Relocation system and method

Technical field

The invention relates generally to detection systems and in particular to a device and a method for relocalization, notably underwater relocalization, using a sonar system.

Sonar systems are used in the field of underwater acoustics to detect and locate objects under water.

Sonar systems may be used by various surveillance infrastructures, for example for the detection of submarines or objects placed on the seabed, or also in the field of archaeology (for example subaquatic and underwater archaeology).

Sonar systems are provided with antennas to transmit and/or receive signals. The processing of the signals received by the sonar system makes it possible to detect the presence of objects or to form images of the seabed on which it is possible to detect objects.

For example, within the context of a surveillance system used to carry out a surveillance mission of an area by using a sonar, the sonar may implement a first phase (first detection) consisting in detecting one or more objects of interest (for example a threatening object) from the sonar images, which provides a set of detection data. These detection data generally take the form of geographically projected images and comprise the position of each object of interest. The position of the object of interest may be affected by a positioning error inherent in the sonar system and in its carrier.

In a second phase, the surveillance system must verify whether the detected object is indeed an object of interest (for example whether it indeed constitutes a threat) and where applicable implement suitable actions (for example neutralization of the threat) by using another robotic underwater system or divers who must then find the geographic position of the detected object.

However, robotic underwater systems (such as a Remotely Operated Vehicle (ROV)) or divers must be based on the sometimes imprecise position information to effectively find the detected object, in turbid waters and on cluttered bottoms. Indeed, in the case of a bottom cluttered with multiple objects around the detected object for example, it is sometimes difficult to find the position of the detected object in the uncertainty circle given by the sonar in the 1st detection phase.

This results in a fairly long search time for the detected object (which is critical in the case where the detected object is a threat) and a risk of error on the ocean floor due to the positioning error intrinsic to the sonar system having carried out the first detection and localization phase, or even a risk of error in the object found if the bottom is cluttered.

Different localization solutions are known in the terrestrial field as described for example in EP2932182. In particular, known detection solutions, applicable to terrestrial environments, use a GNSS system to position a detected object. However, a GNSS (Global Navigation

Satellite Systems) system cannot be used directly underwater (the frequencies used do not pass through water). When a sonar (towed sonar for example) or an underwater relocalization system (such as an underwater autonomous robot or Autonomous Underwater Vehicle (AUV)) establishes the position of an echo to be classified on the ocean floor, it uses its onboard attitude unit or inertial unit to locate this echo. These units are all the more precise as the data provided to them are precise. In the case for example of an AUV, the GNSS data collected at the surface have drifted during the entire descent phase and with the elapsed time, and in the case of the towed sonar, the GNSS position data are relayed to a lever arm established by positioning acoustics. In the case of sonars carried on the surface, which could benefit from the advantage of being coupled to the GNSS system directly, their positioning performance is degraded due to the distance to the bottom (for a side-scan sonar, a measurement error of the yaw or of the speed of sound in water entails a positioning error).

There is thus a need for an improved underwater detection system and method.

General definition of the invention

To this end, a surveillance system is proposed configured to monitor the presence of objects, in a surveillance area, in water, the surveillance system comprising a detection sonar and an identification device mobile in water. The detection sonar is able to detect the presence of a set of objects in the surveillance area, the set comprising at least one object of interest and one or more auxiliary objects. The detection sonar is able to determine prior detection information comprising, for each detected object of interest, at least the position of the object of interest, called starting position, and a reference image corresponding to a sonar image taken by the detection sonar comprising the objects detected by the detection sonar. The detection sonar is able to transmit the prior detection information to the identification device.

The identification device is configured to move toward at least one target object of interest among the objects of interest, in response to the reception of the prior detection information, the identification device comprising a relocalization sonar configured to detect objects in the surveillance area, the sector of the relocalization sonar being initially directed toward the starting position of the target object of interest, which provides secondary detection information relating to the objects detected by the relocalization sonar.

The identification device further comprises a relocalization unit configured to:

- determine a position error correction vector between the starting position of the target object of interest estimated by the detection sonar and the position of the target object of interest estimated by the relocalization sonar, from the prior detection information and the secondary detection information;
- apply the position error correction vector to correct at least the position of the target object of interest estimated by the relocalization sonar, the movement of the identification device toward the target object of interest being controlled by using the corrected position of the target object of interest.

In one embodiment, the relocalization unit may comprise an association module configured to determine pairs associating an object detected by the detection sonar and an object detected by the identification device, the position correction vector determination module being configured to determine a position error correction vector from the pairs.

According to certain aspects, the identification device may comprise an imaging unit configured to generate a consolidated representation comprising the reference image including the objects detected by the detection sonar, and superimposed on the reference image, the sonar sector of the relocalization sonar and the objects detected by the relocalization sonar.

In embodiments, the association module may be configured to determine the pairs by applying a translation to the sonar image of the relocalization sonar in the consolidated representation, as a function of a criterion a criterion based on the distances between the objects.

The position error correction vector determination module may be configured to determine the position error correction vector by browsing the different determined association pairs and by determining for each pair a candidate correction vector corresponding to the position translation from one element of the pair to the other, the position error correction vector determination module being configured to select the candidate correction vector which minimizes the quadratic sum or a minimization criterion of the distances between each element of each pair.

In one embodiment, the association module may use an association technique of the 'Iterative Closest Point' type.

As a variant, the position error correction vector determination module may be configured to apply an image processing technique to the consolidated representation and a cost function to determine the position error correction vector.

According to certain aspects, the identification device may comprise an absolute localization system having a maximum positioning error less than the range of the relocalization sonar.

In embodiments, the identification device may be a remotely controlled underwater robot.

A surveillance method is further proposed configured to monitor the presence of objects, in a surveillance area in water, implemented in a mobile identification device. The method advantageously comprises the steps consisting in:

- receiving prior detection information relating to objects detected by a detection sonar in the surveillance area comprising at least one object of interest and one or more auxiliary objects, the prior detection information comprising for each detected object of interest, at least the position of the object of interest, called starting position, and a reference image corresponding to a sonar image taken the detection sonar comprising the objects detected by the detection sonar;

- determining secondary detection information relating to objects detected by a relocalization sonar carried by the identification device during its movement toward a target object of interest among the objects of interest;

the method comprising one or more iterations of the following steps:

- determining a position error correction vector between the starting position of the target object of interest estimated by the detection sonar and the position of the target object of interest estimated by the relocalization sonar, from the prior detection information and the secondary detection information;
- correcting at least the position of the target object of interest estimated by the relocalization sonar, by applying the position error correction vector,
- controlling the movement of the identification device toward the target object of interest by using the corrected position of the target object of interest.

The embodiments of the invention thus allow improved relocalization of the objects detected in the first detection phase by minimizing the risk of error and by improving the relocalization time of the detected object.

Brief Description of the Figures

Other features, details and advantages of the invention will emerge upon reading the description made with reference to the appended drawings given by way of example and which represent, respectively:

[Fig.1] - Figure 1 represents a surveillance system according to embodiments.

[Fig.2] - Figure 2 illustrates an example of representation of the reference image extracted in the first detection phase.

[Fig.3] - Figure 3 represents the structure of the relocalization unit, according to embodiments.

[Fig.4] - Figure 4 represents the structure of the relocalization unit, according to other embodiments.

[Fig.5] - Figure 5 illustrates the navigation of the identification device toward an object of interest according to an exemplary embodiment.

[Fig.6] - Figure 6 illustrates a phase of the relocalization of the target objects of interest.

[Fig.7] - Figure 7 illustrates another phase of the relocalization of the target objects of interest.

[Fig.8] - Figure 8 illustrates yet another phase of the relocalization of the target objects of interest.

[Fig.9] - Figure 9 is a flowchart representing the object relocalization method implemented by the identification device, according to embodiments.

[Fig.10] - Figure 10 represents an example of progression of an identification device of the ROV type toward a target object of interest.

Detailed description of the application

Figure 1 schematically represents an example of an environment in which certain embodiments of the invention may be implemented.

The embodiments of the invention provide a surveillance system 100 (also called object relocalization system) configured to monitor the presence of objects, in a surveillance area, in water, such as for example in a maritime environment.

The surveillance system comprises a detection sonar 10 and an identification device 20 (also called ‘relocalization device’).

The detection sonar 10 may be part of a system for acquiring prior detection data (not represented).

The detection sonar 10 is configured to determine prior detection information relating to objects detected in the surveillance area, the detected objects comprising at least one object of interest. The prior detection information comprises at least, for each detected object of interest, the starting position of the object of interest estimated by the detection sonar 10 and a reference image corresponding to a geolocated sonar image taken by the detection sonar 10, representing a part of the surveillance area comprising the object of interest and the auxiliary objects detected in the vicinity of the object of interest.

The reference image may be a geolocated image representing the seabed when the surveillance area is a maritime area.

The detection sonar 10 is configured to transmit the prior detection information to the identification device 20.

The identification device 20 is a mobile device (such as a vehicle) able to move in water to approach at least one object of interest, called target object of interest, to identify it and/or implement an action. The identification device 20 comprises a relocalization sonar 200 configured to determine secondary relocalization information relating to objects detected by the relocalization sonar 200 in the surveillance area, during the movement of the identification device 20. The sonar sector of the relocalization sonar 200 is initially directed toward the starting position of the target object of interest provided by the prior detection information.

The identification device 20 may also comprise an absolute localization system 201 allowing it to be directed toward the area of the target object of interest with a maximum uncertainty less than the range of the relocalization sonar.

The absolute localization system 201 advantageously has a maximum positioning error less than the range of the relocalization sonar 200 which equips the identification device 20, which allows the identification device to approach a contact of interest by being directed with the localization system, so that the positioning error does not prevent the object of interest from being present in the sonar image taken by the detection sonar 200.

Advantageously, the identification device 20 is able to be directed toward a target object of interest by carrying out a relocalization of the target object of interest from the prior detection information, the secondary relocalization information detected by the relocalization sonar 200, and known relative position data between landmark objects, among the auxiliary objects

detected around the object of interest, these landmark objects forming a constellation around the target object of interest.

The landmark objects (also called “seamarks” or ‘landmark’ in English) are fixed landmark objects positioned on the seabed whose position is known (stored in a database of the device 20), with an uncertainty intrinsic to the detection system which was used to determine this position beforehand (this detection system being able to be a system distinct from the detection sonar 10). In the embodiments of the invention, the constellations formed of landmark objects (comprising at least one landmark object) and of an object of interest are exploited to allow the relocalization of an object of interest previously detected by the detection sonar 10.

The constellation of landmark objects is advantageously used to find the object of interest by matching the constellation in the reference image with the constellation in the sonar image of the identification device 20 (sonar image of the relocalization sonar 200). If no landmark object is present around the object of interest, then the relocalization requires no use of a constellation.

The detection sonar 10 may be arranged on a carrier such as for example a naval vessel or a submarine able to be immersed in water. The detection sonar 10 may for example be a sonar towed or installed on an autonomous underwater vehicle (AUV).

The detection sonar 10 is configured to transmit sound pulses and receive in response waves reflected by the bottom and objects under water, which allows the formation of images and the detection of objects.

The surveillance system 100 may be used in different fields of applications such as for example and without limitations in the field of target detection to detect threats, in the field of underwater biology and ecology (for example to analyze aquatic pollution), or in the field of archaeology (for example subaquatic and underwater archaeology), etc. In such fields, it may be useful or required to approach detected objects of interest to identify them, or implement an intervention action at the level of the target object of interest according to the field of application of the invention (an action may be for example an image capture, a video taking, a measurement taking, a target neutralization action, etc.)

The detection sonar 10 and the relocalization sonar 200 may be active sonars. An active sonar comprises a transmitter and a receiver. The transmitter and the receiver comprise a set of transducers configured to transmit and/or receive sound waves.

Upon transmission, the transducers of the sonar transmitter are able to transmit pulses in a given direction. Upon reception, the conversion of the acoustic data (pressure of the incident acoustic wave) into electrical data (output voltage) is carried out by one or more transducers.

A sonar receiver is configured to listen to the echoes reflected in response to the transmissions of the sonar, in a given frequency band (expressed in Hz), with a given hydrophonic sensitivity (designated by ‘Sh’ and expressed in decibels dB) and a given processing gain (expressed in dB) of the received signals, which allows object detection.

A sonar receiver is further configured to locate the detected objects. To carry out a localization of a detected object, a sonar receiver locates the echoes in direction (or ‘bearing’) by means of its spatial directivity (in dB) obtained by temporal beamforming, and to estimate the distance (in meters m) of the echoes from the delay time (in seconds s) of the echo for a sonar in active mode.

The detection sonar 10 and the relocalization sonar 200 may be able to form a sonar image representing the scene detected by the sonar.

The detection sonar 10 is thus used in a first phase of the detection to detect objects of interest and auxiliary objects around the objects of interest, and to determine the prior detection information (for each object of interest, starting position of the object of interest estimated by the detection sonar 10 and associated geolocated reference image). The first detection phase may further comprise an object classification making it possible to determine whether a detected object is an object of interest (the first detection phase is then also called ‘DCL phase’ for ‘Detection Classification, Localization’).

The surveillance system 100 may further comprise a control unit 18 configured to control the operation of the identification device 20 and/or transmit commands to communication equipment equipping a diver, when the identification device 20 is directly implemented by the relocalization sonar 200 carried by such a diver. The control unit 18 may also control the operation of the detection sonar 10. The surveillance system 100 may further comprise a display device (not represented) comprising a graphical interface in which a representation of the reference images provided by the detection sonar 10, of the sonar image detected by the relocalization sonar 200 or a consolidated representation of these two images, during the first detection phase, and/or in the second relocalization phase, may be displayed. The display device may be connected to the control unit 18. The surveillance system 100 may also comprise one or more input/output devices (such as a mouse, a keyboard, a touch input device, a voice command input device, or any equivalent form of input) capable of being used by an operator to enter commands into the control unit 18. The control device 18 is notably able to modify the display on the graphical interface as a function of commands entered into the control unit 18 by means of the input devices or as a function of the detection carried out by the detection sonar 10 and/or the relocalization sonar 200.

The identification device 20 may be robotic and/or automated. The identification device 20 may be remotely controlled, by the operator via the control unit 18.

The control unit 18 may be located in an operational center such as a surface vessel or a submarine. The control unit 18 may for example and without limitation be located at the level of the carrier of the detection sonar 10.

The identification device 20 is able to move toward one or more target objects of interest from relocalization information calculated for the target object of interest. The identification device 20 may be for example and without limitation a remotely operated underwater vehicle

ROV which may be equipped with the relocalization sonar 200. The identification device 20 may be entirely implemented in the relocalization sonar 200 (the identification device 20 then coincides with the relocalization sonar 200) when the relocalization sonar 200 is a portable sonar carried by a diver (for example mine-clearance diver).

The identification device 200 may be connected to the same carrier as the detection sonar 10. The carrier of the detection sonar 10 may be for example an autonomous surface vessel (Unmanned Surface Vehicle (USV)). The identification device 200 may for example be connected by a cable to the carrier (as in the case of an ROV).

In the first detection phase, the detection sonar 10 is configured to insonify the surveillance area in order to detect objects in the surveillance area (i.e. transmit acoustic waves in the surveillance area). After each transmission, the detection sonar 10 may remain waiting (or listening) for a time sufficient to receive the echoes of the detected objects (for example targets) present in the surveillance area. The detection sonar 10 may then process the received echoes in order to detect the objects in the surveillance area, carry out a classification to identify objects of interest, the other detected objects being auxiliary objects, and to estimate the position of each object of interest (called starting position). The detection sonar 10 may use a classification technique to characterize the detected objects in order to classify them in the category of objects of interest or in the category of auxiliary objects, and a positioning technique to estimate the positions of the objects of interest.

The detection sonar 10 is not limited to the use of a detection technique by directly using the echoes. In embodiments, the detection sonar 10 may be configured to generate high-resolution images of the bottom, and to use them to detect and classify objects on the bottom from their echo and also from their shadows. In such embodiments, the detection sonar 10 may be configured to classify the detected objects by using the dimensions of the echoes, their shadows and/or their shapes. In such embodiments exploiting the high-resolution images produced, the detection sonar 10 may be by way of non-limiting example a SAS (Synthetic aperture sonar) side-scan sonar.

The detection sonar 10 being immersed, its absolute position can only be calculated indirectly, from a GNSS position measured before its dive (in the case of an AUV) and maintained while diving by an inertial system (or a system combining an inertial system and an acoustic DVL sensor, acronym for “Doppler Velocity Log”), or else from an acoustic localization measurement between a surface vehicle localized by a GNSS system and the detection sonar 10. In these cases, the absolute positioning of the detection sonar is known with a non-negligible uncertainty which depends on the performance of its localization system. To this absolute positioning error of the detection sonar 10, there is added a relative positioning uncertainty of the objects detected by the detection sonar with respect to the latter (linked to the uncertainty on the speed of sound and to the uncertainty on the azimuth of the sonar beams formed of the detection sonar 10).

Advantageously, the embodiments of the invention allow a relocalization of the target objects of interest and a guidance of the identification device 20 toward these objects despite such absolute position uncertainties.

The objects of interest and the auxiliary objects thus detected may then be located on the sonar data of the detection sonar 10.

In the embodiments where the detection sonar uses a sonar image for the detection, the detection sonar 10 may be configured to geographically project sonar images of the underwater bottom detected by the detection sonar 10, in the surveillance area and carry out the detections of objects of interest and of auxiliary objects from a sonar image. The sonar image used for the detection of an object of interest is a geolocated image, also called 'geolocated reference image'. It represents the detected scene (underwater bottom when the invention is implemented in a maritime environment) around an object of interest (step of extracting a geolocated image around each object of interest).

The first detection phase thus makes it possible to obtain the prior detection information comprising:

The list of objects of interest (for example suspicious object or object constituting a potential threat) which need to be approached (for example to inspect them), each object of interest being associated with position data representing the estimated absolute position (or starting position) of the object of interest, associated with a positioning uncertainty;

For each object of interest, the geolocated reference image around the object of interest (an image of the seabed for example). These images may show other auxiliary objects, around the object of interest, if such objects have been detected in the first detection phase.

In one embodiment, the prior detection information may be determined by a detection sonar 10 independent of the identification device 200 (controlled by a distinct control unit and mounted on an independent carrier).

The information obtained at the end of the first detection phase is then used by the identification device 20. The identification device 20 may comprise a relocalization unit 202 configured to determine relocalization information for each target object of interest (i.e. which must be approached by the identification device 20), the identification device 20 being configured to be directed toward the target object of interest by using the relocalization information.

Figure 2 illustrates an example of representation of the reference image 101 extracted in the first detection phase. The reference image 101 comprises a detected object of interest 102 and auxiliary objects 104 in the vicinity of the object of interest.

In the second phase, called relocalization phase, the identification device 200 receives, from the detection sonar 10, the prior detection information $\mathcal{D}_1$ acquired during the first detection phase comprising at least the geolocated reference image I_{ref_1}, the prior positions P_{i_1} of the

different objects of interest O_i, and the positioning uncertainties associated with the positions P_{i_1}.

The prior detection information $\mathcal{D}_1$ may comprise additional information such as the positions of the detected auxiliary objects.

The prior detection information $\mathcal{D}_1$ may be stored by the identification device 20 in a storage memory. A display of this stored information may be generated on a control screen onboard the identification device 20.

For example, if the identification device 20 is an ROV, the geolocated reference image I_{ref_1} and the prior positions P_{i_1} of the different objects of interest O_i may be stored by the identification device 20 and a display of this stored information may be generated on a control screen onboard the identification device 20 (pilot screen) and connected to the relocalization sonar 200.

In another example, if the identification device 20 is a diver and the relocalization sonar 200 equipping the identification device 20 is a portable sonar, the geolocated reference image I_{ref_1} and the prior positions P_{i_1} of the different objects of interest O_i may be stored by the relocalization sonar 200 and a display of this information may be generated on a control screen onboard directly on the portable sonar 200 (in this case the identification device 20 corresponds to the portable relocalization sonar 200).

The relocalization sonar 200 equipping the identification device 20 may be of a type different from the detection sonar 10 which was used in the DCL phase. The detection sonar 10 may be for example a side-scan sonar, a synthetic aperture side-scan sonar, a hull-mounted frontal sonar, or any other sonar capable of generating images of the bottom. The relocalization sonar 200 of the identification device 20 may be for example and without limitation a multi-beam frontal sonar, or any other sonar.

The identification device 20 may comprise an imaging unit 203 configured to generate a consolidated representation R comprising the geolocated reference image I_{ref_1} determined in the DCL phase, and received from the detection sonar 10, and superimposed on the geolocated reference image I_{ref_1}, data derived from the secondary detection information $\mathcal{D}_2$ determined by the relocation sonar 200 and comprising:

Points representing the objects O'_j detected by the relocalization sonar 200 of the identification device 20, in the relocalization phase, these points being positioned on the reference image at their estimated positions P'_j ;

The secondary sonar image I_{sec_2} obtained with the relocalization sonar 200 of the identification device 20 by projecting it onto the reference image I_{ref_1} at its estimated position; the display may be generated with a sufficient degree of transparency to make visible the rendering of the reference image I_{ref_1} underneath the auxiliary sonar image I_{sec_2}.

Thus, the secondary detection information $\mathcal{D}_2$ may comprise the information P'_j determined for the different objects O'_j detected by the relocalization sonar 200 and the auxiliary sonar image I_{sec_2} obtained with the relocalization sonar 200 on which the different objects O'_j detected are positioned.

The imaging unit 203 may further generate a display of the contour of the sonar sector of the relocalization sonar 200 and of the position of the identification device 20 on the displayed reference image I_{ref_1}.

Advantageously, the relocalization unit 202 is able to use the received preliminary detection information $\mathcal{D}_1$, the secondary detection information $\mathcal{D}_2$ detected by the relocalization sonar 200 and the identification of at least one landmark object among the detected objects (also called landmarks) having known position information to guide the identification device 20 toward one or more selected target objects of interest, by minimizing the risk of position error and thus optimizing the time required to approach an object of interest. The landmark objects may for example be rocks present on the seabed, the initial position of which is determined during the preliminary detection and of which their positions and the associated position uncertainty are available.

Figure 3 represents the structure of the relocalization unit 202 according to one embodiment.

The relocalization unit 202 comprises a position error correction vector determination module 2022 configured to determine a position error correction vector (also called 'registration vector'), from the preliminary detection information $\mathcal{D}_1$ received from the detection sonar 10, the secondary detection information $\mathcal{D}_2$ detected by the relocalization sonar, and the known position of at least two landmark objects identified among the detected objects and present both on the reference image I_{ref_1} and on the image I_{sec_2} of the relocalization sonar 200.

The relocalization unit 202 may comprise a position correction module 2024 configured to apply the determined position error correction vector to correct the estimated position of each object detected by the relocalization sonar 200 in the sonar image of the relocalization sonar by a translation corresponding to the position correction vector, which makes it possible to relocalize all of the images and objects relative to the position of the objects in the first detection phase (preliminary detection).

For each target object of interest, the constellation of objects comprising the target object of interest and all of the landmark objects (among the auxiliary objects) in the vicinity of the target object of interest in the relocalization image $\mathrm{I}_{\mathrm{sec}_2}$is compared with the constellation of objects formed by the target object of interest and all of the landmark objects in the reference image $\mathrm{I}_{\mathrm{ref}_1}$ produced in the first detection phase, using a comparison technique.

The identification device 20 may further comprise a controller 205 able to control the movement of the identification device 20 toward the target object of interest using the position corrected by the position correction module 2024 (the corrected position is the position of the

target object of interest estimated by the identification device 20, after correction by applying the calculated position error correction vector. The identification device 20 is equipped with positioning means (for example inertial system, DVL sensor, acoustic positioning means, etc.) to move relative to the object of interest, from the corrected position.

During the movement of the identification device 20 toward an object of interest to be identified, the positioning error correction module 2022 may reiterate the position correction dynamically several times until the object of interest is reached, which makes it possible to avoid drift.

In one embodiment, the relocalization unit 202 may comprise an association unit configured 2020 to determine pairs associating an object detected by the detection sonar 10 and an object detected by the identification device 200 using the received preliminary detection information $\mathcal{D}_1$ and the secondary detection information $\mathcal{D}_2$ detected by the relocalization sonar 200 (for example in the consolidated representation R. The position error correction vector determination module 2022 is then configured to determine the position error correction vector from the association pairs.

An association pair may correspond to the same object, one element of the pair corresponding to the object detected by the detection sonar 10 and the other element of the pair then corresponding to the same object detected by the relocalization sonar 200. It is however not essential that the target object of interest be part of the formed pairs (for example if it is not detected by the relocalization sonar).

According to one aspect, the association module 2020 may be configured to determine the association pairs by applying a translation to the sonar image of the relocalization sonar 200 in the consolidated representation R, the translation being carried out so as to minimize the sums of distances between the pairs of objects.

In one embodiment, the pairwise association method may use the ICP transformation method, for 'Iterative Closest Point » (iterative closest point), as described for example in Paul J. Besl and N.D. McKay, “A Method for Registration of 3-D Shapes”, IEEE Trans. on Pattern Analysis and Machine Intelligence, Los Alamitos, CA, USA, IEEE Computer Society, vol. 14, n° 2, 1992) or any other similar association method. The ICP transformation method is a method that makes it possible to match two sets of point clouds in order to iteratively minimize the distances between these points. The person skilled in the art will readily understand that the invention is not limited to the ICP association technique and encompasses any association technique that makes it possible to estimate a translation and a rotation between two sets of points.

In one embodiment, the position error correction vector determination module may be configured to determine the position error correction vector by going through the different determined association pairs and by determining for each pair a candidate correction vector corresponding to the translation of position from one element of the pair to the other, the

position error correction vector determination module being configured to select the candidate correction vector that minimizes the quadratic sum or any other criterion for minimizing the distances between each element of each pair.

As a variant, instead of using the pairwise associations, the correction vector determination module 2022 may comprise an image processing module 2021 configured to apply an image processing technique (also called “image registration”) to the consolidated representation and a cost function to determine the position error correction vector as illustrated in figure 4.

Figure 5 illustrates the navigation of the identification device 20 toward an object of interest 502 according to an exemplary embodiment. Figure 5 more precisely shows the extracted sonar image 501 around the object of interest 502, auxiliary objects 504 around the object and the position of the identification device 20. The dotted arrow 505 represents the trajectory of the identification device 20 toward an object of interest 502.

The relocalization sonar 200 of the identification device 20 may be activated when the identification device 20 arrives in proximity to the object of interest (502 in figure 5), or before.

When the identification device 20 arrives in proximity to the object of interest (502 in figure 5), the relocalization sonar 200 is active and the objects O'_j (504) visible on the sonar image of the relocalization sonar 200 may be detected by any suitable method such as an automatic detection method that may be based on artificial intelligence. The identification device 20 may additionally carry out a localization of the detected objects O'_j visible on the sonar image of the relocalization sonar 200, from the localization of the identification device 20 and the position relative to the identification device 20 in the sonar image of the relocalization sonar 200.

Figures 6, 7 and 8 illustrate different phases of the relocalization of the target objects of interest. These figures show successive views of the consolidated representation 600 generated by the imaging unit 203, in an exemplary embodiment, corresponding to the sonar image obtained with the relocalization sonar 200 of the identification device 20 at different successive instants t_0, t_1 and t_2 (with $t_0<t_1<t_2$).

As shown in figures, 6, 7 and 8, the consolidated representation 600 comprises the reference image 601 (I_{ref}) obtained in the DCL phase with the detection sonar 10, the objects 602 (O_i) detected by the detection sonar 10 (each represented by a point), an object of interest 603 detected by the detection sonar 10, the objects 604 (O'_j) detected by the identification device 20 (each represented by the sign ‘+’) and projected at their estimated positions, the point 20 representing the position of the identification device, and the sonar sector 606 of the identification device 20.

The association module 2020 may determine association pairs, denoted $O_i \rightarrow O'_j$, between a detected object O'_j (604 in figures 6 to 8) on the sonar image of the identification device 20 and an object O_i (602 in figures 6 to 8) detected on the reference image in the DCL phase. The association pairs are represented by an arrow going from an object O'_j toward an object O_i, in figures 7 and 8.

Figure 8 shows the translation carried out by applying the position error correction vector. In the example of figure 8 the translation carried out brings the objects of the same pairs substantially back to the same position.

Figure 9 is a flowchart representing the object relocalization method implemented by the identification device 200, according to embodiments.

All the positions of objects or geolocated images detected by the detection sonar 10 are associated with an uncertainty, which may be recalculated when these positions are updated.

Steps 901 (movement of the identification device 20 toward the target object of interest) to 906 (application of the position error correction vector) may be repeated until the identification device 20 is close enough to the target object of interest (for example suspect contact) to carry out an action that is assigned to the identification device 20 (for example an identification action using a camera, or an action of neutralizing the target object of interest by depositing or applying an explosive charge on the target object of interest).

In step 900, the preliminary detection information (or data) originating from the detection sonar 10 (which may more generally be part of an acquisition system) is transmitted to the identification device 20, for example by a direct communication link or by radio. The identification device 20 may then store them in a memory space.

The preliminary detection information D_1 comprises, for each object of interest, the position of the object of interest estimated by the detection sonar, the geolocated reference image and may comprise the position of the auxiliary objects detected in the vicinity of the object of interest.

In step 901, for each target object of interest among the objects of interest detected by the detection sonar 10, the identification device 20, which comprises an absolute positioning system 201 (inertial and/or acoustic for example), heads toward an absolute position in proximity to the target object of interest. As used herein, the term “in proximity” means at a distance greater than the sum of the absolute positioning uncertainty of the identification device 20 and of the absolute positioning uncertainty of the target object of interest (for example suspect object), and at a distance less than the maximum range of the relocalization sonar 200. When this step 901 is repeated, the absolute position of the target object of interest is modified by the position error correction vector and its positioning uncertainty is reduced.

In step 902, the identification device 20 uses the relocation sonar 200 to acquire an image of the seabed over a sonar sector directed toward the front of the identification device 20. The relocalization sonar 200 is started up (i.e. activated) to acquire the secondary detection information, record the corresponding sonar image, and acquire only the corresponding position of the identification device 20. Step 902 thus corresponds to the detection of the sonar data by the relocalization sonar.

In step 903, objects are detected in the sonar image produced by the relocalization sonar 200, for example by using an automatic detection method capable of extracting the objects

from the image by applying a suitable image processing (for example of thresholding type) or artificial intelligence algorithms trained to detect objects on this type of images. The objects detected by the relocalization sonar 200 are then localized by calculating or estimating their relative position with respect to the relocalization sonar (distance and azimuth) and by adding thereto the absolute position of the identification device which carries the relocalization sonar. Step 903 thus provides a set of secondary detection information D_2 corresponding to the objects detected by the relocalization sonar 200.

In step 904, an association step is implemented to determine association pairs (pairing of objects) between the objects detected by the detection sonar 10 and the relocalization sonar 200 from the preliminary detection information D_1 and from the secondary detection information D_2. In this phase, the detected objects originating from D_1 (objects of the reference image) and the detected objects originating from D_2 (objects detected in the sonar image of the relocalization sonar 200). Various association techniques may be used, the constraint being that the relative positions of the objects of the reference image between one another are preserved in the image of the relocalization sonar 200.

In step 905, the position error correction vector (or 'registration vector') is determined to correct the position error between the starting position of the target object of interest estimated by the detection sonar 10 and the position of the object of interest estimated by the relocation sonar 200. The position error correction vector may be calculated as being the average of the position error vectors of the pairs of associated objects in step 904.

In step 906, the position error correction vector is applied to correct the position of the target object of interest, estimated by the relocalization sonar 200 and may also be applied to correct the position of the other objects detected by the relocalization sonar 200, estimated by the latter.

Step 901 is then repeated using the registered (or corrected) position of the target object of interest to control the movement of the identification device 20 toward the target object of interest.

Figure 10 represents an example of progression of an identification device 20 of ROV type toward a target object of interest 603 using the detected auxiliary objects 604 in the vicinity of the target object of interest 603.

In figure 10, the relocalization sonar 200 has a given search sector (in degrees) and a given resolution (in cm).

The relative distance between the identification device 20 and the target object of interest 603 goes from 150m, to 40 m, then to 20 m.

Sector A is an enlargement of the zone

The person skilled in the art will understand that the system or sub-systems according to the embodiments of the invention may be implemented in various ways by hardware, software, or a combination of hardware and software, in particular in the form of program code that may

be distributed in the form of a program product, in various forms. In particular, the program code may be distributed using computer-readable media, which may include computer-readable storage media and communication media. The methods described in the present description may in particular be implemented in the form of computer program instructions executable by one or more processors in a computer computing device. These computer program instructions may also be stored in a computer-readable medium.

Furthermore, the invention is not limited to the embodiments described hereinabove by way of non-limiting example. It encompasses all the embodiment variants that may be envisaged by the person skilled in the art.

CLAIMS

1. Surveillance system configured to monitor the presence of objects, in a surveillance zone, in water, the surveillance system comprising a detection sonar (10) and an identification device (20) mobile in water, characterized in that:

- the detection sonar (10) is able to detect the presence of a set of objects in the surveillance zone, said set comprising at least one object of interest and one or more auxiliary objects, said detection sonar being able to determine preliminary detection information comprising, for each detected object of interest, at least the position of the object of interest, called starting position, and a reference image corresponding to a sonar image taken by the detection sonar comprising the objects detected by the detection sonar (10), the detection sonar being able to transmit the preliminary detection information to the identification device (20),
- the identification device (20) is configured to move toward at least one target object of interest among said objects of interest, in response to receiving said preliminary detection information, the identification device comprising a relocalization sonar (200) configured to detect objects in the surveillance zone, the sector of the relocalization sonar being initially directed toward the starting position of the target object of interest, which provides secondary detection information relating to the objects detected by the relocalization sonar, the identification device further comprising a relocalization unit (202) configured to:
- determine a position error correction vector between the starting position of the target object of interest estimated by the detection sonar (10) and the position of the target object of interest estimated by the relocalization sonar (200), from the preliminary detection information and the secondary detection information,
- apply the position error correction vector to correct at least the position of the target object of interest estimated by the relocalization sonar (200),

the movement of the identification device (20) toward the target object of interest being controlled using the corrected position of the target object of interest.

2. System according to claim 1, wherein the relocalization unit (202) comprises an association module (2020) configured to determine pairs associating an object detected by the detection sonar and an object detected by the identification device (200), the position correction vector determination module (2022) being configured to determine a position error correction vector from said pairs.

3. System according to one of the preceding claims, wherein the identification device (20) comprises an imaging unit (203) configured to generate a consolidated representation comprising the reference image including the objects detected by the detection sonar (10),

and superposed on the reference image, the sonar sector of the relocalization sonar (200) and the objects detected by the relocalization sonar (200).

4. System according to claims 2 and 3, wherein the association module (2020) is configured to determine the pairs by applying a translation to the sonar image of the relocalization sonar in the consolidated representation, as a function of a criterion a criterion based on the distances between the objects.

5. System according to claim 2, wherein the position error correction vector determination module is configured to determine the position error correction vector by going through the different determined association pairs and by determining for each pair a candidate correction vector corresponding to the translation of position from one element of the pair to the other, the position error correction vector determination module (2022) being configured to select the candidate correction vector that minimizes the quadratic sum or a criterion for minimizing the distances between each element of each pair.

6. System according to claim 5, wherein the association module uses an association technique of 'Iterative Closest Point » type.

7. System according to claim 3, wherein the position error correction vector determination module (2022) is configured to apply an image processing technique to the consolidated representation and a cost function to determine the position error correction vector.

8. System according to claim 1, wherein the identification device comprises an absolute localization system (201) having a maximum positioning error less than the range of the relocalization sonar (200).

9. System according to one of the preceding claims, wherein the identification device is a remotely controlled underwater robot.

10. Surveillance method configured to monitor the presence of objects, in a surveillance zone in water, implemented in a mobile identification device (20), characterized in that the method comprises the steps consisting in:

- receiving preliminary detection information relating to objects detected by a detection sonar (10) in the surveillance zone comprising at least one object of interest and one or more auxiliary objects, the preliminary detection information comprising for each detected object of interest, at least the position of the object of interest, called starting position, and a reference image corresponding to a sonar image taken the detection sonar (10) comprising the objects detected by the detection sonar (10),
- determining secondary detection information relating to objects detected by a relocalization sonar (200) carried by the identification device (20) during its movement toward a target object of interest among said objects of interest;

the method comprising one or more iterations of the following steps:

- determine a position error correction vector between the starting position of the target object of interest estimated by the detection sonar (10) and the position of the target object of

interest estimated by the relocalization sonar (200), from the preliminary detection information and the secondary detection information,

- correct at least the position of the target object of interest estimated by the relocalization sonar (200), by applying the position error correction vector,
- control the movement of the identification device (20) toward the target object of interest using the corrected position of the target object of interest.