing co-located measurements that measure angle to a damage feature with the actual angle using the method of FIG. 8A.

FIG. 4 is a plot demonstrating the Fourier technique for calculating an angle to a feature.

FIG. 5 is a flow chart representing a method of determining a distance to an event according to an embodiment of the invention.

DETAILED DESCRIPTION OF THE INVENTION

[0011] The features and other details of the invention will now be more particularly described. It will be understood that particular embodiments described herein are shown by way of illustration and not as limitations of the invention. The principal features of this invention can be employed in various embodiments without departing from the scope of the invention.

[0012] Embodiments of the invention are directed to co-located sensors in a single package used to determine the position (angle and radius) of an impact event or damage feature located outside of the sensor package using triangulation methods. Embodiments of the invention can be directed to piezoelectric-based sensors and an actuator that are positioned in close proximity to one another and can be packaged within a single unit and share a common hardware infrastructure. Embodiments of the invention can be used in facilitating damage detection, non-destructive testing ("NDT"), radar, sonar and structural health monitoring ("SHM"). Embodiments of the invention relate to a collection of electrical and mechanical components necessary to conduct in-situ damage detection methods. Embodiments of the invention can be used in SHM of aircraft, spacecraft, naval vessels and automobiles. Embodiments of the invention may be used in other structures using sensor networks and to conduct testing procedures other than NDT and SHM procedures. For example, embodiments of the invention can be used for non-destructive evaluation, measurement, usage monitoring (HUMS), security, surveillance, condition monitoring, quality control, radar or cell phone networks. Embodiments of the invention can be used for other applications.

[0013] Referring to FIG. 1, a sensor node 5 is comprised of a piezoelectric wafer 20, sensors 50 and an actuator 60. The wafer 20 has a radius 70. The sensors 50 are preferably positioned equidistant from each other around a perimeter of the piezoelectric wafer 20. For example, a circular wafer 20 having a radius 70 includes

sensors 50 positioned at equal distances around the perimeter of the wafer 20. The sensors 50 are substantially close in proximity to one another, and in proximity to the actuator 60.

[0014] The node 5 comprises the at least three co-located sensors 50 that allow triangulation using reflected signals. The sensors 50 and the actuator 60 are substantially in-plane components capable of connection to a

¹⁵ circuit without the use of wires. For example, the node 5 can include components, such as those components described in co-pending U.S. Application Serial Nos. 11/071,129 filed March 3, 2005 and entitled, "Sensor Infrastructure," and 11/071,856 filed March 3, 2005 and

²⁰ entitled, "Damage Detection Device,". Referring to FIG. 2, the co-located sensors 50 and the actuator 60 can be a number of alternative shapes and configurations. For example, the sensors 50 can be circular, semicircular, square, triangular, rectangular, pie-shaped, hexagonal,

²⁵ octagonal, and any of a number of other shapes. Three sensors 50 or greater than three sensors 50 can be used to optimize the location detection. The actuator 60 can also be any of a number of shapes configured to be planar to the sensors 50. The substantially concentric design of

the sensors 50 and the actuator 60 provide omnidirectional operation of the node 5. By having an actuator that surrounds a set of sensors (or vice versa) this allows excited signals (electrical, magnetic, acoustic, vibrational or otherwise) to be emanated omni-directionally from a nearly point source, and for response measurements to be taken from nearly that same location.

[0015] Each of the sensors 50 and the actuator 60 can surround, or substantially surround the other. In each of the alternative configurations shown in FIG. 2, the center

40 portion can be the actuator 60, surrounded by one or more than one sensor 50. Thus, a sensor or a set of sensors can be surrounded by an actuator or a set of actuators. Alternatively, an actuator or a set of actuators can be surrounded by a sensor or a set of sensors in the 45 concentric design.

[0016] The in-plane configuration of the actuator 60 and the co-located sensors 50 achieves contact with a material to be monitored or tested using thermoset or thermoplastic tape, epoxy, using a couplant material, or
⁵⁰ with an externally applied force. Other room temperature or elevated cure methods of contact are possible and envisioned. In some applications, the co-located sensors 50 and the actuator 60 are encapsulated in a housing. In other embodiments, the node 5 is substantially directly
⁵⁵ positioned on a material or structure for use. The actuator 60 and the co-located sensors 50 can be actuated with an electrical or magnetic field being applied so as to excite through-thickness, axial, shear or radial modes in

the actuator. This field can be applied to a parallel face of the actuator 60, or using interdigitated electrode patterns. Sensor voltage data can be measured using any of these fields. Preferably, the sensors 50 and the actuator 60 are constructed of a piezo-ceramic material. Other known materials can be used, however, such as other piezoelectric materials (PVDF, PMA, etc), piezoresistive materials or magnetorestrictive materials, for example.

[0017] The particular piezoelectric material used for the wafer 20 can be PZT-5A in order to reduce the dependency of performance on temperature, however other grades of PZT such as PZT-5H would also be acceptable. The piezoelectric elements are either injection molded, machined or micro-fabricated in either addition or subtraction processes into the desired geometry, typically less than 1" in diameter. Other dimensions are possible and envisioned, and may vary depending on optimizing an application.

[0018] A variety of sensor types can be used to accomplish triangulation, including, but not limited to, sensors that measure stress, strain, vibration, acoustics, temperature, humidity, acceleration, radiation, electric or magnetic fields, light and/or motion. Further, a node 5 can be surface-mounted or embedded for applications that include, for example, structural health monitoring, non-destructive evaluation, health usage monitoring, surveillance or security.

[0019] Sizes of the nodes can vary. For example, sensors 50 may include an actuator ranging from a 1" diameter to a 0.1" diameter. Sensors can range from 0.2" diameter with 0.01" spacing, to 0.02" diameter with 0.001" spacing. Other dimensions for the sensors and the actuator are possible. For example, the diameters of the sensors and the actuators, and the spacing between the sensors, can be greater than or less than the dimensions stated above. The ratio of the dimensions can be optimized based on predicted performance. Nodes 5 can utilize between 3 and 6 sensors, or more than 6 sensors, inside of an actuator ring, for example.

[0020] Referring to FIG. 3A, the actuator 60 is configured to excite waveforms in a material to create reflected waves that the co-located sensors 50 measure. The actuator 60 excites a radial Lamb wave mode, which propagates omni-directionally from the source location. The sensors 50 are positioned to measure a time of arrival difference from waves reflected from feature locations (e.g., damage) in order to triangulate a location of an event or feature positioned outside of the perimeter defined by the sensors 50 and the actuator.

[0021] The distance to an event 110 can be calculated according to various methodologies. For example, in a first in-first out method of determining the position of the event 110, a time of flight of the signal sent from the point 100 is recorded for each of the sensors positioned around the circle 102. A vector is drawn between the sensors 50 with the longest and the shortest times of flight to calculate a distance D to the event 110. The method described with respect to FIG. 3A can increase in accuracy as ad-

ditional sensors are added to a node.

[0022] Alternatively, the co-located sensors 50 can be used in a triangulation method to determine the distance D to the event 110. Sensors 50 are positioned in even increments around a circle, for example, 3 sensors are positioned 120-degrees apart from one another around a circle. For each combination of 3 sensors, a triangularization calculation is performed, finding the Cartesian co-ordinates to determine the recorded times of flight using

¹⁰ distance formulas. Each of the combinations are compared and the combinations of results that yield the highest confidence levels are averaged to produce a final feature position.

[0023] For example, according to experimentation, the
 triangulation method yields substantially accurate results for a small number of sensors. Increasing the number of sensors by more than 3 marginally increases resolution, which was experimentally validated for 3-6 sensors. Referring to FIG. 3B, experiments were conducted using
 the triangulation technique. A plot 120 represents results of testing of a single actuator and 3 sensors positioned

on a 1'x 1' aluminum plate with markings at 1-degree increments. A 1-kilogram weight was placed on the plate using shear couplant to represent a feature. The weight
 ²⁵ was placed in several known positions prior to collecting data, in order to compare measured angle-to-damage,

with the known angle-to-damage. Distance to the damage was also displayed, using the average time of flight recorded by all sensors to calculate the position. From these experiments, an error of less than 5 degrees was observed. Further processing and experimental optimization allowed for a reduction in the error to 2 degrees,

or less. Experimental implementation of a passive version of the system shown in FIGS. 3A and 3B has yielded ³⁵ substantially similar results. Experimentation of the passive system was conducted using a pencil tip broken in various locations on the plate. The co-located sensors are capable of determining the location with identical accuracy without the use of an actuator.

40 [0024] Referring to FIG. 4, in an additional alternative method of calculating a distance to an event, a Fourier transform can be used in the calculation of the position of the feature, impact event or damage. The sensors 50 are positioned around the radius of a circle. The sensors

⁴⁵ 50 are used to plot the time of arrival results in cylindrical coordinates, plot 130. A Fourier transform is used to approximate the closest sinew wave that would match this data using the values for amplitude, offset, phase and sensor angle. Once the sine wave has been interpolated, a traditional triangularization method can be used to cal-

a traditional triangularization method can be used to calculate the feature position based on the implied times of flights for the fixed sensor locations.

[0025] In operation, referring to FIG. 5, with further reference to FIGS. 1-4, a process 200 for detecting a fea-⁵⁵ ture, such as damage or an impact event in a material or structure, using a node 5 having multiple sensors includes the stages shown. The process 200, however, is exemplary only and not limiting. The process 200 may be altered, e.g., by having stages added, removed, or rearranged.

[0026] At stage 202, a node 5 is positioned on the surface of a material or a structure for which structural integrity is to be tested or monitored. A single node comprises one or more actuators 60, and a number of sensors 50. For example, a node 5 contains three sensors 50 equidistant from each other around a perimeter of the node 5, circumscribed by a ring actuator 60. The node 5 can be embedded in a material or structure to conduct detection. The node 5 can be used to locate other features or events, such as in a radar or sonar application. Although the system can operate continuously, the system can be accessed on demand, for example, to conserve power and computation needs.

[0027] At stage 204, the node 5 collects data related to the structure to which it is affixed. The node 5 can collect data actively (e.g., pulse and listen), or passively, for example, using strain and acoustic emission methods. Passive damage detection methods can be used continuously to sense the presence of an impact to the structure. Passive methods are generally those that operate by detecting responses due to perturbations of ambient conditions. Acoustic emission can be performed passively to detect and record impact events and approximate the energy of impact.

[0028] Active methods such as Lamb wave techniques can give more information about the type and severity, in addition to the location of damage. Active methods, for example, use an externally supplied energy in the form of a stress or electromagnetic wave to function. Examples of active methods include, but are not limited to, electrical and magnetic impedance measurements, eddy currents, optical fibers that use a laser light source, modal analysis and Lamb wave propagation. At stage 206, the nodes pass the collected information to a local processing unit

[0029] At stage 208, the position of damage is determined using the data collected, and using algorithms to triangulate feature locations from a single point. For example, a node 5 having three or more sensors 50 equally spaced about a circle having a given radius can record the time of flight of a signal sent to the event for each sensor 50. The time of flight of the signal is used to calculate a position of the event with respect to the position of the sensor 50. More than three sensors can be used in a node to detect the location of an event.

[0030] At stage 210, the collected and processed data is displayed to the user for verification. The display is possible using any of a number of methods, for example, through LED indicators, text reports or graphically. It is also possible to set up feedback with the system being monitored for action to take place based upon the results. Data may be communicated to a central location (e.g., ground crew), locally (e.g., operator), or to other nodes for collaboration via data fusion, for example.

[0031] In embodiments of the invention, structural monitoring tests are facilitated with the electronics on a

printed circuit board. A microprocessor can be encapsulated in the node 5 to initiate testing by triggering the arbitrary function generator to excite the actuator in the node 5 and initiating data collection by a datalogger on

- ⁵ the printed circuit board. The tests can be initiated remotely by a user, pre-programmed to be executed at certain intervals, or run substantially continuously. Digital data from the buffer is collected by a central processor via a wired or wireless data link. The data is processed
- ¹⁰ by a central processor. The microprocessor on the printed circuit board can provide processing to locally assess damage.

[0032] Those skilled in the art will recognize, or be able to ascertain using no more than routine experimentation,

¹⁵ numerous equivalents to the specific procedures described herein. Such equivalents are considered to be within the scope of the invention. Other aspects, advantages, and modifications are within the scope of the invention. The appropriate components, processes, and ²⁰ methods of those patents, applications and other documents may be selected for the invention and embodiments thereof.

25 Claims

1. A method of detecting an event (110) in a mechanical structure using sensors (50) and at least one actuator (60), the method comprising:

generating an excited signal in the structure using the at least one actuator (60);

detecting a reflected signal from the event using each of three or more of the sensors (50), the three or more of the sensors (50) being positioned around a circle having a central axis (100), and the sensors and the at least one actuator (60) being positioned concentrically with respect to the central axis (100);

determining respective durations of time for which the reflected signal travels from the event (110) to each of the sensors (50); and

calculating a location of the event (110) by using differences in the respective durations of time for which the signal travels from the event (110) to each of the sensors (50) to determine an angle and a distance at which the event (110) is positioned.

- 50 **2.** The method of claim 1, wherein the event (110) comprises one of an impact event, physical damage or a feature in the structure.
 - **3.** The method of claim 1 or 2, wherein the sensors (50) are positioned at even intervals around a circle.
 - **4.** A device for detecting an event (110) in a mechanical structure, the device comprising:

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at least one actuator (60); and at least three sensors (50) being positioned around a circle having a central axis (100), the at least one actuator (60) and the sensors (50) being positioned concentrically around the central axis (100), wherein the device is configured to determine

the location of the event (110) by using the at least one actuator (60) to generate an excited signal in the structure and using each of the at least three sensors (50) to detect a reflected signal from the event (110).

- The device of claim 4, wherein the at least one actuator (60) surrounds the at least three sensors (50). ¹⁵
- **6.** The device of claim 4 or 5 wherein the at least one actuator (60) is positioned in plane with the at least three sensors (50).
- 7. The device of claim 4 or 6, wherein the at least three sensors (50) surrounds the at least one actuator (60).
- 8. The device of claims 4 to 7, wherein an arrangement of the at least three sensors (50) and an arrangement of the at least one actuator (60) are concentrically aligned.
- **9.** The device of claims 4 to 8, wherein the at least three sensors (50) are positioned at even intervals around ³⁰ the circle.
- The device of claims 4 to 9, wherein the at least one actuator (60) used to generate the excited signal is a separate component from the at least three sensors (50) used to detect the reflected signal.
- **11.** The device of claims 4 to 10, wherein the event (110) comprises one of an impact event, physical damage or a feature in the structure.
- **12.** The device of claims 4 to 11, wherein the at least one actuator (60) and the at least three sensors (50) are co-planar.

Patentansprüche

 Verfahren zum Erkennen eines Events (110) in einer mechanischen Struktur mit Hilfe von Sensoren (50) 50 und wenigstens einem Aktuator (60), wobei das Verfahren Folgendes beinhaltet:

> Erzeugen eines angeregten Signals in der Struktur mit Hilfe des wenigstens einen Aktuators (60);

> Erkennen eines reflektierten Signals von dem Event anhand von jedem von drei oder mehr der

Sensoren (50), wobei die drei oder mehr der Sensoren (50) um einen Kreis mit einer Mittelachse (100) herum positioniert sind, und die Sensoren und der wenigstens eine Aktuator (60) konzentrisch mit Bezug auf die Mittelachse (100) positioniert sind; Ermitteln von jeweiligen Zeitdauern, während der das reflektierte Signal von dem Event (110) zu jedem der Sensoren (50) wandert; und

- Berechnen eines Orts des Events (110) anhand von Differenzen zwischen den jeweiligen Zeitdauern, während der das Signal von dem Event (110) zu jedem der Sensoren (50) wandert, um einen Winkel und einen Abstand zu ermitteln, in dem das Event (110) positioniert ist.
- 2. Verfahren nach Anspruch 1, wobei das Event (110) ein Aufprallevent, einen physischen Schaden oder ein Merkmal in der Struktur umfasst.
- **3.** Verfahren nach Anspruch 1 oder 2, wobei die Sensoren (50) in gleichmäßigen Intervallen um einen Kreis herum positioniert sind.
- Vorrichtung zum Erkennen eines Events (110) in einer mechanischen Struktur, wobei die Vorrichtung Folgendes umfasst:

wenigstens einen Aktuator (60); und wenigstens drei Sensoren (50), die um einen Kreis mit einer Mittelachse (100) herum positioniert sind, wobei der wenigstens eine Aktuator (60) und die Sensoren (50) konzentrisch um die Mittelachse (100) herum positioniert sind, wobei die Vorrichtung zum Ermitteln des Ortes des Events (110) durch Verwenden des wenigstens einen Aktuators (60) zum Erzeugen eines angeregten Signals in der Struktur und durch Verwenden jedes der wenigstens drei Sensoren (50) zum Erkennen eines reflektierten Signals von dem Event (110) konfiguriert ist.

- 5. Vorrichtung nach Anspruch 4, wobei der wenigstens eine Aktuator (60) die wenigstens drei Sensoren (50) umgibt.
- **6.** Vorrichtung nach Anspruch 4 oder 5, wobei der wenigstens eine Aktuator (60) in einer Ebene mit den wenigstens drei Sensoren (50) positioniert ist.
- 7. Vorrichtung nach Anspruch 4 oder 6, wobei die wenigstens drei Sensoren (50) den wenigstens einen Aktuator (60) umgeben.
- ⁵⁵ 8. Vorrichtung nach den Ansprüchen 4 bis 7, wobei eine Anordnung der wenigstens drei Sensoren (50) und eine Anordnung des wenigstens einen Aktuators (60) konzentrisch ausgerichtet sind.

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- **9.** Vorrichtung nach den Ansprüchen 4 bis 8, wobei die wenigstens drei Sensoren (50) in gleichmäßigen Intervallen um den Kreis herum positioniert sind.
- Vorrichtung nach den Ansprüchen 4 bis 9, wobei der wenigstens eine Aktuator (60), der zum Erzeugen des angeregten Signals benutzt wird, eine separate Komponente von den wenigstens drei Sensoren (50) ist, die zum Erkennen des reflektierten Signals benutzt werden.
- **11.** Vorrichtung nach den Ansprüchen 4 bis 10, wobei das Event (110) ein Aufprallevent, einen physischen Schaden oder ein Merkmal in der Struktur umfasst.
- **12.** Vorrichtung nach den Ansprüchen 4 bis 11, wobei der wenigstens eine Aktuator (60) und die wenigstens drei Sensoren (50) koplanar sind.

Revendications

 Procédé de détection d'un événement (110) dans une structure mécanique en utilisant des capteurs (50) et au moins un actionneur (60), ledit procédé comprenant les étapes consistant à :

> générer un signal excité dans la structure en utilisant ledit au moins un actionneur (60) ;

détecter un signal réfléchi à partir de l'événement en utilisant chacun parmi trois ou plus des capteurs (50), lesdits trois ou plus des capteurs (50) étant positionnés sur un cercle ayant un axe central (100) et les capteurs et ledit au moins un actionneur (60) étant positionnés concentriquement par rapport à l'axe central (100) ;

déterminer des durées respectives du temps mis par le signal réfléchi pour parcourir la distance entre l'événement (110) et chacun des capteurs (50) ; et

calculer une localisation de l'événement (110) en utilisant les différences entre les durées respectives du temps mis par le signal pour parcourir la distance entre l'événement (110) et chacun des capteurs (50) afin de déterminer un angle et une distance auxquels l'événement (110) est positionné.

- 2. Procédé selon la revendication 1, dans lequel l'événement (110) comprend un événement parmi un impact, un dommage physique ou une caractéristique de la structure.
- Procédé selon la revendication 1 ou la revendication
 , dans lequel les capteurs (50) sont positionnés à ⁵⁵ des intervalles réguliers sur un cercle.
- 4. Dispositif de détection d'un événement (110) dans

une structure mécanique, le dispositif comprenant :

au moins un actionneur (60) ; et

- au moins trois capteurs (50) qui sont positionnés sur un cercle ayant un axe central (100), ledit au moins un actionneur (60) et les capteurs (50) étant positionnés concentriquement autour de l'axe central (100),
- dans lequel le dispositif est configuré pour déterminer la localisation de l'événement (110) en utilisant ledit au moins un actionneur (60) afin de générer un signal excité dans la structure et en utilisant chacun desdits au moins trois capteurs (50) pour détecter un signal réfléchi à partir de l'événement (110).
- **5.** Dispositif selon la revendication 4, dans lequel ledit au moins un actionneur (60) entoure lesdits au moins trois capteurs (50).
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- Dispositif selon la revendication 4 ou la revendication 5, dans lequel ledit au moins un actionneur (60) est positionné dans le même plan que lesdits au moins trois capteurs (50).
- Dispositif selon la revendication 4 ou la revendication
 6, dans lequel lesdits au moins trois capteurs (50) entourent ledit au moins un actionneur (60).
- 8. Dispositif selon les revendications 4 à 7, dans lequel une disposition desdits au moins trois capteurs (50) et une disposition dudit au moins un actionneur (60) sont alignées concentriquement.
- ³⁵ 9. Dispositif selon les revendications 4 à 8, dans lequel lesdits au moins trois capteurs (50) sont positionnés à des intervalles réguliers sur le cercle.
 - 10. Dispositif selon les revendications 4 à 9, dans lequel ledit au moins un actionneur (60) utilisé pour générer le signal excité est un composant distinct desdits au moins trois capteurs (50) utilisés pour détecter le signal réfléchi.
 - 11. Dispositif selon les revendications 4 à 10, dans lequel l'événement (110) comprend un événement parmi un impact, un dommage physique ou une caractéristique de la structure.
 - **12.** Dispositif selon les revendications 4 à 11, dans lequel ledit au moins un actionneur (60) et lesdits au moins trois capteurs (50) sont coplanaires.



Fig. 1

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Fig. 4



REFERENCES CITED IN THE DESCRIPTION

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