

DESCRIPTION

Title of the invention: Method for determining the spatial coverage of a detection system

[0001] Prior art

[0002] The invention relates to detection systems, and in particular to the three-dimensional representation of the spatial coverage of a detection system.

[0003] At the present time, detection systems, such as sonars or radars, are used in many fields of application. For example, sonars are used in the field of undersea acoustics to detect and locate objects under water.

[0004] Detection systems may be used by various pieces of surveillance infrastructure (for example to detect submarines or objects placed on the seabed, in the field of fishing to detect schools of fish, in the field of cartography to map a geographic region or the floor of oceans or of other bodies of water, or even in the field of archeology, for example underwater and undersea archeology).

[0005] Detection systems are equipped with antennas for transmitting and/or receiving signals.

[0006] Detection systems are conventionally used to detect threats in regions to be protected, for example in regions defined with respect to a sensitive piece of infrastructure to be protected.

[0007] For example, in a detection system of sonar type, it is known to use an anti-submarine-warfare system comprising elements for managing naval air-fleet scenarios and for modeling the spatial coverage of the sonar, and tools for assisting with making tactical decisions.

[0008] For example, in "P. C. Etter, Underwater Acoustic Modeling and Simulation, CRC Press, 5th edition, 2018, Taylor & Francis Group", modeling and simulation technologies for assisting with making tactical decisions in the context of anti-submarine warfare have been proposed with a view to improving the efficiency of the management and deployment of the deployed resources. Such a solution uses a network of geographically distributed components comprising autonomous undersea vehicles (AUV), surface ships, submarines, airplanes, and/or satellites. Such network components deploy distributed sensors.

[0009] The processing of the signals received by the detection system uses a signal-processing step and an information-processing step. Processing the data collected by the various components of the detection-system network allows a representation of the

spatial coverage of the detection system to be generated, on the basis of which representation an operator of the detection system may determine the rate of movement and path of target objects, the position of the target objects in distance, in azimuth and in depth, and the nature of the target objects.

[0010] It is known to use a representation called “performance of the day” (POD). A POD representation is a representation of detection probabilities that allows the spatial coverage of a detection system to be determined and the ability of the detection system to detect target objects to be estimated. Such a representation is generated on the basis of a matrix of detection-probability data depending on distance with respect to the position of the antenna of the detection system and on depth between the surface and the seabed, using color coding. The detection probabilities may be displayed graphically in the form of color data or elements, each color representing a probability range varying from 0 to 10%, from 11 to 20%, up to the interval of values [91,100%].

[0011] The shapes obtained by means of this representation are relatively complex and non-uniform because of the non-linearity of the propagation of the waves through the environment in question (for example the propagation of sound through water for a detection system of sonar type) and because the image that represents these detection probabilities allows only part of the scene in question to be viewed. In complex environments, the final three-dimensional (3D) shape obtained may be relatively complex to interpret. Moreover, this representation does not allow attention to be drawn to danger zones that represent a potential risk to the piece of infrastructure (platform or vessel to be protected for example) using the detection system. It also does not allow a complete three-dimensional overview of the geographic region covered by the detection system to be obtained. Furthermore, such a representation does not allow, with respect to the scale of the piece of infrastructure using the detection system, a sufficiently large region to be covered.

[0012] Tools for assisting with making tactical decisions have been proposed for detection systems of sonar type. However, such tools are sub-optimal. Specifically, known tools for assisting with making decisions generate a modeling environment that considers a single sensor at a time and, for each sensor, a distance related to its maximum range, this preventing an overview of the geographic region covered by the sonar from being obtained and possibly exposing the piece of infrastructure to be protected (a naval fleet for example) to the risk of attacks by threats that will be unable to be detected if they move through regions not covered by the sensor in question.

[0013] Furthermore, in existing solutions based on the representation of detection probabilities with a view to evaluating the detection capacity of the detection system, the representation takes into account detection probabilities of a single sensor of the detection system at a time and does not allow the entire region to be viewed in a way that is usable by the operator of the detection system, this possibly limiting the efficiency of the naval fleet.

[0014] There is therefore a need for an improved method and device capable of determining the spatial coverage of a detection system in an efficient manner. To this end, one subject of the invention is a method for determining a spatial coverage of a multi-sensor detection system comprising a plurality of sensors, the plurality of sensors being borne by carrying structures moving through a given geographic region, at least some of the carrying structures being mobile, the method being characterized in that it comprises the steps of:

- determining a set of parameters representing the geographic region and comprising environmental data, data relating to the carrying structures and data relating to the sensors;
- iteratively computing the detection probabilities of the plurality of sensors in the geographic region on the basis of at least some of the parameters;
- determining a three-dimensional representation of the spatial coverage of the detection system for the plurality of sensors;
- determining 3D shadow zones of the geographic region, in which zones the detection probability is lower than at least one given threshold;
- selecting the shadow zones located in at least one predefined security zone of the system.

[0015] According to certain embodiments, the method further comprises determining an intersection of the selected shadow zones forming an access channel to security zones.

[0016] According to certain embodiments, the detection system may be a detection system of sonar type, the environment being a maritime environment, said environmental data comprising data that are variable in space and in time and that represent a profile of the seabed in a defined geographic region, a temperature profile of the volume of water, information defining the state of the sea, and information related to sea noise, the data of carrying structures moving through the marine domain defining one or more mobile platforms and/or one or more seabed objects.

[0017] According to certain embodiments, said computation may be carried out periodically according to a chosen period or continuously.

[0018] According to certain embodiments, the spatial coverage of the detection system is represented according to a given viewing position and orientation, the step of determining a three-dimensional representation of the spatial coverage of the detection system comprising, for each sensor of said detection system, the steps of:

- receiving a dataset comprising a detection probability of said sensor in said geographic region, the detection probability being determined in a computation region associated with said sensor and included in said geographic region, the data of said set comprising computation-region position data and computation-region dimension data,
- determining a 3D rendering of said detection probability of said sensor on the basis of at least some of the probability data, of the computation-region position data and of the dimension data.

[0019] According to certain embodiments, the method further comprises a step of determining a main data structure having at least three dimensions on the basis of said probability data.

[0020] According to certain embodiments, the method may further comprise a step of determining a depth rendering of the volume encompassing the computation region on the basis of the computation-region position data, of the dimension data, and of the viewing position and orientation.

[0021] According to certain embodiments, the 3D rendering may be volume rendering, the method further comprising a step of determining a volume rendering of the detection probability according to at least one function in a given color space on the basis of said main data structure and of said depth rendering.

[0022] According to certain embodiments, the step of determining a volume rendering may comprise the steps of:

- determining a grayscale volume rendering of the detection probability on the basis of said 3D data structure and of said depth rendering;
- determining a color volume rendering of the detection probability on the basis of the grayscale volume rendering.

[0023] According to certain embodiments, the step of determining a three-dimensional representation of the spatial coverage of the detection system comprises a step of generating the display of said three-dimensional representation of the spatial coverage,

of shadow zones inside security zones and of access channels to the security zones on a screen or in augmented-reality mode or in virtual-reality mode.

[0024] Advantageously, the embodiments of the invention allow real-time computation of the detection probabilities associated with a multi-sensor detection system.

[0025] Advantageously, the embodiments of the invention allow a real-time representation of the detection probabilities associated with a multi-sensor detection system to be generated for an actual three-dimensional scene.

[0026] Advantageously, the embodiments of the invention are able to provide a mode of representation of the detection probabilities in volume form, this allowing a 3D display of the spatial coverage of the detection system in the whole of the geographic region in question.

[0027] Advantageously, the embodiments of the invention allow a three-dimensional representation of the spatial coverage of the detection system to be generated on a viewing device such as a screen or an augmented-reality device.

[0028] The representation of the spatial coverage of the detection system on an augmented-reality device in particular allows a better perception of the three-dimensional representation, the same tactical situation to be shared between a number of decision makers or control systems, and a hologram to be viewed on a tactical table without requiring the addition of supplementary screens to the operational environment in question.

[0029] Embodiments of the invention also allow the actions to be taken in response to the revelation of shadow zones of non-coverage, i.e. zones not covered by the detection of the system, located in security zones in the geographic region to be determined, or an access channel to be constructed by summing the shadow zones of non-coverage leading to these security zones, regardless of the complexity of the shape of these shadow zones or of these access channels.

[0030] Brief description of the drawings

[0031] Other features and advantages of the invention will become apparent from the following description, which is given with reference to the appended drawings, which are given by way of example, and which show, respectively:

[0032] [Fig.1] is one example of an environment of use of a method for determining a spatial coverage of a detection system of sonar type, according to certain embodiments.

[0033] [Fig.2] is a flowchart showing a method for determining a spatial coverage of a multi-sensor detection system, according to certain embodiments of the invention.

[0034] [Fig.3] is a flowchart showing a method for determining a three-dimensional representation of the spatial coverage of a multi-sensor detection system, according to certain embodiments of the invention.

[0035] [Fig.4] is a schematic view showing a ray-marching algorithm, according to certain embodiments of the invention.

[0036] [Fig.5] shows one example of spatial coverage of a detection system of sonar type used to detect objects, said coverage having been obtained using prior-art methods for displaying spatial coverage.

[0037] [Fig.6] is a schematic representation of target-theoretical-detection regions in one example of application to detection of objects in an undersea environment.

[0038] [Fig.7] is a schematic representation of likely detection regions in one example of application to detection of objects in an undersea environment.

[0039] [Fig.8] shows one example of display on a screen of the spatial coverage, of a multi-sensor detection system of sonar type, obtained on the basis of volume rendering of detection probabilities, according to certain embodiments of the invention.

[0040] [Fig.9] shows one example of display in augmented-reality mode of the spatial coverage, of a multi-sensor detection system of sonar type, obtained on the basis of volume rendering of detection probabilities, according to certain embodiments of the invention.

[0041] [Fig.10] is a schematic view of a device for determining the spatial coverage of a detection system, according to certain embodiments of the invention.

[0042] Detailed description

[0043] The embodiments of the invention provide a method for determining the spatial coverage of a multi-sensor detection system deploying a plurality of sensors and moving through a given geographic region. The geographic region includes a computation region, the computation region being a small geometric region that is: included in the geographic region; such that it comprises all of the non-zero computed detection probabilities of the detection system; and determined by a center and a frame of reference (for example a Cartesian frame of reference).

[0044] Figure 1 shows an example of an environment 100 in which a method for determining a three-dimensional representation of the spatial coverage of a detection system moving through a geographic region is used.

[0045] The detection system may be any detection system borne by a carrying structure capable of moving through the geographic region, such as a radar or a sonar for example. In the example of figure 1, the detection system is a sonar borne by a carrying structure consisting of a surface vessel 101. The spatial coverage of the detection system is shown according to a given viewing position and orientation (the set of position and orientation data is also called the “viewpoint”). The data of the dataset associated with a detection system borne by a carrying structure comprise, by way of nonlimiting example, computation-region position data, computation-region dimension data, and information on the carrying structure and the sensors.

[0046] The detection system may be used in various systems or pieces of infrastructure to detect and locate objects in the geographic region in question (for example in water for a detection system of sonar type). For example, the detection system may comprise one or more acoustic detection devices (for example the sonars 107, 108 and/or 109) used:

- to detect submarines or surface vessels and/or threats (for example mines) or objects placed on the seabed;
- to detect schools of fish, in the field of maritime and river navigation;
- in hydrography to map the floor of oceans and of other bodies of water,
- in underwater and undersea archeology or in sensors of aquatic pollution.

[0047] The detection system may further be used to locate the detected objects.

[0048] In the example of the environment 100 of figure 1 (which shows an anti-submarine-warfare device), other auxiliary elements may be deployed to take preventive, defensive or offensive actions, the actions depending on the detected object. The auxiliary elements may for example comprise a surface ship 101 equipped with one or more sonars, one or more maritime patrol aircraft, and one or more attack submarines. The sonars may for example comprise an active bow sonar 107, an active towed sonar 108, and an active dipping sonar 109 deployed by the helicopter 103.

[0049] The various elements of the environment 100 may be controlled by an operator or a control system present for example in the surface ship 101, to monitor and protect the elements of the environment 100 from threats by implementing operations or taking actions. The operator or the control system may for example take preventive, defensive or offensive actions.

[0050] To facilitate comprehension of the embodiments of the invention, and by way of non-limiting example, the description of the embodiments of the invention that follows

will be given mainly with reference to a detection system of sonar type implementing at least one passive or active multi-sensor sonar. However, those skilled in the art will easily understand that the invention is more generally applicable to any detection system capable of detecting an object in water or in any other environment.

[0051] Figure 2 shows a method for determining a spatial coverage of a multi-sensor detection system deploying a plurality of sensors borne by carrying structures moving through a given geographic region is illustrated. A carrying structure may bear one or more sensors. A sensor may operate in passive, mono-static, or multistatic mode.

[0052] According to certain embodiments, the carrying structures may be independent or not independent.

[0053] In step 201, a set of parameters representing the given geographic region, and comprising environmental data (for example the undersea, marine or terrestrial environment), data relating to the carrying structures (for example the speed of the carrying structure) and data relating to the sensors of the multi-sensor detection system (for example, for a detection system of sonar type, the data relating to the sensors may comprise the passive or active mode of the sonar, the one or more frequencies of the sonar, the maximum range of the sonar, the gain of the sonar). The environmental data may further comprise tactical data. Such parameters allow the location of the detection system, environmental conditions relating to this location, the initial paths followed by various platforms of the detection system, threats, the units to be protected, and/or the equipment of the platforms that may be called upon to provide this protection, to be defined.

[0054] In a detection system of sonar type, the environmental data may comprise marine and/or terrestrial environmental data that are variable in space and in time and that represent:

- the profile of the seabed in a defined geographic region (which may be chosen to have a high resolution, ranging for example up to 20 cm); this profile may be supplemented by the type of bed (combinations of mud, sand and/or rock);
- a profile of temperature of the volume of water and of salinity, the temperature of the volume of water and the salinity influencing the propagation of acoustic waves;
- information defining the state of the sea (for example the height of the waves and their direction), which has an influence on the way in which the acoustic waves are reflected from the surface;

- information related to sea noise (for example rain, traffic noise, diffuse biological noise, seismic noise, etc.).

[0055] According to certain embodiments, the data relating to the carrying structures moving through the given geographic region may be associated with the carrying structures moving through the marine-domain geographic region, i.e. structures such as one or more mobile platforms (for example surface vessels, submarines, drones, airplanes, helicopters, drifting sonobuoys, biological entities, etc.) and/or one or more seabed objects (for example mines, static acoustic detection systems, wrecks, or any other seabed object having an influence on detection). The carrying structures may have a predefined path, and be controlled by an operator of the detection system or by a control system. The carrying structures may have their own noise (due for example to machines and/or noises of flow into the water), may be equipped with sensors of any type, and/or may also emit sounds. Seabed objects may be equipped with sensors, behavior-based robots and explosive charges.

[0056] In one exemplary embodiment, the tactical data may be associated with one or more threats to be detected (mixed fleet for example), and the carrying structures may comprise one or more high-value units (HVV), and one or more HVV-protecting elements arranged in surveillance zones or on limiting lines of approach (LLA).

[0057] In one exemplary embodiment, step 201 may be carried out by a scenario generator in the environment in question (marine environment for example).

[0058] In step 203, a detection probability may be computed iteratively, for example at predefined time intervals or according to a set period or continuously, for the plurality of sensors of the multi-sensor detection system on the basis of at least some of the set of parameters determined in step 201. A detection probability, denoted $p(D)$, designates the probability that an actual target echo is detected when an actual target echo exists. In a passive-sonar detection system, the detection probability represents the probability of detecting an actual target object emitting a given noise level at various frequencies. In an active-sonar detection system, the detection probability represents the probability of obtaining a viable echo by virtue of transmission of acoustic waves by the active sonar. The probability that an actual target echo is not detected when the target echo exists is $1-p(D)$. The probability of false alarm, denoted $p(FA)$, designates the probability that a false echo (or spurious echo) is detected, i.e. the probability of false detection of an echo that is actually noise.

[0059] The detection probability computed for the plurality of sensors may be determined by combining the elementary detection probabilities of the various sensors.

[0060] The detection probabilities may change at any time on account of the profile of the environment in the vicinity of the carrying structure (seabed under the platform in question for example), of the movements of the carrying structure and of the environmental conditions. In one embodiment, the detection probabilities may be updated periodically according to a chosen period of less than one minute, for example every 30 seconds (or more rapidly depending on the available computing power), taking into account the speeds of the carrying structures (for example the speed of naval platforms is low) and the fact that the detection probabilities vary as a function of certain quantities relating to the environment (for example they decrease when the noise of water flowing over sensors of sonar type increases).

[0061] Step 203 may comprise a step of saving data representing the detection probabilities computed for the plurality of sensors in a file. In one embodiment, the detection-probability data may be represented by a probability data matrix. The position of the center of this matrix (center of the frame of reference of the matrix) may then be located at the position of the carrying structure of the detection system.

[0062] In step 205, a three-dimensional representation of the spatial coverage of the detection system may be determined for the plurality of sensors. The three-dimensional representation of the spatial coverage according to the embodiments of the invention allows detection probabilities to be represented for all the sensors of the multi-sensor detection system and over the whole geographic region, while taking into account the parameters representing the geographic region. For example, in an application of the invention to a detection system of sonar type, the three-dimensional representation of the spatial coverage may take into account the relief of the seabed, the carrying structures moving through the geographic region in a marine environment, and tactical zones determined in step 201. The relief of the environment in question, such as for example the relief of a seabed, may be imported from maps such as S-57 nautical charts used for example for navigation. The relief may be subject to processing to smooth and light it with processing of shadows, in order to be able to optimize the representation of the whole region. The carrying structures may be associated with a 3D model that is fairly faithful, given the scale of the objects. The position of the carrying structures may be updated periodically, such as for example every 200 ms, the period being chosen or determined to be compatible with fluid movements of the carrying structures given their speeds.

[0063] According to certain embodiments, step 205 may comprise displaying the three-dimensional representation of the spatial coverage of the detection system on a rendering device such as a screen, an augmented-reality rendering device or even a

virtual-reality rendering device. The display in augmented-reality mode advantageously allows the perception of the three-dimensional representation to be improved by virtue of holograms, the same tactical situation to be shared between a number of operators equipped with rendering devices allowing them to view the holograms from different viewpoints, and the hologram to be overlaid on a tactical table without requiring the addition of supplementary screens to an already cluttered operational environment. The display of the hologram may be synchronized with the data of the tactical table.

[0064] In step 207, the three-dimensional representation of the spatial coverage may be analyzed to determine 3D shadow zones of the geographic region, the shadow zones being zones in which the detection probability is lower than at least one given threshold.

[0065] In step 209, the shadow zones may be located in at least one predefined security zone of the system. The security zones may be selected based on strategic criteria.

[0066] The security zone with respect to a structure to be protected by the multi-sensor detection system may be substantially a sphere centered on the piece of infrastructure to be protected, the radius of the sphere being for example of the order of 30 km.

[0067] A 3D shadow zone may be for example a gap in coverage.

[0068] According to certain embodiments, step 209 may comprise determining an intersection of the selected shadow zones forming an access channel to security zones, a channel designating the sum of the shadow zones leading to the security zone. A zone of risk is a shadow zone within the security zone.

[0069] According to certain embodiments, the three-dimensional representation of the spatial coverage of the multi-sensor sonar in step 205 may be based on determination of a 3D rendering of the detection probabilities computed for the set of sensors in step 203. In one embodiment, the step of determining the 3D (three-dimensional) rendering of the detection probability may further take into account the viewing data (position and orientation data).

[0070] It is possible to determine the 3D rendering of the detection probabilities using techniques for synthesizing 3D images to convert the raw data of the detection probabilities into a 3D image to generate a display of the 3D image on a chosen rendering device (a screen-based 3D device, an augmented-reality device or a virtual-reality device).

[0071] The 3D representation of the spatial coverage may advantageously be superposed with a representation of the geographic region on the rendering device, this

allowing a 3D display of the spatial coverage of the detection system in the geographic region in question.

[0072] The creation of a synthetic image may be broken down into three main steps: geometric modeling of the objects of the scene to be represented, creation of the scene, and rendering.

[0073] The geometric modeling allows the geometric properties of the objects to be defined, either by a mathematical representation on the basis of mathematical definitions or systems that describe them, or by a representation based on a design tree with complex objects represented as a composition of simple objects called primitives, or by a representation that represents an object by delineating the limit between the interior of the object and the exterior of the object by a series of geometric elements (generally triangles) that are linked together.

[0074] The step of creation of the scene allows the appearance of the objects to be defined and non-geometric parameters of the scene to be displayed to be determined. The appearance of the objects is defined by determining surface or volume properties of the objects, these including optical properties, color and texture. The non-geometric parameters of the scene comprise the position and type of light sources, and the position from which and orientation with which the scene is viewed, this position and orientation forming the chosen viewpoint.

[0075] The attribution of a color to an object according to the embodiments of the invention is based on the use of a color space that takes opacity into account. For example, the data conversion may be carried out by using the RGBA color-coding format, which is an extension of the RGB format taking into account the notion of transparency. In such an example, each displayed pixel in the image represents a vector of four components, comprising a first value R representing a red color value, a second value G representing a green color value, a third value B representing a blue color value, and a fourth value A representing a transparency component (or alpha component). When geometric representation in Euclidean space is used, each pixel is associated with three geometric dimensions (x, y, z) in a frame of reference XYZ comprising a width x (or abscissa of the frame of reference), a depth y (or ordinate of the frame of reference) and a height z (or applicate of the frame of reference). The frame of reference XYZ is defined by the computation region and may be centered on the center of the computation region.

[0076] As used here, a 3D texture refers to a data structure for representing a synthetic image.

[0077] A rendering method refers to a computational method consisting in converting the model of the objects into an image displayable on the chosen rendering device.

[0078] The determination of the spatial coverage of the three-dimensional detection system on the basis of the detection probabilities may use transformation (or conversion) of the raw data of the detection probabilities into a structure usable by the rendering computation functions.

[0079] Figure 3, a flowchart representing step 205 of determining a three-dimensional representation of the spatial coverage of a multi-sensor detection system moving through a geographic region according to certain embodiments.

[0080] The steps in figure 3 are carried out for each sensor of the detection system.

[0081] In step 301, data of the dataset comprising a probability of the sensor in the geographic region are received, the detection probability being determined in a computation region associated with the sensor in question and included in said geographic region. The data of the dataset further comprises the dimension of the computation region associated with the sensor in question, and computation-region position data. In particular, the data of the dataset may be read or extracted. In step 301, viewing data (position and orientation) may also be received.

[0082] A 3D rendering of the detection probability of the sensor is then determined on the basis of at least some of the probability data, of the computation-region position data and of the dimension data.

[0083] In one embodiment, to generate the 3D rendering, the method may comprise a step 303 in which a main data structure having at least three dimensions (in particular 3D or 4D), which structure is also conventionally called a '3D texture', is determined on the basis of the detection-probability data. The data structure may for example be a matrix.

[0084] In one embodiment, the input dataset may further comprise the input resolution, the input resolution corresponding to the distance between two points of the computation region. Step 303 of determining the data structure may then comprise the steps of:

- generating an auxiliary data structure on the basis of the detection-probability data, the auxiliary data structure having dimensions defined on the basis of the probability, and of the input resolution, and
- determining the 3D texture using a conversion of the data of the auxiliary structure into colorimetric data.

[0085] In step 305, a depth rendering of the volume encompassing the computation region may be determined on the basis of the computation-region position and dimension data, and of the viewing position and orientation data.

[0086] In particular, step 305 of determining the depth rendering may comprise determining a first depth image of a cube encompassing the data structure and a second depth image of the rear face of the cube. The depth of the cube encompassing the main data structure (3D texture) representing the distance of the surface of the cube with respect to the viewing position and orientation (the Z-depth), the depth rendering comprising the first depth image and the second depth image. A depth image comprises a set of surfaces associated with position information. In one embodiment, the second depth image may be determined as the depth image of the cube the normals of which have been inverted, corresponding to the depth image of the rear face of the cube at the viewpoint.

[0087] In one embodiment, the 3D rendering may be a volume rendering. In such an embodiment, in step 307, a volume rendering of the detection probability is determined according to at least one function in a given color space on the basis of the main data structure (3D texture) and of the depth rendering.

[0088] In one embodiment, the functions used to determine the volume rendering may comprise at least one transfer function defined on the basis of a minimum probability limit, a maximum probability limit, a minimum colorimetric limit, and a maximum colorimetric limit.

[0089] Each information item of a depth image associated with geometric dimensions x, y, z may be defined in a color space, for example in the RGBA coding format.

[0090] In one embodiment, the step 307 of determining a volume rendering may comprise:

- a step 3071 of determining a grayscale volume rendering of the detection probabilities, on the basis of the 3D texture and of the depth rendering and
- a step 3073 of determining a color volume rendering of the detection probability, on the basis of the grayscale volume rendering.

[0091] In one embodiment, the grayscale volume rendering may be determined on the basis of the 3D texture, of the first depth image, and the second depth image by applying a volume-rendering computation algorithm (or technique) of ray-marching type.

[0092] A ray-marching algorithm is illustrated in figure 4 in one embodiment using RGBA coding. A ray-marching algorithm employs geometric optics to simulate the path of light

energy in the image to be displayed. A projection plane 403, placed in front of a viewpoint 401, represents the viewed image (i.e. the grayscale volume rendering). Each point of the projection plane 403 corresponds to one pixel of the grayscale volume rendering. Implementing step 307 by applying a ray-marching algorithm according to the embodiments of the invention may comprise generating a ray 407 (defined by a point of origin and a direction) for each pixel of the desired image of the grayscale volume rendering. The ray may be sampled at regular intervals inside the volume 405 and the values in the color space (RGBA colors for example) of the various pixels thus computed may be summed in proportion to their transparency contribution Alpha. The algorithm scans, in the direction of the projection plane 403, the oriented volumes of the results representing the detection probabilities, while collecting step-by-step the probability values. The value of a displayed pixel is the result of a function (for example transfer function) of the collected values.

[0093] For each point of the projection plane, each point corresponding to one pixel of the volume rendering, the ray-marching algorithm may be applied to compute a probability value accumulated by a ray 407 traced from the front of the cube encompassing the 3D texture to the rear of the cube.

[0094] In one embodiment, the application of a ray-marching algorithm in step 307 may comprise the operations of, for each pixel of the volume rendering and for each update of the detection probabilities:

- determining the 3D positions of departure and arrival of the ray 407 on the basis of the read values of colors of the textures of the first depth image and of the second depth image for the selected pixel;
- computing a stepwise displacement vector, for a given or predetermined number of iterations, on the basis of the direction displacement vector of the ray 407, and of the distance of the step of the iterations, which distance is determined by dividing the total distance by the number iterations, and by multiplying the direction displacement vector by the step distance.

[0095] For each iteration, the determination of a color representing a probability value for a selected pixel may comprise the operations of:

- updating the position of the path of the ray 407 by adding the displacement vector;
- associating a grayscale value with the probability color corresponding to the updated position in the 3D texture, such a color representing a grayscale level associated with the corresponding probability: for example, a value 'black' may be associated with a

probability close to zero ('0') and a value 'white' may be associated with a probability close to one ('1');

- determining the transparency component Alpha of the value of the color;
- applying a function (for example transfer function) in the color space;
- adding the determined color to the color of the pixel resulting from the algorithm.

[0096] In one embodiment, the transfer function may be a software function configured to execute a linear or non-linear interpolation, between a minimum color limit and a maximum color limit, the color space in which the volume rendering is determined representing a detection probability comprised between a minimum probability limit and a maximum probability limit.

[0097] For example, in step 3073, a color volume rendering of the detection probabilities is determined on the basis of the grayscale volume rendering of the detection probabilities determined in substep 3071, the color volume rendering may be determined by applying a color transfer function to the grayscale volume rendering, the color transfer function using the minimum probability limit, the maximum probability limit, the minimum color limit, and the maximum color limit. The color transfer function may then for example execute a linear interpolation, between the minimum color limit and the maximum color limit, the colors of the volume rendering representing a detection probability comprised between the minimum probability limit and the maximum probability limit.

[0098] In another embodiment, the 3D rendering may be surface rendering. The method then comprises, as an alternative to steps 303, 305 and 307, a step 311 of determining a surface rendering on the basis of the detection probabilities, of the computation-region position data, of the dimension data, of at least one detection-probability threshold value, and of the viewing position and orientation.

[0099] In particular, step 311 of determining the surface rendering may comprise generating polygonal objects on the basis of the three-dimensional data matrix so as to approximate at least one iso-surface constructed on the basis of at least one given detection-probability threshold (marching cube).

[0100] The functions of computing the detection probabilities and of determining the texture may be software functions executed by a processing unit or processor. The functions implemented in the rendering process may be software programs, called shaders, executed by a graphics processing unit.

[0101] The method according to the various embodiments of the invention may be implemented in a detection system in 'mission preparation' mode or in 'online' mode. The

'mission preparation' mode makes it possible to optimize the movement of the detection system by simulating a scenario based on a future mission. The 'online' mode consists in implementing the method by coupling the detection system to tactical links. In this 'online' mode, the actual positions, speeds and headings of the various carrying structures, along with the use of their various sensors, may be used to update the parameters defining the environment and allow a real-time representation to be generated. The data collected on board the 'online' detection system may be converted into information able to be used to update the detection probabilities.

[0102] Figure 5 shows one example of spatial coverage of a detection system of sonar type used in an anti-submarine-warfare device, said coverage having been obtained using a prior-art technique for displaying detection probabilities. This representation is generated on the basis of a probability data matrix of the detection system depending on distance with respect to the antenna of the detection system and on depth between the surface and the seabed, using color coding, this making it possible to evaluate the ability of the sonar to detect a threat. In the example of figure 5, region 1 corresponds to a region associated with a 100% probability of detecting a threat (enemy platform for example), and region 2 corresponds to a region associated with a 0% probability of detecting a threat. The shapes thus obtained are complex and non-uniform.

[0103] Figure 6 is a schematic representation of target-theoretical-detection regions in an anti-submarine-warfare device using circles to identify the protection provided to a naval fleet against a possible threat, and figure 7 is a schematic representation of likely detection regions obtained using prior-art methods for displaying the spatial coverage. The two figures show that the actual overall detection region is very different from the desired theoretical overall detection region, this making it impossible to carry out effective preventive surveillance to protect the naval fleet and possibly representing a danger in the presence of potential threats.

[0104] Figure 7 shows one example of display on a screen of a spatial coverage, of a multi-sensor detection system of sonar type, obtained according to one embodiment with volume rendering of the detection probabilities of the detection system. As illustrated by figure 7, the three-dimensional representation of the spatial coverage according to the invention allows an overview of the complete region to be displayed in three dimensions, a region that is very large on the scale of the naval fleet to be covered, and non-insonified danger zones and gaps in coverage to be revealed.

[0105] Figure 8 shows one example of display in augmented-reality mode of a multi-sensor spatial coverage obtained in modes of volume rendering of the detection probabilities of the sonar according to embodiments of the invention.

[0106] The invention also provides a device for determining a spatial coverage of a multi-sensor detection system comprising a plurality of sensors, said plurality of sensors being borne by carrying structures moving through a given geographic region, at least some of the carrying structures being mobile, characterized in that the device is configured to:

- determine a set of parameters representing said geographic region and comprising environmental data, data relating to said carrying structures and data relating to said sensors;
- iteratively compute the detection probabilities of said plurality of sensors in the geographic region on the basis of at least some of said parameters;
- determine a three-dimensional representation of the spatial coverage of the detection system for the plurality of sensors;
- determine 3D shadow zones of said geographic region, in which zones said detection probability is lower than at least one given threshold;
- select the shadow zones located in at least one predefined security zone of the system.

[0107] The invention further provides a computer program product for determining a spatial coverage of a multi-sensor detection system comprising a plurality of sensors, said plurality of sensors being borne by carrying structures moving through a given geographic region, at least some of the carrying structures being mobile, characterized in that the computer program product comprises computer-program-code instructions that, when they are executed by one or more processors, cause the one or more processors to:

- determine a set of parameters representing said geographic region and comprising environmental data, data relating to said carrying structures and data relating to said sensors;
- iteratively compute the detection probabilities of said plurality of sensors in the geographic region on the basis of at least some of said parameters;
- determine a three-dimensional representation of the spatial coverage of the detection system for the plurality of sensors;

- determine 3D shadow zones of said geographic region, in which zones said detection probability is lower than at least one given threshold;
- select the shadow zones located in at least one predefined security zone of the system.

[0108] Figure 10 shows the device 4000 for determining a three-dimensional representation of the spatial coverage of a detection system (for example of sonar type) moving through a geographic region (marine scene for example) on the basis of the dataset comprising the detection probabilities of the detection system. The dataset may for example be saved in a memory 430 or in a mass storage device 420. The device 4000 may be any type of device or computational system, designated by the name computer. The device 4000 may comprise at least one processing unit 4010 configured to determine a 3D rendering of the detection probabilities on the basis of at least some of the probability data, of the computation-region position data and of the dimension data. In one embodiment, the 3D (three-dimensional) rendering of the detection probabilities may further be determined on the basis of the viewing data (position and orientation data).

[0109] The device 4000 may further include a memory 430, a database 420 forming part of a mass storage device, an I/O (input/output) interface 470, and a human-machine interface 410 for receiving inputs or returning outputs to/from an operator of the detection system. The interface 410 may for example be used to configure or parameterize various parameters or functions used by the representation-determining method according to certain embodiments of the invention, such as the configuration of the volume rendering of the detection probabilities. The external resources may include, but are not limited to, servers, databases, mass storage devices, peripheral devices, cloud services, or any other suitable computer resource which may be used with the device 4000.

[0110] The processing unit 4010 may include one or more devices selected from microprocessors, microcontrollers, digital signal processors, microcomputers, central processing units, programmable gate arrays, programmable logic devices, finite-state machines, logic circuits, analog circuits, digital circuits, or any other device used to handle (analog or digital) signals based on operating instructions stored in the memory 430. The memory 430 may include a single memory device or a plurality of memory devices, in particular, but not being limited to, read-only memory (ROM), random-access memory (RAM), volatile memory, non-volatile memory, static random-access memory (SRAM), dynamic random-access memory (DRAM), flash memory, cache memory or

any other device capable of storing information. The mass storage device 420 may include data storage devices such as a hard drive, an optical disk, a magnetic tape drive, a volatile or non-volatile solid-state circuit or any other device capable of storing information. A database may reside in the mass storage device 420.

[0111] The processing unit 4010 may operate under the control of an operating system 440 that resides in the memory 430. The operating system 440 may manage the computational resources in such a way that the program code of the computer, which is integrated in the form of one or more software applications, such as the application 450 that resides in the memory 430, may have instructions executed by the processing unit 4010. The device 4000 may comprise a graphics processing unit 4030 implemented on a graphics card, on a motherboard, or in a central processing unit. The graphics processing unit may generate a display of the 3D rendering on a display device.

[0112] In general, the routines executed to implement the embodiments of the invention, whether they are implemented in the context of an operating system or a specific application, a component, a program, an object, a module or a sequence of instructions, or even a subset thereof, may be designated as "computer program code" or just "program code". The program code typically comprises instructions that are readable by computer which reside at various times in various memory and storage devices in a computer and which, when they are read and executed by one or more processors in a computer, cause the computer to perform the operations required to execute the operations and/or the elements specific to the various aspects of the embodiments of the invention. The instructions of a program, which are readable by computer, for performing the operations of the embodiments of the invention may be, for example, the assembly language, or else a source code or an object code written in combination with one or more programming languages.

[0113] The invention is not limited to the embodiments described above by way of non-limiting example. It encompasses all of the variant embodiments that may be contemplated by those skilled in the art.

CLAIMS

1. A method for determining a spatial coverage of a multi-sensor detection system comprising a plurality of sensors, said plurality of sensors being borne by carrying structures moving through a given geographic region, at least some of the carrying structures being mobile, the method being characterized in that it comprises the steps of:
 - determining (201) a set of parameters representing said geographic region and comprising environmental data, data relating to said carrying structures and data relating to said sensors;
 - iteratively computing (203) the detection probabilities of said plurality of sensors in the geographic region on the basis of at least some of said parameters;
 - determining (205) a three-dimensional representation of the spatial coverage of the detection system for the plurality of sensors;
 - determining (207) 3D shadow zones of said geographic region, in which zones said detection probability is lower than at least one given threshold;
 - selecting (209) the shadow zones located in at least one predefined security zone of the system.
2. The method as claimed in claim 1, characterized in that it further comprises determining an intersection of the selected shadow zones forming an access channel to security zones.
3. The method as claimed in claim 1, characterized in that said detection system is a detection system of sonar type, said environment being a maritime environment, said environmental data comprising data that are variable in space and in time and that represent a profile of the seabed in a defined geographic region, a temperature profile of the volume of water, information defining the state of the sea, and information related to sea noise, said data of carrying structures moving through said marine domain defining one or more mobile platforms and/or one or more seabed objects.
4. The method as claimed in any one of the preceding claims, characterized in that said computation (203) is carried out periodically according to a chosen period or continuously.

5. The method as claimed in any one of the preceding claims, characterized in that the spatial coverage of the detection system is represented according to a given viewing position and orientation, the step (205) of determining a three-dimensional representation of the spatial coverage of the detection system comprising, for each sensor of said detection system, the steps of:
 - receiving a dataset comprising a detection probability of said sensor in said geographic region, the detection probability being determined in a computation region associated with said sensor and included in said geographic region, the data of said set comprising computation-region position data and computation-region dimension data,
 - determining a 3D rendering of said detection probability of said sensor on the basis of at least some of the probability data, of the computation-region position data and of the dimension data.
6. The method as claimed in claim 5, characterized in that it further comprises a step of determining (303) a main data structure having at least three dimensions on the basis of said probability data.
7. The method as claimed in either of claims 5 and 6, characterized in that it further comprises a step of determining (305) a depth rendering of the volume encompassing the computation region on the basis of the computation-region position data, of the dimension data, and of the viewing position and orientation.
8. The method as claimed in claims 2 and 3, characterized in that said 3D rendering is volume rendering and in that the method further comprises a step of determining (307) a volume rendering of the detection probability according to at least one function in a given color space on the basis of said main data structure and of said depth rendering.
9. The method as claimed in claim 8, characterized in that said step of determining a volume rendering (307) comprises the steps of:
 - determining a grayscale volume rendering of the detection probability on the basis of said 3D data structure and of said depth rendering;
 - determining a color volume rendering of the detection probability on the basis of the grayscale volume rendering.

10. The method as claimed in one of the preceding claims, characterized in that the step of determining (205) a three-dimensional representation of the spatial coverage of the detection system comprises a step of generating the display of said three-dimensional representation of the spatial coverage, of shadow zones inside security zones and of access channels to the security zones on a screen or in augmented-reality mode or in virtual-reality mode.
11. A device for determining a spatial coverage of a multi-sensor detection system comprising a plurality of sensors, said plurality of sensors being borne by carrying structures moving through a given geographic region, at least some of the carrying structures being mobile, characterized in that the device is configured to:
 - determine a set of parameters representing said geographic region and comprising environmental data, data relating to said carrying structures and data relating to said sensors;
 - iteratively compute the detection probabilities of said plurality of sensors in the geographic region on the basis of at least some of said parameters;
 - determine a three-dimensional representation of the spatial coverage of the detection system for the plurality of sensors;
 - determine 3D shadow zones of said geographic region, in which zones said detection probability is lower than at least one given threshold;
 - select the shadow zones located in at least one predefined security zone of the system.
12. A computer program product for determining a spatial coverage of a multi-sensor detection system comprising a plurality of sensors, said plurality of sensors being borne by carrying structures moving through a given geographic region, at least some of the carrying structures being mobile, characterized in that the computer program product comprises computer-program-code instructions that, when they are executed by one or more processors, cause the one or more processors to:
 - determine a set of parameters representing said geographic region and comprising environmental data, data relating to said carrying structures and data relating to said sensors;
 - iteratively compute the detection probabilities of said plurality of sensors in the geographic region on the basis of at least some of said parameters;

- determine a three-dimensional representation of the spatial coverage of the detection system for the plurality of sensors;
- determine 3D shadow zones of said geographic region, in which zones said detection probability is lower than at least one given threshold;
- select the shadow zones located in at least one predefined security zone of the system.