IMAGING SYSTEM FOR DETECTING UNDERGROUND AND UNDERWATER OBJECTS AND ASSOCIATED METHOD

A method for detecting hidden objects utilizes a plurality of electromechanical transducers including at least one electroacoustic pressure wave generator and at least one scistoelectric sensor above a selected ground or water surface or a surface of an object located underground or underwater. Accordingly, the method is useful for detecting underground or underwater objects. Pursuant to the method, locations of the transducers relative to one another are determined, the pressure wave generator is energized to produce an outgoing pressure wave, and the outgoing pressure wave is transmitted through the selected surface. Incoming pressure waves are detected which are reflected by hidden surfaces generally below the selected surface in response to the outgoing pressure wave. The incoming pressure waves are analyzed to determine three-dimensional shapes of hidden objects disposed below the selected surface, whether underground or underwater. Various views of the hidden objects are displayable on a video monitor.
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IMAGING SYSTEM FOR DETECTING UNDERGROUND AND UNDERWATER OBJECTS AND ASSOCIATED METHOD

BACKGROUND OF THE INVENTION

This invention relates to an imaging system utilizing sonic or ultrasonic pressure waves for sensing purposes. More particularly, this invention relates to such a system for use in detecting and surveying generally invisible surfaces, whether those surfaces are underground or underwater. This invention also relates to an associated method.

There are many situations where objects are visually inaccessible. Such objects may be buried underground or sunken underwater. It is frequently of great importance to various interested people to determine the exact location of such buried or sunken objects but also to be able to obtain a view of such objects from a location on the surface of the earth.

One of the great problems in the world today is the presence of substantial numbers of land mines in various regions of the world. These mines were placed during armed conflicts, guerilla and civil wars and although those conflicts have been terminated in many cases, the land mines remain. The land mines are particularly dangerous for children.

Treasure hunters' first and sometimes primary chore is determining the locations of valuable artifacts. A considerable number of artifacts of interest to archeologists and/or paleontologists remain underground or underwater. These artifacts are detected only with considered trial and error, if not happenstance. With respect to underwater treasure hunting, this state of affairs has not changed even with the recent introduction of submersibles and robotic cameras to scout for sunken ships.

Despite these modern solutions, the hunt for underwater artifacts remains impeded by the difficulty of detecting objects underwater when available light levels are low. Such low
light levels exist at great depths and in shallower waters where silt and other waterborne particles scatter light. Of course, visual detection is completely impeded where artifacts have been covered by sand or silt. Although ferrous artifacts can be located in such conditions with the aid of magnetic detectors, non-ferrous artifacts such as bronzes, pottery, gold and silver remain undetectable.

OBJECTS OF THE INVENTION

An object of the present invention is to provide an automated sensing system which facilitates detection of objects underground and/or underwater.

An associated object of the present invention is to provide such imaging system which facilitates identification of objects which are located underground and/or underwater.

It is a more specific object of the present invention to provide such an imaging system capable of detecting objects inside other objects which are underground and/or underwater.

A further object of the present invention is to provide an associated imaging method enabling the visual inspection of underground and/or underwater objects.

Another object of the present invention is to provide such an imaging system and/or method which is unaffected by existing light levels.

A more particular object of the present invention is to provide such a sensing system which facilitates the detection of land mines. Such imaging system preferably facilitates identification of underground objects and may be capable of determining the type of land mine. This information is useful in selecting a method of destroying detected land mines.

A further object of the present invention is to provide an associated imaging method enabling the visual inspection of underground objects.

These and other objects of the present invention will be apparent from the drawings
and descriptions herein.

SUMMARY OF THE INVENTION

These objects are attained in a method for detecting hidden objects which utilizes a plurality of electromechanical transducers including at least one electroacoustic pressure wave generator and at least one acoustoelectric sensor above a selected surface. The selected surface may be a land or ground surface or a water surface or, alternatively, the selected surface may be an outer or upper surface of an object which is located underground or underwater. Pursuant to the method, locations of the transducers relative to one another are determined, the pressure wave generator is energized to produce an outgoing pressure wave, and the outgoing pressure wave are transmitted through the selected surface. Incoming pressure waves are detecting which are reflected by hidden surfaces generally below the selected surface in response to the outgoing pressure wave. The incoming pressure waves are analyzed to determine three-dimensional shapes of hidden objects disposed below the selected surface, whether underground or underwater. Various views of the hidden objects are displayable on a video monitor.

Generally, the three-dimensional shapes as calculated during the analysis of the incoming reflected pressure waves are stored in a memory, which permits selection of different views of the objects, from different angles and at different magnifications. In addition, a selection function may be employed to view internal surfaces of detected objects, i.e., to remove or filter out overlying surfaces. The stored three-dimensional shapes may be compared automatically to previously stored three dimensional shapes of known classes of objects, thereby enabling the automatic recognition and identification of hidden objects which are buried in a land mass or located underwater. For example, land mines may be detected
and identified, thereby facilitating selection of appropriate deactivation procedures. Where the hidden objects are buried or sunken artifacts, the insides of the objects may be examined by the automatic pattern recognition function, thereby determining whether valuable objects are hidden behind the overlying surfaces.

In many applications of the present invention, it is advantageous to have the electromechanical transducers all attached to a common carrier. In that case, the disposing of the electromechanical transducers above the selected surface includes moving the carrier into position above the selected surface. The carrier may be spaced from the selected surface, for example, where the selected surface is a surface of an underwater object or where the carrier is located above a land surface. Alternatively, the carrier may be placed in contact with the selected surface, for example, where the selected surface is a land surface of a certain variety. The locations of the transducers are determined, in many application of the method, after the placing of the carrier in contact with the selected surface. In that event, determining the locations of the transducers relative to one another includes analyzing pressure waves transmitted directly from the pressure wave generator to the sensor.

Where the carrier is substantially rigid, the disposing of the electromechanical transducers above the selected surface includes holding the carrier above and spaced from the selected surface. This scenario is applicable where the selected surface belongs to an underwater object or when the selected surface is a ground surface below which suspected land mines are located. In the latter case, the carrier may be a frame or truss work extending outwardly from the front, rear or side of a land vehicle such as a tank or other all-terrain vehicle. The carrier or frame may be movably mounted to the land vehicle for varying the vertical distance between the transducers and an underlying ground surface. This may be
necessary where the terrain is uneven. Also, the detection of underground objects such as
land mines may be facilitated by varying the spacing between the carrier and the ground
surface.

Where the carrier is mounted to an air-borne vehicle, the disposing of the
electromechanical transducers above the selected surface includes moving the air-borne
vehicle over a ground surface. Where the carrier and the electromechanical transducers are
air-borne, the disposing of the electromechanical transducers above the selected surface
includes suspending the carrier and the electromechanical transducers over the selected
surface.

Generally, it is contemplated that the outgoing pressure wave has a plurality of
different frequencies. The different frequencies may be produced and emitted at different
times. Alternatively, the different frequencies may be emitted simultaneously. Pursuant to
this alternative, selective detectors exemplarily including filters are used to separate incoming
pressure waves of different frequencies generated at reflective surfaces in response to
outgoing pressure waves of the respective frequencies. Where there are multiple
electromechanical transducers for generating pressure waves, these transducers may be
designed for producing pressure waves within respective ranges. Alternatively, each such
transducer may be capable of producing pressure wave of different frequencies in a
predetermined sequence or simultaneously.

Different kinds of information are obtainable by pressure waves of different
frequencies. For example, data pertaining to surface details are more readily obtainable by
higher frequency pressure waves inasmuch as pressure waves of higher frequencies yield an
enhanced resolution relative to pressure waves of lower frequencies. Pressure waves of lower
frequencies may be relied on in an initial scanning step to determine whether there are any
objects in a predetermined size range beneath a ground surface. Subsequent scans at higher
frequencies are used to determine details of possible objects of interest.

In accordance with another feature of the present invention, the disposing of the
electromechanical transducers above the selected surface includes operating a remote control
robot to shift the transducers into a predetermined position above the selected surface. This
feature of the invention is useful where the transducer carrier moves along a path underwater
or over an area suspected of containing land mines.

Where the selected surface is a ground surface of a ground structure and the outgoing
pressure wave and the incoming pressure waves are ultrasonic, the method may further
comprise wetting a ground structure contiguous with the selected surface to facilitate
transmission of the outgoing pressure wave and the incoming pressure waves through the
ground structure.

In the detection of land mines, the transducer carrier may mounted to an air-borne
vehicle such as a helicopter or a balloon. In that case, the disposing of the electromechanical
transducers above the ground structure includes moving the air-borne vehicle over a ground
surface and suspending the carrier and the electromechanical transducers from the air-borne
vehicle. A human operator and a video monitor may be located in the air-borne vehicle.
Alternatively, the operator and the monitor may be remotely located. In the latter case, the
movement of the vehicle and the carrier over the land surface is effectuated by a remotely
controlled robot mechanism.

Where the outgoing pressure wave and the incoming pressure waves are ultrasonic, the
implementation of the invention is enhanced in many cases by wetting the ground to facilitate
transmission of the outgoing pressure wave and the incoming pressure waves through the ground.

Where the underground objects include land mines, the method may further comprise detonating the land mines after identification of the underground objects as land mines. The land mines may be marked and subsequently detonated. Alternatively, the carrier vehicle may be equipped with small explosive charges which are deposited in an area about a detected land mine and subsequently detonated under remote control when the area is clear of people.

A system for detecting objects such as land mines hidden underground comprises, in accordance with the present invention, a carrier movable over a land surface and a plurality of electromechanical transducers mounted to the carrier, the electromechanical transducers including at least one electroacoustic pressure wave generator and at least one acoustoelectric sensor. A source of alternating electrical current is operatively connected to the pressure wave generator for energizing the generator to produce an outgoing pressure wave transmittable to an effective extent through upper layers of a ground formation. Components are operatively connected to the electromechanical transducers for determining locations of the transducers relative to one another. These components may be the carrier itself, in the case of a rigid carrier, or circuitry such as software-modified generic computer circuits for computing the relative locations of the transducers from the transmission times and/or signal strengths of pressure waves transmitted from the pressure wave generator(s) to the sensor(s).

A wave analyzer is operatively connected to the sensor(s) for analyzing incoming pressure waves reflected by an underground surfaces in response to the outgoing pressure wave, to determine three-dimensional shapes of underground objects. Also, a propulsion mechanism is operatively connected to the carrier for moving the carrier over the land surface.
The carrier for detecting land mines may take the form of a flexible web. For instance, the web may be a rubber blanket which is rolled out over or dragged along a ground surface to lie on a selected section of ground. Alternatively, the web may be the lower panel of a container holding a fluid medium. The container may include a substantially rigid upper panel and flexible panels connected to the rigid panel. The fluid acts to press the lower panel of the container into substantial conforming contact with an underlying ground surface.

Another system for underground surveying comprises, in accordance with the present invention, a plurality of substantially rigid frames and a plurality of acoustoelectric sensors for generating electrical signals encoding echo responses of underground surfaces. Each of the frames carries at least one of the sensors, the sensors being disposable in effective physical contact with underground structures upon an insertion of the frames through a ground surface. An acoustic energy generator is disposable in effective physical contact (pressure-wave-transmitting contact) with the underground structures, while position determination componentry is operatively connected to the sensors for determining locations of the sensors relative to one another. An electronic signal processor is operatively connected to the sensors for analyzing the electrical signals in accordance with the determined locations of the sensors to determine surfaces of an object hidden underground and for generating a video signal encoding an image of the object. A video monitor is operatively connected to the processor for displaying the image of the object.

The acoustic energy or pressure wave generator in this system for underground surveying may be an electroacoustic transducer. In that case, the system further comprises an a-c current generator operatively connected to the electroacoustic transducer for energizing the electroacoustic transducer with an electrical signal of a pre-established frequency, preferably
an ultrasonic frequency. This embodiment of the invention is particularly useful where the
ground formation or underground structures are wet. Wet ground formations naturally occur
in marshlands, clay deposits and below the water table and may be induced by injecting water
into a dry ground structure. Alternatively, the acoustic energy or pressure waves transmitted
through the underground structures may be generated by an explosive device.

A method for underground surveying comprises, in accordance with the present
invention, disposing an array of acoustoelectric sensors in operative contact with a ground
formation capable of transmitting pressure waves, thereafter determining physical locations of
the acoustoelectric sensors relative to each other and generating a pressure wave in the ground
formation, subsequently energizing the acoustoelectric sensors to generate a series of
electrical signals encoding echo responses of underground surfaces to the pressure wave,
automatically analyzing the electrical signals to generate a video signal encoding an image of
the surfaces, and feeding the video signal to a video monitor to thereby display the surfaces on
the monitor.

Where the sensors in this method are mounted to a plurality of substantially rigid
frame members, the disposing of the sensor array includes inserting the frames through a
ground surface and into the ground formation. Where the frame members each have an
elongate dimension, the disposing of the sensor array includes disposing the frame members
so that the respective elongate dimensions extend approximately parallel to a gravity vector or
at an acute angle with respect to the gravity vector.

Where the sensors are mounted to a carrier such as a fluid filled container, the
disposing of the sensor array includes disposing the container on the ground formation. The
container may have a wedge shape with a first wall and a second wall disposed at an angle
relative to one another. The sensors are fixed to the second wall. In that case, the disposing of the sensor array includes disposing the first wall in contact with the formation and the second wall at the angle with respect to the first wall. The container may be disposed in an arcuate configuration, e.g., a circle or a regular polygon, on the formation.

In order to facilitate the conduction of ultrasonic pressure waves through the ground formation, a liquid such as water may be introduced into the formation. This step is generally of special advantage where the ground formation is made of a dry material. In some cases, for example, in marshlands, bogs, swamps, and clay deposits, the introduction into the ground formation of a liquid such as water may be superfluous.

A system for surveying an underwater topography comprises, in accordance with the present invention, an ultrasonic sensor array disposable in physical contact with a body of water for generating electrical signals encoding ultrasonic echo responses of underwater objects in the body of water. The sensor array includes a plurality of electromechanical transducers in turn including at least one electroacoustic transducer and one acoustoelectric transducer. The transducers are disposed in a configuration extending in at least two dimensions. An a-c current generator is operatively connected to the electroacoustic transducer for energizing the electroacoustic transducer with an electrical signal of a pre-established ultrasonic frequency. Means are provided which operatively connected to the sensor array for determining locations of the electromechanical transducers relative to one another. A processor or computer is operatively connected to the sensor array for analyzing the electrical signals in accordance with the determined locations of the electromechanical transducers to determine surfaces of objects disposed at least partially in the body of water and for generating a video signal encoding an image of the objects. A video monitor is
operatively connected to the processing means for displaying the image of the objects.

It is generally contemplated that the sensor array of the system for surveying an underwater topography includes a carrier such as a net or a rigid frame structure, the transducers being mounted to the carrier. In either case, motive or propeller elements may be attached to the carrier for applying a force to the carrier relative to the body of water. The motive or propeller elements may be activated to move the carrier and the entrained sensor array through the body of water, for example, below the surface. The motive or propeller elements are optionally motor modules with wireless signal receivers for receiving instructions from a surface or underwater vessel. Alternatively, in a simpler embodiment of the invention, a ship or other vessel drags the carrier through the body of water, either along the surface or below the surface, where wave action is reduced if not eliminated.

Where the electromechanical transducers include a plurality of electroacoustic transducers disposed in a predetermined array, circuitry is provided for energizing the electroacoustic transducers in a predetermined sequence. Thus, the processor is able to associate any set of incoming reflected pressure waves with the particular transducer which generated the pressure waves. The different transducer locations as well as multiple scanning operations provide enhanced information for data processing purposes. This enables not only the refinement of the image (increased resolution) but also enables the selection (by the operator, usually) of different view angles.

Where the electromechanical transducers include a plurality of acoustoelectric transducers or sensors disposed in a predetermined array, circuitry is provided for receiving signals from the acoustoelectric transducers in a predetermined sequence. Because of this structure, the processor processes multiple sets of incoming reflected pressure waves each
associated with the particular sensor which detects the pressure waves. Again, the different
sensor locations as well as multiple scanning operations provide enhanced information which
enables image refinement and the selection of different view angles. Of course, information
utilized in image processing is maximized where the sensor array includes multiple distributed
pressure wave generators and multiple distributed pressure wave receivers.

The determination of transducer position may be implemented simply in the case of a
substantially rigid carrier. The electromechanical transducers are mounted to the carrier so
that the locations of the electromechanical transducers relative to one another are fixed by the
carrier. However, it is alternatively possible for the transducers to be disposed at variable
locations relative to one another. In that case, the instantaneous positions of the pressure
wave generators and the pressure wave receivers relative to each other are determined by
processing or analyzing additional electrical signals generated by the sensors or receivers in
response to pressure waves transmitted through the body of water directly from the
electroacoustic transducers or generators to the acoustoelectric sensors or receivers.

Where the electromechanical transducers include a single electroacoustic transducer
and a plurality of acoustoelectric transducers, the sensor array includes means for sampling
output signals of the acoustoelectric transducers in a predetermined sequence. Where the
electromechanical transducers include a plurality of electroacoustic transducers and a single
acoustoelectric transducer, the sensor array includes means for activating the electroacoustic
transducers in a predetermined sequence.

A method for surveying an underwater topography comprises, in accordance with the
present invention, disposing an array of electroacoustic transducers in operative contact with a
body of water, determining physical locations of the transducers relative to each other, and
energizing the transducers to generate a series of electrical signals encoding echo responses of underwater objects in the body of water, the echo responses corresponding to a multiplicity of pressure wave paths from the transducers to each of the objects and back to the transducers. The electrical signals are automatically analyzed to generate a video signal encoding an image of the objects, the video signal being fed to a video monitor to thereby display the objects on the monitor.

It is contemplated that the disposing of the transducers in operative contact with the body of water includes deploying a carrier in the body of water, the transducers all being attached to the carrier. The method may further comprise operating motive or propulsion devices attached to the carrier, thereby moving the carrier relative to the body of water. The motion may be translation parallel to an underwater surface or rotation to facilitate the collection of ultrasonic data pertaining to a non-horizontal surface. In the latter case, the operating of the propulsion devices includes differentially operating the propulsion devices to change an orientation of the carrier relative to the body of water and relative to the objects.

Where the carrier is a net, the method further comprises operating the propulsion devices to pull in opposing directions on the net to maintain the net in an extended configuration.

Where the electromechanical transducers include a plurality of acoustoelectric sensors, the energizing of the transducers includes receiving signals from the sensors in a predetermined sequence.

Pursuant to another feature of the invention, determining the physical locations of the transducers includes analyzing additional electrical signals generated by the sensors in response to pressure waves transmitted through the body of water directly from selected
transducers to the sensors. Preferably, the analyzing of the electrical signals includes
analyzing the electrical signals to determine three-dimensional shapes of the objects.

An ultrasonic imaging system for underwater surveying in accordance with the present
invention facilitates detection of underwater objects, even when the ambient light levels are
insufficient to allow visual inspection.

A system for surveying an underwater topography comprises, in accordance with the
present invention, an ultrasonic sensor network disposable in physical contact with a body of
water for generating electrical signals encoding ultrasonic echo responses of underwater
objects in the body of water. The sensor network includes a plurality of electromechanical
transducers in turn including at least one electroacoustic transducer and one acoustoelectric
transducer. The electromechanical transducers are disposed in an array which has at least two
dimensions. An a-c current generator is operatively connected to the electroacoustic
transducer for energizing the electroacoustic transducer with an electrical signal of a
pre-established ultrasonic frequency. A position determination element is operatively
connected to the sensor network for determining locations of the electromechanical
transducers relative to one another. A processor is operatively connected to the sensor
network for analyzing the electrical signals in accordance with the determined locations of the
electromechanical transducers to determine surfaces of objects disposed at least partially in
the body of water. The processor includes pattern recognition circuitry for comparing the
determined object surfaces with a stored electronic library of stored surface data to identify
the determined object surfaces as being consistent with a predetermined class of objects.

The system further comprises, in accordance with another aspect of the present
invention, a position determination circuit operatively connected to the processor for
determining locations of the determined object surfaces relative to a global frame of reference.

A recording component is operatively connected to the processor and the position
determination circuit for recording locations of the determined object surfaces relative to the
global frame of reference. Thus, the latitude and longitude, as well as the depth, of a detected
object of interest may be recorded for future reference. The recording component may include
an electronic data store or, alternatively, a printer.

Where the underwater sensor network includes a carrier, with the transducers being
mounted to the carrier, the detection system further comprises one or more motors operatively
connected to the carrier for moving the carrier through the body of water. The motors may be
mounted directly to the carrier, in a self-propelled implementation, or to motor modules, or to
a surface or submarine vessel which then drags the sensor network carrier through the body of
water. The motor modules are provided with wireless signal receivers for receiving
instructions from a surface or underwater vessel.

The pattern recognition circuitry is operatively connected to the motor or motors for
arresting the motors upon detecting that one of the determined object surfaces falls into a
predetermined class of objects of interest. Thus, if something of particular interest is detected,
other investigations may be undertaken immediately to confirm the identity and the
importance of the find.

The processor may be located on the carrier itself or on a vessel which is pulling the
carrier through the body of water. Alternatively, the processor may be disposed at a more
remote location, on land, at sea or in the air. In that case, the sensor network may be linked to
the processor (and the processor to the motors) via a wireless communications link.

The various components of the processor, including the analyzer, are realized in a
general purpose computer by generic processing circuits configured by programmed
instructions.

Where the electromechanical transducers include a plurality of acoustoelectric
transducers disposed in a predetermined array, the underwater detection system further
comprises means for receiving signals from the acoustoelectric transducers in a predetermined
sequence. Because of this structure, the processor processes multiple sets of incoming
reflected pressure waves each associated with the particular sensor which detects the pressure
waves. Again, the different sensor locations as well as multiple scanning operations provide
enhanced information which enables image refinement and the selection of different view
angles. Of course, information utilized in image processing is maximized where the sensor
array includes multiple distributed pressure wave generators and multiple distributed pressure
wave receivers.

A method for surveying an underwater topography comprises, in accordance with the
present invention, steps of disposing an array of electroacoustic transducers in operative
contact with a body of water, determining physical locations of the transducers relative to
each other, and energizing the transducers to generate a series of electrical signals encoding
echo responses of underwater objects in the body of water, the echo responses corresponding
to a multiplicity of pressure wave paths from the transducers to each of the objects and back to
the transducers. The method further comprises a step of automatically analyzing the electrical
signals to determine surfaces of objects disposed at least partially in the body of water. This
analyzing includes the step of comparing the determined object surfaces with a stored
electronic library of stored surface data to identify the determined object surfaces as being
consistent with a predetermined class of objects.
In accordance with another feature of the present invention, further comprises the steps of determining locations of the determined object surfaces relative to a global frame of reference, and automatically recording locations of the determined object surfaces relative to the global frame of reference.

**BRIEF DESCRIPTION OF THE DRAWINGS**

Fig. 1 is partially a schematic perspective view, partly broken away, and partially a block diagram of an ultrasonic system for underground surveying, showing a plurality of transducer carriers or frames.

Fig. 2 is a schematic side elevational view of the system of Fig. 1, showing a modification in use of the system.

Fig. 3 is a block diagram showing selected components of a wave analyzer and a surface detector module shown in Fig. 1.

Fig. 4 is a schematic perspective view of a modified transducer carrier or frame.

Fig. 5 is a schematic perspective view of another modified transducer carrier or frame.

Fig. 6 is a block diagram showing a specific variant of the system of Fig. 1.

Fig. 7 is a block diagram showing another variant of the system of Fig. 1.

Fig. 8 is a schematic perspective view of a system for underground surveying, in accordance with the present invention.

Fig. 9 is a schematic perspective view of another system for underground surveying, in accordance with the present invention.

Fig. 10 is a schematic perspective view of a transducer pad utilizable in an underground surveying system in accordance with the present invention.

Fig. 11 is a schematic perspective view of an alternatively inflatable and collapsible
frame member utilizable in an underground surveying system.

Fig. 12 is a schematic perspective view of an underground surveying system utilizing the elements of Figs. 10 and 11.

Fig. 13 is a schematic perspective view of another alternatively inflatable and collapsible frame member utilizable in an underground surveying system, showing the frame member in a collapsed configuration.

Fig. 14 is a view similar to Fig. 13, showing the frame member of in an expanded configuration.

Fig. 15 is a schematic perspective view of an underground surveying system utilizing the elements of Figs. 13 and 14.

Fig. 16 is a schematic perspective view of a hand-held or hand-manipulable underground surveying device.

Fig. 17 is a schematic perspective bottom view of a transducer carrier component shown in Fig. 16.

Fig. 18 is a schematic perspective bottom view showing a modification of the transducer carrier component of Figs. 16 and 17.

Fig. 19 is a partial elevational view of another modification of the transducer carrier component of Figs. 16 and 17.

Fig. 20 is a partial elevational view of yet another modification of the transducer carrier component of Figs. 16 and 17.

Fig. 21 is a schematic perspective view of transducer-carrying elements of a sonic and/or ultrasonic object detection system in accordance with the present invention.

Fig. 22 is a schematic perspective view of transducer-carrying elements of another
sonic and/or ultrasonic object detection system in accordance with the present invention.

Fig. 23 is a schematic perspective view of transducer-carrying elements of a further sonic and/or ultrasonic object detection system in accordance with the present invention.

Fig. 24 is a schematic perspective view of transducer-carrying elements of a modified sonic and/or ultrasonic object detection system in accordance with the present invention.

Fig. 25 is a schematic perspective view of transducer-carrying elements of yet another sonic and/or ultrasonic object detection system in accordance with the present invention.

Fig. 26 is a transducer-carrying pad and storage container of another sonic and/or ultrasonic object detection system in accordance with the present invention.

Fig. 27 is a schematic perspective view of transducer-carrying elements of yet another sonic and/or ultrasonic object detection system in accordance with the present invention.

Fig. 28 is a partially a schematic perspective view and partially a block diagram of a nautical ultrasonic imaging system in accordance with the present invention.

Fig. 29 is a block diagram showing components of a processing system depicted in Fig. 28.

Fig. 30 is a block diagram of a preliminary signal processing circuit illustrated in Fig. 29.

Fig. 31 is a block diagram of an ultrasonic waveform generator shown in Fig. 29.

Fig. 32 is a block diagram of a digital-to-analog converter shown in Fig. 29.

Fig. 33 is a block diagram showing a specific variant of the system of Figs. 28 and 29.

Fig. 34 is a block diagram showing another variant of the system of Figs. 28 and 29.

Fig. 35 is a schematic perspective view of an ultrasonic pressure wave generating and/or sensing unit utilizable in an ultrasonic imaging system in accordance with the present
invention.

Fig. 36 is a schematic perspective view of a carrier net and dedicated propeller units of a modified ultrasonic imaging system in accordance with the present invention.

Fig. 37 is a schematic perspective view of a rigid carrier and dedicated propeller units of another modified ultrasonic imaging system in accordance with the present invention.

Fig. 38 is a schematic perspective view of another rigid carrier of transducers of an ultrasonic imaging system in accordance with the present invention.

Fig. 39 is a block diagram similar to Fig. 29 and containing additional elements of a processor and of an ultrasonic imaging system in accordance with the present invention.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

As illustrated in Fig. 1, a system for underground surveying comprises a plurality of substantially rigid frames 12 each carrying a plurality of electromechanical transducers 14 for generating electrical signals encoding ultrasonic echo responses of underground surfaces, for example, a lid surface 16 (see Fig. 2) and a body surface 18 of an object UO buried underground. Object UO might, for example, be a chest or an urn containing valuable archeological objects.

Each frame 12 carries at least one ultrasonic transducer 14. Upon an insertion of the frames through a ground surface 24, transducers 14 are disposed in physical contact with underground structures 22 capable of transmitting ultrasonic pressure waves. As illustrated in Fig. 2, the underground structures 22 may include a plurality of geologic layers 22a, 22b and 22c each capable of transmitting ultrasonic pressure waves. In most cases, the material of the underground structures incorporates significant quantities of water. Thus, the underground mass may be a clay deposit, a marsh or a water-filled porous land mass. The water may be
present naturally or supplied to the land mass in order to carry out the ultrasonic sensing techniques described herein.

Transducers 14 include one or more electroacoustic transducers 26 and one or more acoustoelectric sensors 28. Frames 12, with the electromechanical transducers 14 thereon, are deployable underground so that the transducers are disposed in an array which has at least two dimensions. An a-c current or ultrasonic signal generator 30 is operatively connected to electroacoustic transducers 26 for energizing the electroacoustic transducers with electrical signals of one or more pre-established ultrasonic frequencies. So energized, the electroacoustic transducers 26 produce ultrasonic pressure waves in the underground formations or structures 22 in which the respective frames or carriers 12 are disposed.

In order to make use of the ultrasonic signal information obtained by sensors or electromagnetic transducers 14, the relative positions of the sensors must be known. Pursuant to one methodology, frames 12 are deployed at predetermined positions and at pre-established angles relative to ground surface 24. Accordingly, because the locations of the transducers 14 on frames 12 are known, the underground locations of the sensors relative to one another will be known. Alternatively, a position determination circuit 32 (Fig. 3) is operatively connected to sensors or electromechanical transducers 14 for determining locations of the sensors relative to one another.

After being reflected or echoed by underground surfaces, where there is a change in the rate of transmission or conduction of the pressure waves, the pressure waves are detected by acoustoelectric sensors 28. Sensors 28 generate electrical signals having frequencies corresponding to those of the incoming pressure waves. The electrical signals are transmitted via a multiplexer or switching circuit 33 to an analog-to-digital converter 34 into digital
signals which are temporarily stored in a buffer 36 for timely analysis by a preliminary signal processing circuit or ultrasonic wave analyzer 38. Wave analyzer 38 includes position determination circuit 32 (Fig. 3) and a time base 40.

Circuit 32 receives, via a lead or multiple 41 extending from analog-to-digital converter 34 and buffer 36, electrical signals derived from incoming pressure waves. Circuit 32 separates out those signals corresponding to direct or unreflected ultrasonic pressure wave transmission paths to determine the relative locations of sensors or transducers 14 (both electroacoustic transducers 26 and acoustoelectric sensors 28). The encoded locations of transducers 14 are communicated by circuit 32 to a surfaces detector module 42. Module 42 analyzes incoming electrical signals from sensors 28 to determine and analytically define the surfaces of an underground object UO which generate reflected or echoed pressure waves in response to ultrasonic pressure waves from transducers 26. Time base 40 enables operation of circuit 32 and module 42.

As illustrated in Fig. 1, module 42 is connected at an output to an object construction module 44 which analyzes the surface information from module 42 to determine whether a collection of detected surfaces fit together to form an object. Module 44 thus determines the three-dimensional shapes of the underground object UO. Module 44 is connected at outputs to a video signal generator 46 which produces, from the object information from module 44, an image of underground object UO. The image is varied by generator 46 in accordance with instructions from a view selector module 48 and a surface filter module 50. In response to commands from an input device 52 such as a keyboard or a mouse, view selector 48 provides instructions to video signal generator 46 as to the angle and magnification of the image encoded in the video signal. In response to additional commands from input device 52, filter
module 50 instructs video signal generator 46 to remove one or more surfaces from the image of underground object UO, thereby enabling the inclusion in the image of objects inside of or behind object UO.

Object construction module 44 is also connected at an output to an object identifier circuit 54 which consults a memory 56 in a pattern recognition or comparison operation to determine the identity or object type of underground object UO. If an identification is established, object identifier circuit 54 provides instructions to video signal generator for incorporating identification information into the video signal. The identification information may include words or symbols providing a name and known historical data pertaining to the class of objects into which object UO is determined to fall.

Generator 46 is connected to a video monitor 58 for displaying the view-selected and surface-filtered image of underground object UO, together with any ancillary information discovered by object identifier circuit 54.

Preliminary signal processing circuit or wave analyzer 38 is operatively connected to a-c current or ultrasonic signal generator 30 via an outgoing signal control unit 60. Control unit 60 produces a control signal which determines, for example, the frequency of an outgoing ultrasonic pressure wave produced by electroacoustic transducers 26 and the identity of the particular electroacoustic transducer 28 generating that pressure wave. Signal generator 30 is a variable-frequency ultrasonic signal source and is connected to electroacoustic transducers 26 via a multiplexer or switching circuit 62. Signal generator 30 and switching circuit 62 receive control signals via respective leads 64 and 66 from control unit 60. Switching circuit 62 operates to connect signal generator 30 sequentially to different electroacoustic transducers 26. Typically, the energization sequence of transducers 26 is pre-established and determined
in part by the specific configurations of transducers 26 and sensors 28 on frames 12.

Similarly, control unit 60 is connected to multiplexer or switching circuit 33 via a lead or multiple 68 for inducing that circuit to sequentially connect analog-to-digital converter 36 to different acoustoelectric sensors 28. The connection sequence of sensors 28 is also pre-established and determined in part by the specific configurations of transducers 26 and sensors 28 on frames 12.

In many cases, in order to facilitate the separation of incoming reflected signals originating at different electroacoustic transducers 26, these transducers are activated with signals of detectably different ultrasonic frequencies. The sequence of transducer activation and the frequency or frequencies of actuation are communicated by control unit 60 to surfaces detector module 42. Detector module 42 utilizes that information to properly analyze the arriving ultrasonic signals. In the event that the incoming data are insufficient for detector module 42 to isolate, calculate and define surfaces of underground object UO, the detector module may transmit a signal to control unit 60 to change the energization sequence of transducers 26 and/or the energization frequencies.

As illustrated in Fig. 2, frames 12 may be inserted into ground formations or underground structures 22 in substantial parallelism with a local gravity vector G or, alternatively, at an angle to that vector, as indicated in phantom lines 70.

Figs. 4 and 5 depict alternative frames or transducer carriers 72 and 74. These alternative frames are provided with sharp end points 73 and 75 for facilitating the insertion of the frames through a ground surface (24 in Fig. 2). As described hereinabove with reference to Fig. 1, frames 72 and 74 carry electromechanical transducers 76 and 78 which include electroacoustic transducers (not separately designated) for generating outgoing pressure waves
and acoustoelectric sensors (not individually labeled) for detecting incoming reflected or refracted pressure waves.

It is to be noted that the connections of transducers 26 and sensors 28 to switching circuits 62 and 33 may be implemented via wireless communications links or via wires.

Fig. 6 shows a specific configuration of an underground-topography imaging system including just one electroacoustic transducer 26 and a multiplicity of acoustoelectric sensors 28. Here the enhancement of image resolution and optimization of surface detection and definition are accomplished mainly by varying the ultrasonic output frequency of the one electroacoustic transducer and the sequence of signal transmission from acoustoelectric sensors 28.

Fig. 7 depicts a particular configuration of another underground-topography imaging system including just multiple electroacoustic transducers 26 and a single acoustoelectric sensor or transducer 28. In this case, the enhancement of image resolution and optimization of surface detection and definition are accomplished by varying the ultrasonic output frequencies and the energization sequence of the electroacoustic transducers.

As illustrated in Fig. 8, another system for conducting an underground survey comprises a liquid filled receptacle 80 disposable on a ground surface 82. Generally, the receptacle is disposed on the ground surface prior to being filled with liquid such as water from a supply 84. Supply 84 is connected to an inlet port 86 of receptacle 80. A valve (not shown) may be provided for regulating liquid flow to and from receptacle 80.

Receptacle 80 may take the form of a rubber or polymeric bag which may have a single internal chamber (not shown) or multiple internal chambers separated by partitions (not shown). In a specific variation of the receptacle 80, an upper wall (not separately designated)
of the receptacle is a rigid panel while the other walls of the receptacle are flexible, thereby permitting a conforming of the bag to a ground surface. This variation with its rigid upper panel, or any other variation where receptacle has a substantially rigid frame or support structure, facilitates transport and relocation of the receptacle, for instance, by a helicopter, a crane, a forklift, etc.

Disposed on or inside receptacle 80 are a plurality of electromechanical transducers 88 including one or more electroacoustic transducers 90 and one or more acoustoelectric sensors 92. Electronic circuit functional block components of the embodiment of Fig. 8 are the same as in the embodiment of Fig. 1 and carry the same reference numerals. Thus, electroacoustic transducers 90 are operatively connected in a predetermined sequence to signal generator 30 via multiplexer or switching circuit 62 under the control of unit 60. Acoustoelectric sensors 92 are connected to wave analyzer 38 via switching circuit 33, analog-to-digital converter 34 and buffer 36. The digitized reflected pressure wave signals are processed by analyzer 38, surfaces detector module 42, object construction module 44, and object identifier 54 as discussed above with reference to Fig. 1. These circuit components, together with video signal generator 46, view selector module 48, filter module 50 and outgoing signal control unit 60, may be implemented as generic computer circuits modified by special purpose programming. Reference numeral 94 designates a computer.

As discussed above with reference to Figs. 1 and 2, ground surface 82, as well as underlying subsurface structures (see Fig. 2), may be wetted to facilitate the conduction of ultrasonic pressure waves. To that end, receptacle 80 may be provided in a lower surface with apertures 96 for enabling the passage of liquid from the receptacle onto ground surface 82 and into the underlying subsurface structures. Of course, this technique will be applicable only if
the underlying surfaces are capable of absorbing the liquid.

It is to be noted that the transducer-carrying frames 12 of Figs. 1 and 2, as well as the receptacle 80 of Fig. 8, may be used where acoustic or pressure waves are generated by a source other than a transducer, for example, an explosive charge. To that end, a number of frames 12 in the embodiment of Fig. 1 may be provided with explosive charges. To compute effectively exact locations of the explosive charges relative to the acoustoelectric sensors 28 and of the acoustoelectric charges relative to each other, the explosive charges may be provided in pairs, with a first charge being detonated to enable automatic determination of the relative positions of the explosive charges and the acoustoelectric transducers. The second charge of each pair is then deployed in the same location as the respective detonated charge and subsequently detonated to generate acoustic or pressure waves of different frequencies in the underground structures or formations. The explosive charges used in this process are of substantially less power than the charges used in oil and seismic exploration inasmuch as the depths of underground searching for buried artifacts and other articles of manufacture are generally substantially less than the search depths for oil and gas deposits.

Fig. 9 illustrates a frame or carrier in the form of a net 98 to which a plurality of electromechanical transducers 100 are attached. Transducers 100 include one or more acoustoelectric sensors (not separately designated) and optionally includes one or more electroacoustic transducers (not separately designated). Transducers 100 are adapted for placement in pressure-wave-transmitting contact with a ground surface 102. The exact design of the transducers depends on the type (frequency) of pressure waves being used in the surveying process. The type of pressure waves in turn depends in part on the nature of the underground structures or formations below surface 102 and on the nature of surface 102.
Higher frequencies (e.g., ultrasonic) may be transmitted through wet land structures than through dry land structures (rock).

Fig. 10 depicts a carrier pad 104 to which a plurality of electromechanical transducers 106 are attached. Pad 104 may be used with the circuitry illustrated, for example, in Fig. 8, to determine the locations, shapes, contents, and identities of objects buried underground. It is to be noted that in many cases, the frequencies of emitted pressure waves are most effectively distributed through a range of sonic frequencies. Of course, because resolution capability of a scanning or search process is dependent on the frequencies being used, a range of frequencies are suggested where the sizes of possible buried objects vary dramatically.

Where ultrasonic frequencies are used, it is advantageous in many instances if the ground structure being surveyed is wet, such as clay or marshland. A ground structure may be infused with water to produce a desirable degree of wetness.

Fig. 11 shows a wedge-shaped frame 108 having a lower wall 110 and an upper wall 112 disposed at an angle relative to one another. Frame 108 may be a balloon or container which is expandable into the illustrated configuration upon being filled via a port 114 with a liquid such as water. As shown in Fig. 12, a plurality of expanded frames 108 are disposed in a predetermined configuration such as a circle, with a plurality of pads 104 being disposed on the upper walls 112 of frames 108 in pressure-wave-transmitting contact therewith. Pads 104 are effectively part of upper walls 112.

In an alternative pressure-wave transmission assembly, a plurality of collapsible containers or balloons 116 (Fig. 13) each having an arcuate configuration in an expanded condition (Fig. 14) are placed side by side to form a circle (Fig. 15). Each container or balloon 116 has an upper wall 118 and a lower wall 120 oriented at a wedge angle to one
another in the expanded condition of the respective balloon or container. Each container or balloon 116 is provided on upper wall 118 with a plurality of electromechanical transducers 122 in a pre-established array.

The underground surveying equipment of Figs. 10-12 and Figs. 13-15 are disposed at a site above buried treasure or other artifacts of value. The circular configurations are intended to surround the suspected site to facilitate the derivation or generation of reflected or echoed sonic or ultrasonic signals.

The underground surveying equipment of Figs. 10-12 and Figs. 13-15 may use ultrasonic pressure waves to detect underground objects and the surfaces of those objects, as discussed above with reference to Figs. 1 and 8. In another alternative technique, the pressure waves are sonic waves of controlled frequencies generated by transducers. Alternatively, the underground pressure waves may be generated by explosive devices. For example, an explosive device might be implanted below the surface within the circular configuration of Fig. 12 or 15. Where an explosive device is used, the pressure waves generated by the explosive device must be computer analyzed with Fourier transforms or other wave-deconstructing algorithms to determine the frequency spread of the pressure waves generated by the particular explosion. The wave analysis of incoming reflected waves is then carried out based on the computed outgoing wave packet. Of course, the pressure waves generated by an explosive device will include sonic frequencies as well as ultrasonic and subsonic frequencies.

Fig. 16 illustrates a hand-held or hand-manipulable device for conducting underground searches. A shaft 124 is provided at a lower end with a frame 126 carrying an array of electromechanical pressure-wave transducers 128 (Fig. 17). As shown in Fig. 18, a flexible
pad 130 filled with water or other liquid is attachable to the bottom side of frame 126 for enhancing the conduction of pressure waves to and/or from transducers 128. At an upper end, shaft 124 is provided with a handle 130 and a video display 132. Alternative configurations of frame 126 are illustrated in Figs. 19 and 20. In Fig. 19, a frame or transducer carrier component 134 has a pyramidal or conical shape and is provided along sloped sides 136 with an array of electromechanical transducers 138. A water filled pad 140 may be provided along a bottom end of frame or carrier component 134. In Fig. 20, a frame or carrier 142 is ring shaped and has transducers 144.

As illustrated in Fig. 21, a rigid frame 146 carrying a plurality of electromechanical transducers 148 is mounted to a land vehicle 150 via a pair of rigid arms 152 and a cable 154 connected at one end to vehicle 150 and at an opposite end to a pyramidal trusswork 156 rigid with frame 146. Transducers 148 are operatively connected to signal generating components and signal analyzing components as discussed hereinabove with reference to Figs. 1 and 8. The pressure waves generated by transducers 148 may include sonic frequencies, as well as ultrasonic frequencies. Several different frequencies may be generated simultaneously for produced pressure waves of the same multiple frequencies. Reflected waves are separated by filters (not shown) and analyzed separately. Alternatively, or additionally, the different frequencies may be produced in seriatim.

The apparatus of Fig. 21 is especially suited to detecting land mines along a road. A pair of frames 146 (only one illustrated) may be mounted to opposite sides of vehicle 150 for searching a two dimensional area such as a field or a yard. Every other pass of vehicle 150 in a snaking search pattern utilizes the frame on the same side of the vehicle. Thus, the frames alternate from pass to pass.
When a land mine is detected using the apparatus of Fig. 21, a marker is planted at the site of the detected mine. The mine is subsequently detonated by designated personnel. Vehicle 150 may take a path around the detected land mine to continue the search along the subject road. Alternatively, vehicle 150 may reverse itself to await destruction of the detected mine. In a modified procedure, vehicle 150 may be used itself to deposit an explosive device proximately to the detected mine. The explosive device is detonated by remote control, once vehicle 150 has removed itself to a safe location.

Arms 152 may be pivotably mounted to frame 146 and vehicle 150 for purposes of enabling a variation in the height of frame 146 above a road surface. Drives (not shown) may be connected to arms 152, as well as to cable 154 for purposes of automatically changing the height of frame 146.

Another way of moving a rigid frame 158 above a ground surface such as a road RD is depicted in Fig. 22. Frame 158 is suspended by cables 160 from a helium-filled balloon 162. Frame 158 and/or balloon 162 is provided with motors 164 and propellers 166 for changing the position of frame 158 relative to ground or road surface RD. Preferably, motors 164 are remotely connected by a computer 168 transmitting instructions and control signals via a wireless transceiver 170. Conventional means (not shown), wirelessly controlled by computer 168, for elevating or lowering balloon 162 and frame 158 may also be provided.

Frame 158 carries a plurality of electromechanical transducers 172 for generating outgoing pressure waves of different frequencies and for detecting incoming pressure waves reflected by underground surfaces in response to the outgoing pressure waves. Signal generators for energizing the outgoing wave generators may be mounted to frame 158 and controlled by instructions from computer 168 transmitted wirelessly over transceiver 170. In
response to the incoming pressure waves, sensors among transducers 172 produce analog
signals which may be transmitted (after proper modulation) to computer 168 via transceiver
170. Alternatively, some signal processing of the analog signals may be performed on frame
158. In yet another alternative configuration of the system of Fig. 22, computer 168 may be
located on frame 158. In that case, transceiver 170 is used to transmit instructions from an
operator to the on-board computer and to relay, from the on-board computer to a monitor, a
video signal encoding images of underground objects.

As discussed above with reference to Figs. 1 and 8, object identifier 54 may be used to
identify different types of land mines. To that end, memory 56 stores shape and size
specifications of known types of land mines. Memory 56 may additionally store ancillary
information such as operating specifications and deactivating sequences of the various known
types of land mines, if available. Accordingly, in some cases, detected land mines may be
deactivated and subsequently disassembled, rather than detonated.

Scanning systems as described herein for detecting and identifying underground
objects are capable of determining positions of detected underground objects with respect to a
given reference point. The determined coordinates may be used as markers for enabling
subsequent visits to the locations of the detected objects, for instance, with the aim of digging
up the objects, in the case of buried artifacts of value, or destroying the objects, in the case of
land mines. Markers may also be physical indicators deposited on a ground surface for
identifying the locations and/or natures of detected objects which are underground.

Fig. 23 illustrates an alternative transport vehicle 174 in the form of a remote-
controlled airplane. A framework 176 carrying transducers 178 is suspended by cables 180
from plane 174. Fig. 24 depicts a scanning system wherein a frame 182 is suspended by
cables 184 from a helicopter 186. Transducers 188 are mounted to frame 182.

As shown in Fig. 25, an alternative technique for detecting underground objects utilizes a pad 190 to which a plurality of electromechanical transducers 192 are attached. A remote-controlled robot 194 such as a miniature all-terrain vehicle is attached to one end of the pad for dragging the pad along a ground surface. Where the detection of land mines is intended, it is contemplated that robot 194 and pad 190 are sufficiently lightweight to avoid mine detonation when the robot and the pad move over land mines. Pad 190 may be stored in a coiled configuration inside a container. Robot 194 may be used to remove pad 190 from such a container, for example, by pulling and unrolling the pad at the onset of a scanning operation.

It is to be noted that transducers 192 have a density or spacing which facilitates detection of objects of an intended group. Thus, to detect land mines, which are typically located within two feet of the surface, the transducers have a density greater than that necessary to detect buried archeological ruins. Transducers 192 are energizable with alternating electrical waveforms of different frequencies, for purposes of facilitating soil penetration and surface detection.

Fig. 26 shows a flexible pad 196 which is stored in a wound-up configuration (not shown) inside a container 198. Pad 196 carries a plurality of electromechanical transducers 200 (such as speakers and microphone sensors) in a predetermined array. In order to place pad 196 over a ground surface harboring suspected land mines, a rod 202 may be used to grasp or hook a leading edge 204 of pad 196 and pull the pad out of storage container 198. Rod 202 is further used to position pad 196 over a selected ground surface area.

Thus, it is clear that a flexible transducer-carrying pad as discussed hereinabove with
reference to Figs. 10, 25 and 26 may be pushed or pulled over a ground surface. Markers (not shown) may be left on the ground surface to indicate the locations of detected land mines.

Where an air-borne vehicle such as balloon 162, plane 174 or helicopter 186 is used, markers may be dropped from the vehicle. Alternatively, input from the surface scanning may be used to identify pre-existing surface markers or reference points. The locations of detected mines relative to the selected pre-existing reference points are calculated by the wave-analyzing computer and stored for future use in destroying detected land mines.

As illustrated in Fig. 27, a carrier 206 for electromechanical transducers 208 may comprise a rigid panel 210 attached to an upper side or forming an upper wall of a flexible bag 212. Bag 212 may be filled with a fluid medium such as gel or water for purposes of enhancing pressure wave transmission to and from an uneven ground surface. Carrier 206 is placed in position by a crane 214.

Various safety feature may be incorporated into a land mine detection system as described hereinabove, particularly where the carrier vehicle is manned. For example, with reference to Fig. 21, an automatic engine or transmission shut-off may be provided for immediately ceasing forward motion of vehicle 162 if a land mine is detected. This feature is especially advantageous where the vehicle moves continuously during a scanning operation, rather than intermittently.

As illustrated in Fig. 28, a system for surveying an underwater topography comprises an ultrasonic sensor array 312 disposable in physical contact with a body of water BW. The sensor array generates electrical signals encoding ultrasonic echo responses of underwater objects UO in the body of water BW. Sensor array 312 includes a plurality of electromechanical transducers 314 exemplarily realized essentially by piezoelectric wafers.
Sensor array 312 further includes a carrier 316 such as a net. Carrier net 316 is towed through water body BW by a boat BT via a tow line 318. A multiple lead cable or wireless telecommunications link 320 extends along tow line 318 and operatively connects transducers 14 to a processing system 322. Processing system 322 analyzes incoming electrical ultrasonic signals arriving from transducers 314 and generates a video signal encoding an image of an underwater topography including one or more of the underwater objects UO. The video signal is fed to a monitor 346 for display of the image thereon.

Sensor array 312 and more particularly selected transducers 314 produce mechanical pressure waves 324 of one or more ultrasonic frequencies. These outgoing pressure waves 324 are reflected from the underwater objects UO, as indicated at 326, and received by transducers 314. The incoming pressure waves are converted by selected transducers of sensor array 312 into electrical signals transmitted over cable or wireless telecommunications link 320 to processing system 322.

In order to optimize data production, transducers are disposed in a configuration extending in at least two dimensions. This configuration is determined in part by the attachment of transducers 314 to carrier net 316.

As illustrated in Fig. 29, transducers 314 include a plurality of pressure-wave-generating electroacoustic transducers 328 and a plurality of pressure-wave-receiving acoustoelectric transducers or sensors 330. Transducers or wave generators 328 are arranged in a predetermined two- or three-dimensional configuration such as a V. Transducers or sensors 330 also have a two- or three-dimensional configuration.

An a-c current or waveform generator 332 is operatively connected to electroacoustic transducers 328 for energizing the electroacoustic transducers 328 with an electrical signal of
a pre-established ultrasonic frequency. Electroacoustic transducers or wave generators 328 are energized one at a time, in a predetermined sequence, by the same ultrasonic frequency or by different ultrasonic frequencies.

Acoustoelectric transducers or sensors 330 are operatively connected via cable or wireless telecommunications link 320 and an analog-to-digital converter 336 to a digital processor 334. Processor 334 may be implemented by a general purpose computer specially programmed to realize the functional modules shown in Fig. 28. Processor 334 includes, as one such module, a preliminary signal processing circuit 338 which analyzes incoming pressure waves 326 in accordance with the location of the particular electroacoustic transducer 328 which generated the outgoing pressure wave 324 reflected by the underwater objects UO to produce the incoming pressure waves 326.

As illustrated in Fig. 30, preliminary signal processing circuit 338 includes a circuit 340 for determining the positions of transducers 14 relative to one another. Circuit 340 receives, via a lead or multiple 341 extending from analog-to-digital converter 336, electrical signals derived from the incoming pressure waves 326. Circuit 340 separates out those signals corresponding to direct or unreflected ultrasonic pressure wave transmission paths to determine the relative locations of transducers 314. The encoded locations of transducers 314 are communicated by circuit 340 to a surfaces detection circuit 342. Circuit 342 analyzes incoming electrical signals from sensor array 312 to determine and analytically define the surfaces of underwater objects UO which generate reflected pressure waves 326 in response to ultrasonic pressure waves 324 (Fig. 28). Circuit 342 determines the three-dimensional shapes of the underwater objects UO. A time base 343 enables operation of circuits 340 and 342.

As shown in Fig. 29, preliminary signal processing circuit 338 is operatively
connected to a video signal generator 344. Partially in response to surface data from circuit 338, generator 344 produces a video signal encoding an image of an underwater topography including selected underwater objects UO. Generator 344 is connected to video monitor 46 for displaying the underwater image.

Preliminary signal processing circuit 338 is operatively connected to waveform generator 332 via an outgoing signal control unit 348. Control unit 348 produces a control signal which determines, for example, the frequency of an outgoing ultrasonic pressure wave 24 and the identity of the electroacoustic transducer 328 generating that pressure wave. Waveform generator 332 comprises a variable-frequency ultrasonic signal source 350 and a multiplexer 352, as illustrated in Fig. 31. Source 350 and multiplexer 352 receive control signals via respective leads 354 and 356 from control unit 348. Multiplexer 352 operates to connect signal source 350 sequentially to different electroacoustic transducers 328. Typically, the energization sequence of transducers 328 is pre-established and determined in part by the specific configurations of transducers 328 and transducers 330 on carrier 316. In many cases, in order to facilitate the separation of incoming reflected signals 326 originating at different electroacoustic transducers 328, these transducers are sensitive or responsive to signals of detectably different ultrasonic frequencies. The sequence of transducer activation and the frequency or frequencies of actuation are communicated by control unit 348 to surfaces detection circuit 342. Detection circuit 342 utilizes that information to properly analyze the arriving ultrasonic signals. In the event that the incoming data is insufficient for detection circuit 342 to isolate, calculate and define surfaces of underwater objects UO, the detection circuit may transmit a signal to control unit 348 to change the energization sequence of transducers 328 and/or the energization frequencies.
As illustrated in Fig. 32, analog-to-digital converter 336 includes a multiplexer 358 and digitization elements 360. Multiplexer 358 receives a switching control signal via a lead 362 extending from control unit 348. Control unit 348 enables the decoding of incoming ultrasonic pressure waves in a pre-established sequence. This sequence is determined in part by the configurations of transducers 328 and 330 and by the frequencies of energization. In addition, surfaces detection circuit 342 (Fig. 30) may cause control unit 348 to vary the signal reception sequence for purposes of enhancing resolution and surface detection.

Fig. 33 shows a specific configuration of an underwater-topography imaging system including just one electroacoustic transducer 364 and a multiplicity of acoustoelectric transducers 366. Here the enhancement of image resolution and optimization of surface detection and definition are accomplished mainly by varying the ultrasonic output frequency of the one electroacoustic transducer and the sequence of signal transmission from sensors or acoustoelectric transducers 330.

Fig. 34 depicts a particular configuration of another underwater-topography imaging system including just multiple electroacoustic transducers 368 and a single acoustoelectric transducer 369. In this case, the enhancement of image resolution and optimization of surface detection and definition are accomplished by varying the ultrasonic output frequencies and the energization sequence of the electroacoustic transducers.

As shown in Fig. 35, an ultrasonic pressure wave generating and/or sensing unit 370 attachable, for instance, to a junction of different strands of carrier net 316 comprises a body or casing 372 and a plurality of tubular directional elements 374 projecting in different directions from body 372. Each element 374 is associated with a respective piezoelectric wafer or chip (not illustrated). Thus, a single location on carrier net 316 may support a
plurality of electroacoustic transducers 328 and/or acoustoelectric transducers 330. However, there must be a plurality of locations on carrier net 316 which carry one or more ultrasonic pressure wave transducers 314.

As depicted in Fig. 36, a carrier net 376 for an ultrasonic sensor array 378 may be provided with a plurality of self-contained motive or propeller units 380. Units 380 are connected to net 376 via tension lines 382 and have steering vanes 384, as well as propellers 386. Steering vanes 384 and propellers 386 may be controlled from a remote location, for example, a ship (not shown) either via a signal transmission cable (not shown) or via wireless signal transmitters and receivers (not shown).

Propeller units 380 are attached to carrier net 376 for applying a force thereto relative to a body of water in which or one which carrier net 376 is disposed. It is contemplated that an underwater disposition of carrier net 376, for example, below any surface wave action, would be optimal for reducing stress on the carrier and for facilitating the maintenance of the sensor array 378 in a given configuration. The orientations of propeller units 380 relative to carrier net 376 will change, as indicated in phantom lines at 388, to lift carrier net 376 towards the surface of a body of water after completion of a maritime scanning operation. It is to be noted that propeller units 380 can be differentially operated to translate carrier net 376 and the entrained sensor array 378 in different directions, including up and down and parallel to an underlying underwater geologic surface. The orientation of carrier net 376 in a body of water may be changed to facilitate scanning and object detection operations.

Fig. 37 depicts a carrier 390 of rigid frame construction. Fastened to carrier 390 are a plurality of ultrasonic pressure wave generating and/or sensing units 392. Carrier 390 may be dragged along a water surface or beneath the surface by a dedicated propeller unit 394.
Auxiliary propeller units 396 may be tethered to carrier 390 for assisting the main propeller unit 94 in orienting the carrier and in raising and lowering the carrier through a body of water. As discussed above, ultrasonic pressure wave generating and/or sensing units 392 are operatively connected to a processing system 322 (Fig. 28) via a cable or wireless transceiver components. In the embodiment of Fig. 37, the determination of transducer position may be implemented simply and automatically by virtue of fixation of the locations of the electromechanical transducers 392 relative to one another.

Fig. 38 illustrates another transducer carrier 406 of substantially rigid construction. Carrier 406 includes a substantially cylindrical body 408 with a pair of stabilizers 410 and 412. Stabilizers 410 and 412 may be shiftable relative to body 408, by respective motors (not illustrated), for facilitating the steering of carrier 106 through a body of water WB. Carrier 406 is dragged through the water by a tension line 414 connected to a back end of a surface vessel 416.

An array of electromechanical (electroacoustic and acoustoelectric) transducers 418 are mounted to carrier body 416 and optionally stabilizers 410 and 412 for picking up reflected pressure waves of ultrasonic frequencies from underwater surfaces. A signal transmission line (not separately illustrated) extending along tension line 414 or a wireless transmission link may be provided for carrying signals between transducers 418 and vessel 416. If carrier 406 is provided with motors for shifting stabilizers 410 and 412, control signals for those motors may also be carried by this transmission line.

Carrier body 408 may be enclosed and define one or more internal chambers. For example, carrier body 408 may itself be a personnel-carrying submarine. In that event, a propeller 420 is located at the rear end of the carrier body 408.
As illustrated in Fig. 29, processor 334 includes a view selector module 398 which is operatively connected to video monitor 346 for selecting a displayed image from among a multiplicity of possible images of underwater objects UO. More specifically, view selector module 398 operates in response to instructions from a keyboard 400 or a mouse 402 to select a view angle and a magnification for the displayed image. Accordingly, a user may induce a change in the displayed image from one view angle to another or from one magnification to another.

As further illustrated in Fig. 29, processor 334 includes a filter stage or object removal module 404 operatively connected to video monitor 346 for eliminating a selected object or portion of an object from the displayed image. Modules 398 and 404 are incorporated into processor 334 and are realized by generic computer circuits whose functions are determined by programming.

In surveying an underwater topography utilizing an imaging system as described herein above, for instance, with reference to Fig. 28, the sensor array is disposed in operative contact with body of water BW, determining physical locations of the transducers relative to each other, and energizing the transducers to generate a series of electrical signals encoding echo responses of underwater objects in the body of water, the echo responses corresponding to a multiplicity of pressure wave paths from the transducers to each of the objects and back to the transducers. The electrical signals are automatically analyzed to generate a video signal encoding an image of the objects, the video signal being fed to a video monitor to thereby display the objects on the monitor.

Fig. 39 illustrates all of the elements shown in Fig. 29 and shows additional components of processing system 322 and digital processor 334. In particular, a pattern
recognition circuit or module 422 is operatively connected to preliminary signal processing circuit 338 for purposes automatically analyzing the surface data from circuit 338 to identify types of objects located underwater. Pattern recognition circuit 422 consults a memory 424 which is loaded with data describing the shapes of objects of various classes. The contents of memory 424 may vary, depending on the purposes of underwater searching. For example, where the imaging system is used for antiquities hunting, memory 424 contains encoded templates for ancient ships, columns, urns, statuary, and other objects known to be frequently transported via sea going vessels. Where the imaging system is used for applications in marine biology, memory 424 contains three-dimensional surface data describing the shapes of different underwater life forms, which may include fish, mammals, crustaceans, jellyfish, squid, etc. In any case, where images of underwater target objects are to be shown on video monitor 346, object removal module 404 filters out those objects which are not selected as being of interest. Object removal module 404 may also consult memory 424, either directly or indirectly via pattern recognition circuit 422, to determine which objects are to be displayed and which objects are to be deleted from representation on video monitor 346. Of course, input devices such as keyboard 400 may be operatively connected to pattern recognition circuit 422 for purposes of enabling user selection of object classes of interest during any particular ultrasonic underwater search.

Processor 334 further includes a module 426 for determining a location relative to global coordinates (latitude, longitude, and sea or ocean depth). This module receives input from conventional electronic navigation equipment (not illustrated). Coordinates module 426 and pattern recognition circuit 422 are connected to a storage or recording device 428 such as a printer and/or to memory 424 for purposes of recording the identity and location of any
objects detected by pattern recognition circuit 422. Thus, a sensor carrier 316, 376, 390, 406 may move along a search path while continually monitoring underwater objects and maintaining a log of detected objects. Subsequently, a manned or robotic vessel may be dispatched to more closely inspect any located objects of interest.

In an alternative search mode, pattern recognition circuit 422 is connected to motors 430 which propel the sensor carrier 316, 376, 390, 406. Upon detecting an object of possible interest, pattern recognition circuit 422 de-energizes motors 430, thereby maintaining the sensor carrier in proximity to the objects while a closer or more complete investigation is undertaken.

It is to be noted that an ultrasonic transducer carrier 316, 376, 390, 406 as described herein may be provided with various devices for protecting the sensor array from marine creatures such as dolphins or sharks. Such protective devices could include chemical dispensers for releasing repellants into the water. The ultrasonic pressure waves may in themselves have a repellent effect, as with land animals such as rodents.

Sensor carriers 316, 376, 390, 406 may take various forms and shapes and may be provided with various ancillary devices such as video cameras, manipulating arms, storage compartments for objects retrieved by such arms. Where the carrier is provided with dedicated motors, processor 334 may be provided with programs for filtering out ultrasonic vibrations arising from the operation of the motors.

An underwater imaging system as described hereinabove may be supplemented by an acoustic lens (not illustrated) disposed between the sensor array and the underwater surfaces under inspection. A focusing acoustic lens may be formed by a lenticular volume with a velocity of sound slower than that of a surrounding medium, in analogy with optical lens. In
the case of sea water or marine environments, a medium with a lower velocity of sound, but not one discrepant enough to cause a serious impedance mismatch and resultant signal loss, is conveniently provided by fresh water. The fresh water may be held in shape by a polymeric sack or plastic bag. The bag is filled under sufficient pressure to minimize rippling and sloshing at the bag - sea water interface, which would cause image distortion. Ripples significantly below an acoustic wavelength in size are acceptable. The material of the bag itself is chose to be tough and strong, yet thin enough so that its acoustic impedance is irrelevant. The bag may be advantageously strengthened by tensile fibers, and also provided with rigid ribs to assist in holding a lenticular shape. The lenticular shape may be the underwater optical equivalent of a Fresnel lens.

In operation the bag of the acoustic lens is attached to a rigid frame, which holds an acoustic sensor array at a fixed stand-off distance and orientation with respect to the sensor array. Of course, imaging software is modified to take the lens into account. In some cases where an acoustic lens is used, the sensor array functions like the photo-electric sensor array of a digital camera, or the human retina, receiving an ordinary image. The region between the sensor array and the bag is advantageously baffled from stray sound, analogous to light exclusion means in a camera, and the assemblage may be provided with acoustic “spotlight.” The spotlight may be a broadband or narrow band acoustic source, advantageously adjustable in frequency output to maximize resolution in a given situation. Given broadband acoustic illumination, reflectance at different frequencies may be encoded in color at an output display, utilizing another channel of perceptual information. By varying the frequency profile of the “spotlight,” and the range of frequencies color encoded in a display, a skilled operator may investigate an underwater scene in a variety of frequency bands efficiently and intuitively,
finding the band offering greatest penetration and resolution in a given context. The
experienced operator may also become acquainted with the "color" and appearance of various
acoustic objects he may search for on a regular basis, e.g. a particular kind of archeological
artifact or an underwater pipeline, and thereby increase search efficiency.

As a further elaboration of this embodiment, a pair of such sensor systems may be
provided, advantageously mounted in fixed geometric relation on a tethered and controllable
submersible, or possibly a manned underwater vehicle. Perceptual skills of the experienced
operator will now include stereoscopic perception of depth (i.e., range) information, as well as
the ability to ‘take a look around’ a target area while building up a mental conception of it,
inspecting areas of special ambiguity and interest from different angles and with varying
illumination frequencies.

It is to be noted that in general, in an underground or underwater imaging system as
described herein, two sensor arrays spaced from one another along a baseline may provide
separate image data streams for forming two images of the same objects from different angles.

These two angularly differentiated images may be provided to respective eyes of a human
operator by conventional stereoscopic techniques so as to provide the operator with
stereoscopic vision. For instance, a human operator may be given access to stereoscopic
image fields transmitted from the two sensor arrays and viewed through stereoscopic goggles.
Coupled with the ability to steer and reposition a tethered submersible, for example, this gives
an operator the ability to ‘see’ underwater acoustically, and to use the native binocular image
processing ability of the human brain to build up a model of a three-dimensional structure.

It is to be additionally noted that the two sensor arrays in a stereoscopic imaging
system may be composed of different collections of sensors disposed on the same rigid frame.
In that case, there may be some overlap not only in the areas occupied by the two sensor arrays on the frame but also overlap in the specific sensors so that some sensors are used in each array. It is only necessary that the two collections of sensors include some different sensors to provide a baseline to establish different angular views.

Another technique for enhancing data collection and image formation is the use of phased sensor arrays. In accordance with known phased array techniques, the phases of outgoing acoustic pressure waves, as well as the locations of the transducers producing those waves, may be varied to effectively simulate a change in physical orientation of a sensor array, including an array defined as a subset of all sensors on a rigid frame. In accordance with known phased array techniques, phase is also be taken into account in the analysis of incoming acoustic or ultrasonic pressure waves from selected acoustoelectric transducers.

Calibration of the sensor arrays of underwater or underground imaging systems is effectuated in a manner known in the art by disposing a reference object of known shape and dimensions at a predetermined location and in a specified orientation with respect to the transducer assembly. The imaging system is then operated and adjustments made in processing parameters until the shape, position and orientation of the reference object as calculated in response to the reflected waves matches the known shape, position and orientation.

Where a transducer assembly comprises a plurality of rigid frames or carriers each holding a plurality of transducers, the relative locations and orientations of the different frames or carriers may be determined by an ancillary detection system utilizing energy different from acoustic or ultrasonic pressure waves. Where at least a portion of each frame or carrier is disposed in a light-transmitting medium, whether the atmosphere or an upper layer
of a body of water, optical radiation may be used to monitor the positions and orientations of the frames or carriers relative to each other. Each pair of adjacent transducer-carrying frames is provided with a plurality of interferometers or metrology devices which automatically count interference fringes to determine the instantaneous distance between two points each located on a respective one of the adjacent frames. More specifically, one frame is provided at a first point with a laser emitting diode disposed on a substrate with an interference grating and a solid-state optical sensor, while the adjacent frame is provided at a second, counterpart, point with an anisotropically etched silicon mirror. The optical sensor or receiver is connected to a finge counter which determines the distance between the first point on the one frame and the second point on the adjacent frame. Several such metrology systems provided on the two adjacent transducer-carrying frames enable an automatic determination of the six degrees of freedom (three translational coordinates and three rotational coordinates) of the one frame relative to the other.

Of course, a separate distance measuring system which uses acoustic or ultrasonic pressure waves may measure the relative positions and orientations of multiple transducer-carrying frames. Several such acoustic-type interferometric or metrology systems may be provided for each pair of adjacent frames.

Pattern matching may be used to effectively determine relative positions and orientations of a multiplicity of sensors in an array in cases where the sensors are disposed in contact with a curvilinear surface, rather than held in fixed relative positions by a rigid common carrier or frame. In this case, sensors are disposed in sub-arrays on independently movable rigid plates or tiles. Through digital signal processing techniques, the total sensor array may be alternatively operated in two modes. In a first mode, pressure wave generators
or sensors mounted on a single plate are electronically configured to image structures in a
narrow volume normal to each respective plate, the geometry of transducers on a plate being
fixed. Common features in overlapping images formed by this method are matched to
determine displacement and rotation of neighboring plates (calibration). In a second operating
mode, the full array of sensors is utilized cooperatively to construct a single global image of
greater geometric fidelity and resolution. These modes may be executed once sequentially or
else iteratively and alternatively, refining and tracking an operating solution. An “operating
solution” means a simultaneous determination of acoustically detected spatial structures, in
particular of surfaces where partial reflection is occurring, and of the positions and
orientations of sensors with respect to each other and detected structures. “Tracking” a
solution means continually updating a best estimate thereof. A first mode of operation may
only be required for bootstrapping, i.e., where an approximate prior solution is unavailable.

Further, for the purposes of this disclosure, “opaque” or “optically impenetrable” shall
mean “scattering or absorbing light to a degree which renders practical optical image
formation impossible over a range of interest”, whether of not completely optically opaque.

Although the invention has been described in terms of particular embodiments and
applications, one of ordinary skill in the art, in light of this teaching, can generate additional
embodiments and modifications without departing from the spirit of or exceeding the scope of
the claimed invention. Thus, the drawings and descriptions herein are examples to facilitate
comprehension of the invention and should not be construed to limit the scope thereof.
CLAIMS:

1. A method for use in detecting hidden objects, comprising:
   providing a plurality of electromechanical transducers including at least one
electroacoustic pressure wave generator and at least one acoustoelectric sensor;
determining locations of said transducers relative to one another;
energizing said pressure wave generator to produce an outgoing pressure wave;
transmitting said outgoing pressure wave through an effectively opaque or optically
impenetrable medium;
sensing incoming pressure waves reflected by hidden surfaces generally in or below
said medium in response to said outgoing pressure wave; and
analyzing said incoming pressure waves to determine three-dimensional shapes of said
hidden surfaces.

2. The method defined in claim 1 wherein the providing of said plurality of
   electromechanical transducers includes disposing said transducers above a selected surface in
pressure-wave transmitting contact with said medium, the transmitting of said outgoing
pressure wave through said medium includes transmitting said outgoing pressure wave
through said selected surface, the analyzing of said incoming pressure waves includes
determining three-dimensional shapes of hidden objects disposed below said selected surface.

3. The method defined in claim 2 wherein said electromechanical transducers are all
   attached to a common carrier, the disposing of said electromechanical transducers above said
selected surface includes moving said carrier into position above said selected surface.
4. The method defined in claim 3 wherein said carrier is flexible, the disposing of said electromechanical transducers above said selected surface including placing said carrier in contact with said selected surface.

5. The method defined in claim 4 wherein the locations of said transducers are determined after the placing of said carrier in contact with said selected surface, determining the locations of said transducers relative to one another includes analyzing pressure waves transmitted directly from said pressure wave generator to said sensor.

6. The method defined in claim 3 wherein said carrier is substantially rigid, the disposing of said electromechanical transducers above said selected surface including holding said carrier above and spaced from said selected surface.

7. The method defined in claim 6 wherein said selected surface is a ground surface and said carrier is mounted to a land vehicle, the disposing of said electromechanical transducers above said selected surface including moving said land vehicle over a ground surface.

8. The method defined in claim 6 wherein said carrier is mounted to an air-borne vehicle, the disposing of said electromechanical transducers above said selected surface including moving said air-borne vehicle over a ground surface.

9. The method defined in claim 3 wherein said carrier and said electromechanical transducers are air-borne, the disposing of said electromechanical transducers above said
selected surface including suspending said carrier and said electromechanical transducers over said selected surface.

10. The method defined in claim 2 wherein said selected surface is a ground surface and wherein said outgoing pressure wave and said incoming pressure waves are ultrasonic, further comprising wetting a ground structure contiguous with said selected surface to facilitate transmission of said outgoing pressure wave and said incoming pressure waves through said ground structure.

11. The method defined in claim 2 wherein said hidden objects include land mines, further comprising detonating said land mines after identification of said hidden objects as land mines.

12. The method defined in claim 2 wherein the analyzing of said incoming pressure waves includes determining shapes of said hidden objects and comparing said shapes with a reference library of possible objects.

13. The method defined in claim 1 wherein said outgoing pressure wave has a plurality of different frequencies.

14. The method defined in claim 13, further comprising generating said different frequencies at different times.
15. The method defined in claim 1, further comprising generating a video signal encoding an image of one of said hidden surfaces and transmitting said video signal to a video monitor, also comprising selecting said image from among a multiplicity of possible images of said hidden surfaces, additionally comprising subsequently selecting a different image from among said possible images and displaying said different image on said monitor.

16. The method defined in claim 1 wherein the providing of said electromechanical transducers includes operating a remote control robot to shift said transducers into a predetermined position in pressure-wave transmitting communication with said medium.

17. A system for detecting objects hidden underground, comprising:

a carrier movable over a land surface;

a plurality of electromechanical transducers mounted to said carrier, said electromechanical transducers including at least one electroacoustic pressure wave generator and at least one acoustoelectric sensor;

means operatively connected to said electromechanical transducers for determining locations of said transducers relative to one another;

a source of alternating electrical current operatively connected to said pressure wave generator for energizing said generator to produce an outgoing pressure wave transmittable to an effective extent through upper layers of a ground formation;

a wave analyzer operatively connected to said sensor for analyzing incoming pressure waves reflected by an underground surfaces in response to said outgoing pressure wave, to determine three-dimensional shapes of underground objects; and
a propulsion mechanism operatively connected to said carrier for moving said carrier over said land surface.

18. The system defined in claim 17 wherein said carrier is a flexible web.

19. The system defined in claim 18 wherein said web is a part of a container holding a fluid medium.

20. The system defined in claim 19 wherein said container includes a substantially rigid panel and flexible panels connected to said rigid panel.

21. The system defined in claim 17, further comprising a video signal generator operatively connected to said wave analyzer for producing a video signal encoding an image of an underground object, said video signal generator being operatively connected to a video monitor for displaying said image.

22. The system defined in claim 17 wherein carrier is mounted to a land vehicle incorporating said propulsion mechanism.

23. The system defined in claim 17 wherein carrier is mounted to an air-borne vehicle incorporating said propulsion mechanism.

24. The system defined in claim 17 wherein said carrier and said electromechanical
transducers are air-borne, the disposing of said electromechanical transducers above said
ground structure including suspending said carrier and said electromechanical transducers
over said ground surface.

25. The system defined in claim 17 wherein said source includes means for producing
a plurality of different frequencies.

26. The system defined in claim 17, further comprising means operatively connected
to said propulsion mechanism for remotely controlling said propulsion mechanism.

27. A system for underground surveying, comprising:

a plurality of substantially rigid frames;

a plurality of acoustoelectric sensors for generating electrical signals encoding echo
responses of underground surfaces, each of said frames carrying at least one of said sensors,
said sensors being disposable in effective physical contact with underground structures upon
an insertion of said frames through a ground surface;

an acoustic energy generator disposable in effective physical contact with said
underground structures;

position determination componentry operatively connected to said sensors for
determining locations of said sensors relative to one another;

an electronic signal processor operatively connected to said sensors for analyzing said
electrical signals in accordance with the determined locations of said sensors to determine
surfaces of an object hidden underground and for generating a video signal encoding an image
of said object; and

a video monitor operatively connected to said processor for displaying the image of said object.

28. The system set forth in claim 27 wherein said acoustic energy generator is an electroacoustic transducer, further comprising an a-c current generator operatively connected to said electroacoustic transducer for energizing said electroacoustic transducer with an electrical signal of a pre-established ultrasonic frequency.

29. The system defined in claim 28 wherein said electroacoustic transducer is one of a plurality of electroacoustic transducers mounted to said frames, further comprising means operatively connected to said electroacoustic transducers for energizing said electroacoustic transducers in a predetermined sequence.

30. The system set forth in claim 27 wherein said processor includes an analyzer operatively connected to said sensors for determining a three-dimensional shape of said object by analyzing signals generated by said sensors in response to pressure waves produced at said object in response to pressure waves produced by said acoustic energy generator.

31. The system defined in claim 27 wherein said processor includes a view selector operatively connected to said video monitor for selecting said image from among a multiplicity of possible images of said object.
32. The system defined in claim 27, further comprising a filter stage operatively connected to said processor and said video monitor for eliminating a selected surface from said image.

33. The system defined in claim 27 wherein said sensors include a plurality of acoustoelectric transducers mounted to said frames, further comprising means operatively connected to said transducers for receiving signals from said acoustoelectric transducers in a predetermined sequence.

34. The system set forth in claim 27 wherein said position determination component includes an additional processor for analyzing additional electrical signals generated by said sensors in response to pressure waves transmitted underground directly from said acoustic energy generator to said sensors.

35. A method for underground surveying, comprising:

   disposing an array of acoustoelectric sensors in operative contact with a ground formation capable of transmitting pressure waves;

   after the disposing of said array of acoustoelectric sensors in operative contact with said ground formation, determining physical locations of said acoustoelectric sensors relative to each other;

   after the disposing of said array of acoustoelectric sensors in operative contact with said ground formation, generating a pressure wave in said ground formation;

   after the generating of said pressure wave, energizing said acoustoelectric sensors to
generate a series of electrical signals encoding echo responses of underground surfaces to said pressure wave;

automatically analyzing said electrical signals to generate a video signal encoding an image of said surfaces; and

feeding said video signal to a video monitor to thereby display said surfaces on said monitor.

36. The method defined in claim 35 wherein said acoustoelectric sensors are mounted to a plurality of substantially rigid frame members, the disposing of said array of said acoustoelectric sensors including inserting said frames through a ground surface and into said formation.

37. The method defined in claim 36 wherein said frame members each have an elongate dimension, the disposing of said array of acoustoelectric sensors including disposing said frame members so that the respective elongate dimensions extend approximately parallel to a gravity vector.

38. The method defined in claim 36 wherein said frame members each have an elongate dimension, the disposing of said array of acoustoelectric sensors including disposing said frame members so that the respective elongate dimensions extend at an acute angle relative to a gravity vector.

39. The method defined in claim 35 wherein said acoustoelectric sensors are mounted
to a fluid filled container, the disposing of said array of said acoustoelectric sensors including disposing said container on said formation.

40. The method defined in claim 39 wherein said container has a wedge shape with a first wall and a second wall disposed at an angle relative to one another, said acoustoelectric sensors being fixed to said second wall, the disposing of said array of acoustoelectric sensors including disposing said first wall in contact with said formation and said second wall at said angle with respect to said first wall.

41. The method defined in claim 40 wherein the disposing of said container on said formation includes disposing said container in an arcuate configuration along an upper surface of said formation.

42. The method defined in claim 35, further comprising introducing a liquid into said formation.

43. The method defined in claim 35 wherein the disposing of said acoustoelectric sensors in operative contact with said formation includes deploying a carrier on said formation, said acoustoelectric sensors all being attached to said carrier.

44. The method defined in claim 35 wherein the energizing of said acoustoelectric sensors including receiving signals from said acoustoelectric sensors in a predetermined sequence.
45. The method set forth in claim 44 wherein determining the physical locations of said acoustoelectric sensors includes analyzing additional electrical signals generated by said acoustoelectric sensors in response to pressure waves transmitted through said formation directly from a pressure wave generator to said acoustoelectric sensors.

46. The method set forth in claim 35 wherein the analyzing of said electrical signals includes analyzing said electrical signals to determine a three-dimensional shape of an object defined by at least one of said surfaces.

47. The method defined in claim 46, further comprising selecting said image from among a multiplicity of possible images of said surfaces, further comprising subsequently selecting a different image from among said possible images and displaying said different image on said monitor.

48. The method defined in claim 46, further comprising eliminating at least a portion of a selected object from said image to thereby show on said monitor an image of an object behind the eliminated portion of said selected object.

49. The method defined in claim 35 wherein the generating of said pressure wave is accomplished by energizing an electroacoustic transducer which is one of a plurality of electroacoustic transducers disposed in a predetermined configuration, further comprising energizing said transducers in a predetermined sequence.
50. A system for surveying an underwater topography, comprising:

ultrasonic sensor means disposable in physical contact with a body of water for

generating electrical signals encoding ultrasonic echo responses of underwater objects in said

body of water, said sensor means including a plurality of electromechanical transducers in
turn including at least one electroacoustic transducer and one acoustoelectric transducer, said
electromechanical transducers being disposed in an array which has at least two dimensions;

an a-c current generator operatively connected to said electroacoustic transducer for

energizing said electroacoustic transducer with an electrical signal of a pre-established

ultrasonic frequency;

position determination means operatively connected to said sensor means for
determining locations of said electromechanical transducers relative to one another;

processing means operatively connected to said sensor means for analyzing said
electrical signals in accordance with the determined locations of said electromechanical
transducers to determine surfaces of objects disposed at least partially in said body of water
and for generating a video signal encoding an image of said objects; and

a video monitor operatively connected to said processing means for displaying the
image of said objects.

51. The system set forth in claim 50 wherein said sensor means includes a carrier, said
electromechanical transducers being mounted to said carrier.

52. The system set forth in claim 51 wherein said carrier is a net.
53. The system set forth in claim 51 wherein said carrier is a rigid framework.

54. The system set forth in claim 51, further comprising motive means attached to said carrier for applying a force to said carrier relative to said body of water.

55. The system set forth in claim 50 wherein said processing means includes analyzing means operatively connected to said acoustoelectric transducer for determining three-dimensional shapes of said objects by analyzing signals generated by said acoustoelectric transducer in response to ultrasonic pressure waves produced at said objects in response to ultrasonic pressure waves produced by said electromechanical transducers.

56. The system defined in claim 50 wherein said processing means includes a view selector operatively connected to said video monitor for selecting said image from among a multiplicity of possible images of said objects.

57. The system defined in claim 50 wherein said processing means includes a filter stage operatively connected to said video monitor for eliminating a selected object from said image.

58. The system defined in claim 50 wherein said electromechanical transducers include a plurality of electroacoustic transducers disposed in a predetermined array, further comprising means for energizing said electroacoustic transducers in a predetermined sequence.
59. The system defined in claim 50 wherein said electromechanical transducers include a plurality of acoustoelectric transducers disposed in a predetermined array, further comprising means for receiving signals from said acoustoelectric transducers in a predetermined sequence.

60. The system set forth in claim 50 wherein said position determination means includes a substantially rigid carrier, said electromechanical transducers being mounted to said carrier so that the locations of said electromechanical transducers relative to one another are fixed by said carrier.

61. The system set forth in claim 50 wherein said position determination means includes additional processing means for analyzing additional electrical signals generated by said sensor means in response to pressure waves transmitted through said body of water directly from said electroacoustic transducer to said acoustoelectric transducer.

62. The system set forth in claim 50 wherein said electromechanical transducers include a single electroacoustic transducer and a plurality of acoustoelectric transducers, said sensor means including means for sampling output signals of said acoustoelectric transducers in a predetermined sequence.

63. The system set forth in claim 50 wherein said electromechanical transducers include a plurality of electroacoustic transducers and a single acoustoelectric transducer, said sensor means including means for activating said electroacoustic transducers in a
predetermined sequence.

64. A method for surveying an underwater topography, comprising:

disposing an array of electroacoustic transducers in operative contact with a body of water;

determining physical locations of said transducers relative to each other;

energizing said transducers to generate a series of electrical signals encoding echo responses of underwater objects in said body of water, said echo responses corresponding to a multiplicity of pressure wave paths from said transducers to each of said objects and back to said transducers;

automatically analyzing said electrical signals to generate a video signal encoding an image of said objects; and

feeding said video signal to a video monitor to thereby display said objects on said monitor.

65. The method defined in claim 64 wherein the disposing of said transducers in operative contact with said body of water includes deploying a carrier in said body of water, said transducers all being attached to said carrier.

66. The method set forth in claim 65, further comprising operating propulsion devices attached to said carrier, thereby moving said carrier relative to said body of water.

67. The method set forth in claim 66 wherein said carrier is a net, further comprising
operating said propulsion devices to pull in opposing directions on said net to maintain said net in an extended configuration.

68. The method set forth in claim 66 wherein the operating of said propulsion devices includes differentially operating said propulsion devices to change an orientation of said carrier relative to said body of water and relative to said objects.

69. The method defined in claim 64 wherein said electromechanical transducers include a plurality of acoustoelectric sensors, the energizing of said transducers including receiving signals from said sensors in a predetermined sequence.

70. The method set forth in claim 69 wherein determining the physical locations of said transducers includes analyzing additional electrical signals generated by said sensors in response to pressure waves transmitted through said body of water directly from selected ones of said transducers to said sensors.

71. The method set forth in claim 64 wherein the analyzing of said electrical signals includes analyzing said electrical signals to determine three-dimensional shapes of said objects.

72. The method defined in claim 64, further comprising selecting said image from among a multiplicity of possible images of said objects, further comprising subsequently selecting a different image from among said possible images and displaying said different
image on said monitor.

73. The method defined in claim 64, further comprising eliminating at least a portion of a selected object from said image to thereby show on said monitor an image of an object behind the eliminated portion of said selected object.

74. The method defined in claim 64 wherein said transducers include a plurality of pressure wave generators disposed in a predetermined configuration, the energizing of said transducers includes energizing a plurality of said pressure wave generators in a predetermined sequence.

75. The method set forth in claim 64 wherein said transducers include a single pressure wave transducer and a plurality of pressure wave sensors, the energizing of said transducers including sampling output signals of said sensors in a predetermined sequence.

76. A system for surveying an underwater topography, comprising:
- ultrasonic sensor means disposable in physical contact with a body of water for generating electrical signals encoding ultrasonic echo responses of underwater objects in said body of water, said sensor means including a plurality of electromechanical transducers in turn including at least one electroacoustic transducer and one acoustoelectric transducer, said electromechanical transducers being disposed in an array which has at least two dimensions;
- an a-c current generator operatively connected to said electroacoustic transducer for energizing said electroacoustic transducer with an electrical signal of a pre-established
ultrasonic frequency;

position determination means operatively connected to said sensor means for determining locations of said electromechanical transducers relative to one another; and processing means operatively connected to said sensor means for analyzing said electrical signals in accordance with the determined locations of said electromechanical transducers to determine surfaces of objects disposed at least partially in said body of water, said processing means including pattern recognition circuitry for comparing the determined object surfaces with a stored electronic library of stored surface data to identify the determined object surfaces as being consistent with a predetermined class of objects.

77. The system defined in claim 76, further comprising:

additional position determination means operatively connected to said processing means for determining locations of said determined object surfaces relative to a global frame of reference; and

a recording component operatively connected to said processing means and said additional position determination means for recording locations of said determined object surfaces relative to said global frame of reference.

78. The system defined in claim 77 wherein said recording component includes an electronic data store.

79. The system defined in claim 77 wherein said recording component includes a printer.
80. The system defined in claim 76 wherein said underwater sensor means includes a carrier, said transducers being mounted to said carrier, further comprising motor means operatively connected to said carrier for moving said carrier through said body of water.

81. The system defined in claim 80 wherein said pattern recognition circuitry is operatively connected to said motor means for arresting said motor means upon detecting that one of said determined object surfaces falls into a predetermined class of objects of interest.

82. The system defined in claim 80 wherein said motor means is mounted to said carrier so that said carrier is self-propelled.

83. The system defined in claim 80 wherein said motor means is mounted to a vessel, said vessel being tied to said carrier.

84. The system defined in claim 76 wherein said processing means is operatively connected to said sensor means via a wireless communications link.

85. The system defined in claim 76 wherein said processing means includes a video signal circuit generating a video signal encoding an image of said determined object surfaces, further comprising a video monitor operatively connected to said processing means for displaying the image of said determined object surfaces.

86. The system defined in claim 85 wherein said processing means includes a view
selector operatively connected to said video monitor for selecting said image from among a multiplicity of possible images of said objects.

87. The system defined in claim 85 wherein said processing means includes a filter stage operatively connected to said video monitor for eliminating a selected object from said image.

88. The system set forth in claim 76 wherein said processing means includes analyzing means operatively connected to said acoustoelectric transducer for determining three-dimensional shapes of said objects by analyzing signals generated by said acoustoelectric transducer in response to ultrasonic pressure waves produced at said objects in response to ultrasonic pressure waves produced by said electromechanical transducers.

89. The system defined in claim 76 wherein said electromechanical transducers include a plurality of electroacoustic transducers disposed in a predetermined array, further comprising means for energizing said electroacoustic transducers in a predetermined sequence.

90. The system defined in claim 76 wherein said electromechanical transducers include a plurality of acoustoelectric transducers disposed in a predetermined array, further comprising means for receiving signals from said acoustoelectric transducers in a predetermined sequence.
91. The system set forth in claim 76 wherein said position determination means includes a substantially rigid carrier, said electromechanical transducers being mounted to said carrier so that the locations of said electromechanical transducers relative to one another are fixed by said carrier.

92. A method for surveying an underwater topography, comprising:
   disposing an array of electroacoustic transducers in operative contact with a body of water;
   determining physical locations of said transducers relative to each other;
   energizing said transducers to generate a series of electrical signals encoding echo responses of underwater objects in said body of water, said echo responses corresponding to a multiplicity of pressure wave paths from said transducers to each of said objects and back to said transducers;
   automatically analyzing said electrical signals to determine surfaces of objects disposed at least partially in said body of water, said analyzing including comparing the determined object surfaces with a stored electronic library of stored surface data to identify the determined object surfaces as being consistent with a predetermined class of objects.

93. The method defined in claim 92, further comprising:
   determining locations of said determined object surfaces relative to a global frame of reference; and
   automatically recording locations of said determined object surfaces relative to said global frame of reference.
94. The method defined in claim 92 wherein said transducers are mounted to a carrier, further comprising operating a motor to move said carrier through said body of water.

95. The method defined in claim 94, further comprising automatically stopping said motor upon detecting that one of said determined object surfaces falls into a predetermined class of objects of interest.

96. The method defined in claim 92, further comprising generating a video signal encoding an image of said determined object surfaces, and displaying the image of said determined object surfaces.

97. The method defined in claim 96, further comprising automatically eliminating a selected object from said image.

98. The method defined in claim 92 wherein said electromechanical transducers include a plurality of acoustoelectric sensors, the energizing of said transducers including receiving signals from said sensors in a predetermined sequence.

99. The method defined in claim 92, further comprising selecting said image from among a multiplicity of possible images of said objects, further comprising subsequently selecting a different image from among said possible images and displaying said different image on said monitor.
100. A system for surveying an underwater topography, comprising:

a substantially rigid carrier body;

propeller means on said carrier body for propelling said carrier body through a body of water;

ultrasonic sensor means, attached to said carrier body so as to be disposable together with said carrier body in operative contact with a body of water, for generating electrical signals encoding ultrasonic echo responses of underwater objects in said body of water, said sensor means including a plurality of electromechanical transducers in turn including at least one electroacoustic transducer and one acoustoelectric transducer, said electromechanical transducers being disposed in an array on said carrier body which has at least two dimensions;

an a-c current generator operatively connected to said electroacoustic transducer for energizing said electroacoustic transducer with an electrical signal of a pre-established ultrasonic frequency;

processing means operatively connected to said sensor means for analyzing said electrical signals in accordance with the determined locations of said electromechanical transducers to determine surfaces of objects disposed at least partially in said body of water and for generating a video signal encoding an image of said objects; and

a video monitor operatively connected to said processing means for displaying the image of said objects.

101. The system defined in claim 100 wherein said carrier body is a manned submarine.