

DESCRIPTION

Title of the invention: Method for three-dimensional representation of the spatial coverage of one or more detection systems

Prior art

[0001] The invention relates to detection systems, and in particular to three-dimensional representation of the spatial coverage of one or more detection systems.

[0002] 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 underwater acoustics to detect and locate objects underwater.

[0003] 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 (for example 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).

[0004] Detection systems are equipped with antennas with a view to transmitting and/or receiving signals. The processing of the signals received by the detection system uses a signal-processing step and an information-processing step.

[0005] The signal-processing step may comprise operations of preprocessing, antenna processing, coherent processing, normalization and detection. The preprocessing operations may comprise re-amplification of the received signals, filtering, digitization, signal shaping via a demodulation operation allowing the signals to be converted to baseband, additional filtering to keep only part of the signal (i.e. the part containing useful information, noise being rejected) and sampling to reduce the number of samples to be processed.

[0006] Antenna-processing operations exploit the geometry of the antennas to optimize the compromise between performance and the number of sensors deployed.

[0007] Coherent-processing operations consist in correlating the received signals with the transmitted signals, to search for the presence of echoes.

[0008] Normalization operations consist in modifying the parameters of the noise statistics to reveal the signal part.

[0009] Detection operations are implemented to determine whether a target object is present in the water. The detection of target objects in a sonar system is probabilistic. The detection probability, denoted $p(D)$, designates the probability that an actual target echo is detected when an actual target echo exists. For example, 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.

[0010] The normalization and detection operations consist in determining a detection threshold of the receiver by setting a minimum detection probability (or threshold detection probability) and a minimum false-alarm probability. When the signal-to-noise ratio exceeds the value of the threshold detection probability, the receiver may detect the presence of a target echo, and, for values of the signal-to-noise ratio lower than the value of the threshold detection probability, the receiver does not detect the presence of echoes.

[0011] The information-processing step generally comprises operations consisting in fusing data delivered by various platforms and/or various sensors, in tracking, in locating, and in classifying. These operations make it possible to determine the rate of movement and path of the target objects, to determine the azimuthal and depthwise position of the target objects, and to determine the nature of the target objects on the basis of information extracted with the detection system.

[0012] 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. More precisely, the detection probabilities are displayed graphically in the form of color data where each

color represents a probability range varying from 0 to 10%, from 11 to 20%, up to the interval of values [91,100%].

[0013] The shapes obtained by means of this representation are relatively complex and non-uniform due to the non-linearity of the propagation of the waves through the environment in question (for example through water for a detection system of sonar type) and to the fact that 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 infrastructure using the detection system, a sufficiently large region to be covered.

[0014] There is therefore a need for an improved method and improved device for determining a three-dimensional representation of the spatial coverage of one or more detection systems.

[0015] General definition of the invention

[0016] To this end, a method is provided for determining a three-dimensional representation of the spatial coverage of one or more detection systems moving through a geographic region, on the basis of a dataset comprising a detection probability of one or more detection systems, said probability being determined in a computation region included in said geographic region, the spatial coverage of the one or more detection systems being represented according to a given viewing position and orientation, the data of the set comprising computation-region position data and computation-region dimension data. Advantageously, the method comprises a step of determining a 3D rendering of the detection probability, on the basis of at least some of the probability data of said one or more detection systems, of the computation-region position data, and of the dimension data.

[0017] In one embodiment, the method may further comprise a step of determining a main data structure having at least three dimensions on the basis of said probability data of said one or more detection systems.

[0018] Advantageously, 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.

[0019] In one embodiment, the 3D rendering may be volume rendering, the method then 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 the main data structure and of the depth rendering.

[0020] The step of determining the volume rendering may comprise the steps of: determining a grayscale volume rendering of the detection probability, on the basis of the main data structure and of the depth rendering; determining a color volume rendering of the detection probability, on the basis of the grayscale volume rendering.

[0021] In another embodiment, the 3D rendering is surface rendering, the method further comprising a step of determining a surface rendering on the basis of the detection probability, 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.

[0022] The step 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 the detection-probability threshold.

[0023] In one embodiment, the dataset may further comprise an input resolution associated with each detection system, the input resolution associated with a detection system corresponding to a distance between two points of the computation region, the step of determining the main data structure comprising the steps of:
- generating an auxiliary data structure on the basis of at least some of the probability data, the auxiliary data structure having dimensions defined on the basis of the input resolution associated with each of said one or more detection systems;

- determining a main data structure using a conversion of the data of the auxiliary structure into colorimetric data.

[0024] A depth image comprises a set of surfaces associated with position information. Advantageously, the step of determining the depth rendering may comprise determining a first depth image of a cube encompassing the 3D data structure and a second depth image of the rear face of the cube, the depth of the cube encompassing the main data structure representing the distance of the surface of the cube with respect to the viewing position and orientation, the depth rendering comprising the first depth image and the second depth image.

[0025] In one embodiment, the step of determining a volume rendering may comprise determining the volume rendering on the basis of the main data structure and of said first depth image and second depth image, by applying a volume-rendering algorithm of ray-marching type.

[0026] The functions may comprise at least one transfer function defined on the basis of a minimum probability limit, of a maximum probability limit, of a minimum colorimetry limit, and of a maximum colorimetry limit, the transfer function being configured to execute an interpolation between the minimum colorimetry limit and the maximum colorimetry limit, the color space in which the volume rendering is determined representing a detection probability comprised between the minimum probability limit and the maximum probability limit.

[0027] According to certain embodiments, the one or more detection systems may comprise at least two detection systems. According to these embodiments, the step of determining the main structure may further comprise the sub-steps of:

- determining secondary data, said secondary data being determined by applying a linear interpolation to the probability data of each detection system of said at least two detection systems;
- determining a secondary position of the computation region, said secondary position of the computation region being determined, on the basis of the computation-region position data of each detection system of said at least two detection systems, as being the average of the positions of the computation region;
- determining secondary dimensions of the computation region, on the basis of the dimension data of each detection system of said at least two detection systems, said

secondary dimensions being determined as being the dimensions encompassing the dimensions of the computation region of each detection system;

- determining a secondary resolution as being the minimum value of the input resolutions associated with said at least two detection systems;

said main data structure being determined on the basis of said secondary data, secondary position of the computation region, secondary dimensions, and secondary resolution.

[0028] A device is further provided for determining a three-dimensional representation of the spatial coverage of one or more detection systems moving through a geographic region, on the basis of a dataset comprising a detection probability determined in a computation region included in the geographic region, the spatial coverage of said one or more detection systems being represented according to a given viewing position and orientation, the data of the set comprising computation-region position data and computation-region dimension data. Advantageously, the device is configured to determine a 3D rendering of the detection probability, on the basis of at least some of the probability data, of the computation-region position data, and of the dimension data.

[0029] A computer program product is also provided for determining a three-dimensional representation of the spatial coverage of one or more detection systems moving through a geographic region, on the basis of a dataset comprising a detection probability determined in a computation region included in the geographic region, the spatial coverage of said one or more detection systems being represented according to a given viewing position and orientation, the data of the dataset comprising computation-region position data and computation-region dimension data, said computer program product comprising computer program code instructions that, when they are executed by one or more processors, cause the one or more processors to determine a 3D rendering of the detection probability, on the basis of at least some of the probability data of said one or more detection systems, of the computation-region position data, and of the dimension data.

[0030] Advantageously, the embodiments of the invention allow the detection probabilities associated with one or more detection systems to be represented for an actual three-dimensional scene.

[0031] Advantageously, 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 one or more detection systems in the geographic region in question.

[0032] Embodiments of the invention further allow high-risk areas to be displayed, this allowing preventive actions to be triggered or adjusted.

[0033] Advantageously, embodiments of the invention provide 3D-rendering modes that may be used to quickly determine actions to be taken despite the complex shapes representing regions of shadow that are not covered by the detection of one or more detection systems and located in security regions within the geographic region.

[0034] Brief description of the drawings

[0035] Other features, details and advantages of the invention will become apparent on reading the description, which is given with reference to the appended drawings, which are given by way of example and which show, respectively:

[0036] [Fig.1] is one example of an environment of use of the device for determining the representation of the spatial coverage of one or more detection systems of sonar type, according to certain embodiments.

[0037] [Fig. 2] is a flowchart showing a method for determining a three-dimensional representation of the spatial coverage of one or more detection systems, according to certain embodiments of the invention.

[0038] [Fig. 3] is a schematic view showing a ray-marching algorithm, according to certain embodiments of the invention.

[0039] [Fig. 4] is a schematic view of a device for determining a three-dimensional representation of the spatial coverage of one or more detection systems, according to certain embodiments of the invention.

[0040] [Fig. 5] shows one example of spatial coverage of one or more detection systems of sonar type used to detect objects, said coverage having been obtained using prior-art methods for displaying spatial coverage.

[0041] [Fig. 6] is a schematic showing target-theoretical-detection regions, in one example of application of the representation-determining device to the detection of objects in an underwater environment.

[0042] [Fig. 7] is a schematic showing likely detection regions in an anti-submarine-warfare device, in one example of application of the representation-determining device to the detection of objects in an underwater environment.

[0043] [Fig.8] shows one example of spatial coverage of a sonar, said coverage having been obtained using a volume rendering of the detection probabilities of a sonar, according to certain embodiments of the invention.

[0044] Detailed description

[0045] Figure 1 shows one example of an environment 100 in which a device for determining a three-dimensional representation of the spatial coverage of one or more detection systems moving through a geographic region is used, on the basis of a dataset comprising a detection probability of said one or more detection systems, said probability being determined in a computation region included in the geographic region.

[0046] Such as used here, the term "computation region" refers to a geometric region included in the geographic region and comprising all of the computed detection probabilities of one or more detection systems meeting a condition. The computation region is determined by a center and is defined in a frame of reference, such as for example a Cartesian frame of reference XYZ. The computation region may for example comprise all of the computed detection probabilities of one or more detection systems that are non-zero. As a variant, the computation region may for example comprise all of the computed detection probabilities of one or more detection systems that are higher than a non-zero threshold.

[0047] According to certain embodiments, the one or more detection systems may comprise a plurality of collaborative detection systems.

[0048] According to certain embodiments, the one or more detection systems may comprise a plurality of alternative detection systems.

[0049] A detection system of one or more detection systems 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, a detection system may for example be a sonar borne by a carrying structure consisting of a surface vessel 101.

[0050] The spatial coverage of the one or more detection systems is shown according to a given viewing position and orientation (the set of viewing position and orientation data is also called the “viewpoint”). The data of the dataset comprise computation-region position data and computation-region dimension data of each detection system of the one or more detection systems.

[0051] The one or more detection systems may be used in various pieces of infrastructure or systems to detect and locate objects in the geographic region in question (for example underwater for a detection system of sonar type).

[0052] For example, a detection system may be one of the acoustic detection systems 107, 108 and/or 109 used to detect:

[0053] - submarines and/or surface vessels and/or threats (for example mines) or objects placed on the seabed, 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.

[0054] The one or more detection systems may further be used to locate the detected objects.

[0055] In the example of environment 100 of figure 1 forming an anti-submarine-warfare device, other auxiliary elements may be deployed to take preventive, defensive or offensive actions, the actions to be implemented depending on the detected object. The auxiliary elements may comprise, for example, surface ships 101 equipped with sonars 107, 108; one or more maritime patrol aircraft; one or more helicopters 103 equipped with sonar(s) such as the sonar 109; one or more attack submarines; and one or more acoustic buoys 105 released by a maritime patrol. 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.

[0056] 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.

[0057] 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 one or more detection systems of sonar type. 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.

[0058] Advantageously, the representation-determining device according to embodiments of the invention comprises a step of determining a 3D (three-dimensional) rendering of the detection probability, on the basis of at least some of the probability data of the one or more detection systems, of the computation-region position data, and of the dimension data of the one or more detection systems. 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).

[0059] In one embodiment, the detection-probability data of each of the one or more detection systems 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 one or more detection systems.

[0060] In one embodiment, the dimension data of a detection system may be determined on the basis of an input resolution associated with the detection system, the input resolution associated with a detection system corresponding to the distance between two points of the computation region.

[0061] It is possible to determine the 3D rendering 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. The rendering device may for example be a screen-based 3D device, or an augmented-reality device or a virtual-reality device.

[0062] The 3D representation of 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 one or more detection systems in the geographic region in question.

[0063] 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.

[0064] The geometric modeling allows the geometric properties of objects to be defined, either by a mathematical representation on the basis of mathematical definitions or of systems that describe them, or by a representation based on a design tree with complex objects represented by a composition of simple objects called primitives, or by an edge-based representation that represents an object by delineating the limit between its interior and its exterior by a series of geometric elements (generally triangles) that are linked together.

[0065] 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 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 (by a camera or even by eye) forming the viewpoint.

[0066] The attribution of a color to an object according to 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.

[0067] Such as used here, a 'texture' refers to a data structure used for the representation of a synthetic image.

[0068] A rendering method refers to a computational method for converting the model of the objects into an image displayable on the selected display medium, the image comprising both objects and light sources, and a view from a given viewpoint.

[0069] The method according to embodiments of the invention may be implemented by one or more computational devices or systems, collectively designated by the name computer. The method may be implemented in the form of a set of software programs (or software functions) executed by at least one processing unit (or 'processor') of the computer and of a set of computer programs, called shaders, executed by at least one graphics processing unit (or 'graphics processor') of the computer. A graphics processor is an integrated circuit configured to execute display-computation functions and that may be integrated into a motherboard or into a central processing unit (CPU). The functions executed by the processing unit may comprise texture determination. The functions executed by the graphics processing unit may comprise the functions implemented in the rendering process.

[0070] The determination of the spatial coverage of the one or more detection systems may use a transformation (or conversion) of the raw data of the detection probabilities of the one or more detection systems into a structure exploitable by the rendering-computation functions executed by the graphics processing unit.

[0071] Figure 2 shows the method for determining a three-dimensional representation of the spatial coverage of one or more detection systems 109 moving through a geographic region according to certain embodiments.

[0072] The steps of figure 2 are implemented to determine a 3D rendering of the detection probability of one or more detection systems in the geographic region in question, on the basis of at least some of the probability data, of the computation-region position data, and of the dimension data of the one or more detection systems, according to one embodiment. In one embodiment, the 3D (three-dimensional)

rendering of the detection probability may further be determined on the basis of the viewing data (position and orientation data).

[0073] In step 201, the data of the dataset comprising the computation-region position data and computation-region dimension data associated with the one or more detection systems are read or extracted.

[0074] In step 203, a main data structure having at least three dimensions (in particular 3D or 4D), also conventionally called a "3D Texture", is determined on the basis of the probability data of the one or more detection systems. In one embodiment, the main data structure may for example be a matrix.

[0075] According to certain embodiments in which the one or more detection systems comprise at least two detection systems, the step 203 of determining the main data structure may comprise:

- determining secondary data, said secondary data being determined by applying a linear interpolation to the probability data of each detection system of said at least two detection systems;
- determining a secondary position of the computation region, said secondary position of the computation region being determined, on the basis of the computation-region position data of each detection system of said at least two detection systems, as being the average of the positions of the computation region;
- determining secondary dimensions of the computation region, on the basis of the dimension data of each detection system of said at least two detection systems, said secondary dimensions being determined as being the dimensions encompassing the dimensions of the computation region of each detection system. According to these embodiments, the main data structure may be determined on the basis of the secondary data, of the secondary position of the computation region, and of the secondary dimensions.

[0076] In one embodiment, the input dataset may further comprise the input resolution associated with each detection system of the one or more detection systems, the input resolution associated with a detection system corresponding to the distance between two points of the computation region. The step 203 of determining the main data structure may then comprise the steps of:

- generating an auxiliary data structure on the basis of at least some of the probability data of the one or more detection systems, the auxiliary data structure having dimensions defined on the basis of the probability, and of the input resolution associated with each of said one or more detection systems;
- determining the main data structure using a conversion of the data of the auxiliary structure into colorimetric data.

[0077] According to certain embodiments in which the one or more detection systems comprise at least two detection systems, a secondary resolution may be determined as being the minimum value of the input resolutions associated with said at least two detection systems. According to these embodiments, the data structure may further be determined on the basis of the secondary resolution.

[0078] The main data structure (or '3D texture') thus comprises a number of pixels corresponding to the input resolution (or to the secondary resolution in certain embodiments in which the spatial coverage is determined for at least two detection systems), each pixel of the 3D texture being associated with one colorimetric datum. The colorimetric datum may for example be defined in the RGB color space by a vector of three values, each value corresponding to one component R, G, or B of the RGB color space.

[0079] In step 205, a depth rendering of the volume encompassing the computation region may be determined, on the basis of the computation-region position data, of the dimension data, and of the viewing position and orientation.

[0080] In particular, the step 205 of determining the depth rendering may comprise determining a first depth image of a cube encompassing the main data structure ('3D Texture') and a second depth image of the rear face of the cube. The depth of the cube encompassing the main data structure (3D texture) being the distance of the surface of the cube with respect to the viewing position and orientation (i.e. the Z-depth), the depth rendering comprises the first depth image and the second depth image. A depth image comprises a set of surfaces associated with position information.

[0081] In one embodiment, the second depth image may be determined as the depth image of the cube of which the normals have been inverted, corresponding to the depth image of the rear face of the cube at the viewpoint.

[0082] Although the steps 203 and 205 have been shown in a consecutive order, those skilled in the art will easily understand that, as a variant, these steps may be implemented in another order or in parallel.

[0083] In one embodiment, the 3D rendering may be a volume rendering. In such an embodiment, in step 207, 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 3D texture and of the depth rendering.

[0084] 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.

[0085] 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.

[0086] In one embodiment, the step 207 of determining a volume rendering may comprise:

- a step 2070 of determining a grayscale volume rendering of the detection probability, on the basis of the 3D structure and of said depth rendering; and
- a step 2090 of determining a color volume rendering of the detection probability, on the basis of the grayscale volume rendering.

[0087] In one embodiment, the volume rendering may be determined in step 207 on the basis of the 3D texture, of the first depth image and of the second depth image, by applying a volume-rendering algorithm (or technique) of ray-marching type.

[0088] A ray-marching algorithm is illustrated in figure 3, in one embodiment using steps 2070 and 2090 and 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 303, placed in front of a viewpoint 301, represents the viewed image (i.e. the grayscale volume rendering). Each point of the projection plane 303 corresponds to one pixel of the grayscale volume rendering. Implementing step 207 on the basis of the 3D texture by applying a ray-marching algorithm according to embodiments of the invention may comprise generating a ray 307 (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 305 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 303, the oriented volumes of the results representing the detection probability, while collecting the probability values step-by-step. The value of a displayed pixel is the result of a function (transfer function for example) of the collected values.

[0089] 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 307 traced from the front of the cube encompassing the 3D texture to the rear of the cube.

[0090] In one embodiment, the application of a ray-marching algorithm in step 207 may comprise the steps, for each pixel of the volume rendering, of:

- determining the 3D positions of departure and arrival of the ray 307, 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 307, and of the distance of the steps of the iterations, which distance is determined by dividing the total distance by the number of iterations, and by multiplying the direction displacement vector by the step distance.
- For each iteration, the determination of a color representing a probability value for a selected pixel may comprise the steps of:
 - updating the position of the path of the ray 307 by adding the displacement vector;
 - associating a grayscale value with the probability value 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 (transfer function for example) in the color space;

- adding the determined color to the color of the pixel resulting from the algorithm.

[0091] 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 the minimum probability limit and the maximum probability limit associated with the transfer function.

[0092] For example, in step 2090, in which a color volume rendering of the detection probability of one or more detection systems is determined on the basis of the grayscale volume rendering of the detection probability determined in step 2070, the color volume rendering may be determined by applying a color transfer function to the grayscale volume rendering, the color transfer function using the associated minimum probability limit, maximum probability limit, minimum color limit, and maximum color limit. For example, the color transfer function may then execute a linear interpolation, between the minimum color limit and the maximum color limit, the colors of said volume rendering representing a detection probability comprised between the minimum probability limit and the maximum probability limit.

[0093] In another embodiment, the 3D rendering may be surface rendering. The method then comprises, as an alternative to steps 203, 205 and 207, a step 211 of determining a surface rendering on the basis of the detection probability of the one or more detection systems, 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.

[0094] In particular, step 211 may comprise computing an iso-probability surface, this consisting in computing a geometric surface allowing the space to be split in two: inside the geometric surface corresponding to detection-probability values higher than the threshold value, and outside the geometric surface corresponding to values lower than the threshold value. Such surfaces may be generated, for a given value, using a marching-cube algorithm.

[0095] To generate a display of the surface rendering, the method may use a function to generate a mesh, on the basis of the detection probabilities of the one or more detection systems. The term 'mesh' refers to a spatial discretization of a surface, and

to geometric modeling of the surface with finite proportioned elements. The method may for example use a finite element of triangle type.

[0096] The mesh-generation function may be executed each time the detection probabilities and the threshold value are updated.

[0097] The mesh-generation function may be defined to compute the mesh of the detection probabilities of the one or more detection systems delineating the surface encompassing a given probability, or probability iso-value. The space contained in the surface thus meshed bounds detection probabilities higher than the probability iso-value. In one embodiment, a mesh function based on a marching-cube algorithm may implement the following steps:

- reading the input dataset comprising the input resolution associated with each detection system and the probability data of the one or more detection systems in the form of a data table;
- converting the data into a data matrix taking into account the input resolution in question;
- computing the mesh for the input probability value (iso-value) by applying a mesh algorithm, the algorithm scanning the probability volume, taking eight points at a time to form a working cube, comparing the probability values of the points to the threshold probability value, and determining the possible polygons to be created to represent one portion of the iso-surface contained in this cube in a diagram;
- the mesh thus computed is returned in an exchange format suitable for being read by most 3D viewing applications.

[0098] The mesh obtained by means of this function may be non-uniform and complex to interpret. An identification function based on a mesh-segmentation algorithm allows the mesh to be split into a plurality of uniform sub-meshes (for example a surface bounding a region of non-detection inside a larger area of detection). The function makes it possible to make the resulting mesh easily interpretable by applying a different rendering color depending on the average concavity of each of the sub-meshes (for example in order to differentiate the surfaces bounding a region of detection, from those bounding a region of non-detection, i.e. a gap in coverage).

[0099] Figure 4 shows the device 400 for determining a three-dimensional representation of the spatial coverage of one or more detection systems (sonar for example) moving through a geographic region (marine scene for example), on the basis of the dataset comprising at least one detection probability of the one or more detection systems. The dataset may for example be saved in a memory 43 or in a mass storage device 42. The device 400 may be any type of device or computational system, designated by the name computer. The device 400 may comprise at least one processing unit 401 configured to determine a 3D rendering of said detection probability of the one or more detection systems, on the basis of at least some of the probability data of the one or more detection systems, of the computation-region position data, and of the dimension data. In one embodiment, the 3D (three-dimensional) rendering of the detection probability may further be determined on the basis of the viewing data (position and orientation data).

[0100] The device 400 may further include a memory 43, a database 42 forming part of a mass storage device, an I/O (input/output) interface 47, and a human-machine interface 41 for receiving inputs or returning outputs to/from an operator of the detection system. The interface 41 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 400.

[0101] The processing unit 401 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 43. The memory 43 may include a single memory device or a plurality of memory devices, in particular, but without 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 42 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 42.

[0102] The processing unit 401 may operate under the control of an operating system 44 that resides in the memory 43. The operating system 44 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 45 that resides in the memory 43, may have instructions executed by the processing unit 401. The device 400 may comprise a graphics processing unit 403 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.

[0103] The invention also provides a computer program product for determining a three-dimensional representation of the spatial coverage of one or more detection systems, the computer program product comprising computer program code instructions that, when they are executed by one or more processors in a computer, cause the processing unit to execute the representation-determining method.

[0104] Figure 5 shows an example of the spatial coverage of a detection system of sonar type used in an anti-submarine-warfare device and obtained using a prior-art technique for displaying detection probabilities. Such a representation is generated on the basis of probability data of the detection system, 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, this allowing the ability of the sonar to detect a threat to be evaluated. 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.

[0105] Figure 6 shows 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 shows likely detection regions, in an example of application of the representation-determining device to the detection of objects in an underwater environment. 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 any enemies.

[0106] Figure 7 shows an example of spatial coverage of a detection system of sonar type, said coverage being obtained according to an embodiment with volume rendering of the detection probabilities of the detection system, according to one exemplary embodiment of the invention. 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.

CLAIMS

1. A method for determining a three-dimensional representation of the spatial coverage of one or more detection systems moving through a geographic region, on the basis of a dataset comprising a detection probability of said one or more detection systems, said probability being determined in a computation region included in said geographic region, the spatial coverage of said one or more detection systems being represented according to a given viewing position and orientation, the data of said dataset comprising computation-region position data and computation-region dimension data, characterized in that the method comprises a step of determining a 3D rendering of said detection probability, on the basis of at least some of the probability data of said one or more detection systems, of the computation-region position data, and of the dimension data (201, 203, 205, 207, 211).

2. The method as claimed in claim 1, characterized in that it further comprises a step (203) of determining a main data structure having at least three dimensions, on the basis of said probability data of said one or more detection systems.

3. The method as claimed in claim 2, characterized in that said one or more detection systems comprise at least two detection systems, the step (203) of determining said main data structure comprising:

- determining secondary data, said secondary data being determined by applying a linear interpolation to the probability data of each detection system of said at least two detection systems;
- determining a secondary position of the computation region, said secondary position of the computation region being determined, on the basis of the computation-region position data of each detection system of said at least two detection systems, as being the average of the positions of the computation region;
- determining secondary dimensions of the computation region, on the basis of the dimension data of each detection system of said at least two detection systems, said secondary dimensions being determined as being the dimensions encompassing the dimensions of the computation region of each detection system;

said main data structure being determined on the basis of said secondary data, of said secondary position of the computation region, and of said secondary dimensions.

4. The method as claimed in one of claims 1 to 3, characterized in that it further comprises a step of determining (205) 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.

5. The method as claimed in claims 2 and 4, characterized in that said 3D rendering is volume rendering and in that the method further comprises a step of:

- determining (207) 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.

6. The method as claimed in claim 5, characterized in that said step (207) of determining a volume rendering comprises the steps of:

- determining (2070) a grayscale volume rendering of the detection probability, on the basis of said main data structure and of said depth rendering;

- determining (2090) a color volume rendering of the detection probability, on the basis of the grayscale volume rendering.

7. The method as claimed in one of the preceding claims, characterized in that said 3D rendering is surface rendering and in that the method further comprises a step (211) of determining a surface rendering on the basis of the detection probability of said one or more detection systems, 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.

8. The method as claimed in claim 7, characterized in that the step (211) of determining said surface rendering comprises 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 said detection-probability threshold.

9. The method as claimed in claim 2, characterized in that said dataset further comprises an input resolution associated with each of said one or more detection systems, an input resolution associated with a detection system corresponding to a distance between two points of said computation region, and in that said step of determining the main data structure comprises the steps of:

- generating an auxiliary data structure on the basis of at least some of the probability data, said auxiliary data structure having dimensions defined on the basis of the input resolution associated with each of said one or more detection systems;
- determining a main data structure using a conversion of the data of the auxiliary structure into colorimetric data.

10. The method as claimed in claim 9, characterized in that said one or more detection systems comprise at least two detection systems, a secondary resolution being determined as being the minimum value of the input resolutions of each of said at least two detection systems, said main data structure being determined on the basis of said secondary resolution.

11. The method as claimed in one of claims 4 to 6, characterized in that a depth image comprises a set of surfaces associated with position information, and in that the step (205) of determining said depth rendering comprises determining a first depth image of a cube encompassing said 3D data structure and a second depth image of the rear face of said cube, the depth of the cube encompassing said main data structure representing the distance of the surface of said cube with respect to the viewing position and orientation, said depth rendering comprising the first depth image and the second depth image.

12. The method as claimed in claims 5 and 11, characterized in that the step of determining a volume rendering (207) comprises determining said volume rendering on the basis of said main data structure and of said first depth image and second depth image, by applying a volume-rendering algorithm of ray-marching type.

13. The method as claimed in one of claims 4 to 6, characterized in that the said functions comprise at least one transfer function defined on the basis of a minimum probability limit, of a maximum probability limit, of a minimum colorimetry limit, and of

a maximum colorimetry limit, said transfer function being configured to execute an interpolation between said minimum colorimetry limit and said maximum colorimetry limit, the color space in which said volume rendering is determined representing a detection probability comprised between said minimum probability limit and said maximum probability limit.

14. A device (400) for determining a three-dimensional representation of the spatial coverage of one or more detection systems moving through a geographic region, on the basis of a dataset comprising a detection probability of said one or more detection systems, said probability being determined in a computation region included in said geographic region, the spatial coverage of said one or more detection systems being represented according to a given viewing position and orientation, the data of said set comprising computation-region position data and computation-region dimension data, characterized in that the device is configured to determine a 3D rendering of said detection probability, on the basis of at least some of the probability data, of the computation-region position data, and of the dimension data.

15. A computer program product for determining a three-dimensional representation of the spatial coverage of one or more detection systems moving through a geographic region, on the basis of a dataset comprising a detection probability determined in a computation region included in said geographic region, the spatial coverage of said one or more detection systems being represented according to a given viewing position and orientation, the data of said set comprising computation-region position data and computation-region dimension data, said computer program product comprising computer program code instructions that, when they are executed by one or more processors, cause the one or more processors to determine a 3D rendering of said detection probability, on the basis of at least some of the probability data, of the computation-region position data, and of the dimension data.