

THREE-DIMENSIONAL TARGET DETECTION, LOCALIZATION AND TRACKING USING UNDERWATER MAGNETIC AND ACOUSTIC SENSORS

TECHNICAL FIELD

5 The presently disclosed subject matter relates to the field of target detection, localization and/or tracking using underwater sensors.

BACKGROUND

10 There is a need for underwater vehicles to detect targets, which can correspond to underwater targets (e.g., submarines, autonomous underwater vehicles, etc.) and/or floating/surface targets (e.g., ships, buoys, etc.). A typical usage of this detection is collision avoidance.

 Conventional prior art solutions rely on the usage of sonars for detecting targets.
15 However, sonars suffer from several drawbacks. Some of these drawbacks are listed hereinafter:

- at least some of the sonars do not provide elevation (height) of the target(s) – this generates a high level of uncertainty on the actual position of the target(s);
- 20 - sonars are unable to classify the type(s) of the target(s);
- sonars suffer from reverberation effects, in particular close to the surface, which generate incorrect target detections;
- some sonars have a limited range of detection.

 As a consequence, in a typical application of collision avoidance, usage of
25 sonars for detecting targets induces the generation of unnecessary and complex avoidance manoeuvres of the underwater vehicle.

 There is therefore a need to propose new systems and methods for detecting targets by underwater vehicles.

30 GENERAL DESCRIPTION

 In accordance with certain aspects of the presently disclosed subject matter, there is provided a system comprising one or more processing circuitries configured to,

in a period of time comprising a relative motion between a marine vehicle and at least one target, in which the marine vehicle has not passed over the at least one target, obtain first position data informative of one or more first areas determined by at least one underwater detection system associated with the marine vehicle, obtain magnetic
5 detection data of at least one underwater magnetic detection system associated with the marine vehicle, and using at least part of the first position data and at least part of the magnetic detection data to perform at least one target detection enabling estimating position of the at least one target.

In addition to the above features, the system according to this aspect of the
10 presently disclosed subject matter can optionally comprise one or more of features (i) to (xxix) below, in any technically possible combination or permutation:

- i. the at least one detection system comprises an acoustic detection system, or a laser detection system;
- ii. said target detection outputs at least one target position estimate which is
15 outside of said one or more first areas;
- iii. said target detection comprises using a magnetic detection algorithm which searches for one or more targets in space based on the magnetic detection data, wherein the first position data is used to limit at least part of said space;
- 20 iv. the system is configured to use the first position data to determine a set of one or more three-dimensional search areas, and use at least part of the magnetic detection data to perform a target detection within the set of one or more three-dimensional search areas;
- v. said target detection is limited within a space corresponding to said set of
25 one or more three-dimensional search areas;
- vi. said target detection includes using the magnetic detection data to search for one or more targets within a plurality of sub-areas of each three-dimensional search area of the set;
- vii. the system is configured to select one or more dimensions of the one or
30 more three-dimensional search areas based on an estimated range between the marine vehicle and the target;
- viii. the system is configured to use the first position data to determine, for at least one given first area of the one or more first areas, a given three-dimensional search area comprising the given first area, with a larger

- 5 volume than the given first area, thereby obtaining a set of one or more three-dimensional search areas, and feed the magnetic detection data to a magnetic detection algorithm to perform a target detection within a space, wherein said space is defined based on the set of one or more three-dimensional search areas;
- 10 ix. the first position data comprise range and azimuth of each of the one or more first areas, but do not comprise elevation of each of the one or more first areas;
- x. the system is configured to use the first position data to determine a set of one or more three-dimensional search areas, and use at least part of the magnetic detection data to perform a target detection within a space constrained by said set of one or more three-dimensional search areas, said target detection comprising, for each given sub-area of a plurality of sub-areas of each given three-dimensional search area: comparing the magnetic detection data, or data derived thereof, with one or more expected magnetic signatures of one or more targets.
- 15 xi. the system is configured to obtain magnetic detection data for different positions of the marine vehicle relative to the target, thereby obtaining a set of a plurality of magnetic detection data, and responsive to detection that a range between the marine vehicle and the target meets a threshold, use at least part of the first position data and at least part of the set of magnetic detection data to perform a target detection enabling estimating position of the at least one target;
- 20 xii. the system is configured to perform a target detection with last magnetic detection data obtained in a given sub-period of time together with previous magnetic detection data obtained before said given sub-period of time, wherein the target detection takes into account the previous magnetic detection data with a lower weight than the last magnetic detection data;
- 25 xiii. the system is configured to perform a target detection at a given instant time with last magnetic detection data obtained only in a sub-period of time of the period of time ending at this given instant of time;
- 30 xiv. the system is configured to use the estimate of the position of the target to control operation of the at least one detection system;

- xv. the system is configured to control the at least one detection system to orient its field of view based on the estimate of the position of the target;
- xvi. the system is configured to perform target detection at a given position of the marine vehicle relative to the target, based on magnetic detection data of the magnetic detection system and on first position data of the detection system, thereby obtaining a given set of a plurality of position estimates, and process at least part of the given set of a plurality of position estimates to determine an estimate of the position of the target;
- xvii. the processing enables obtaining at least one of: (i) a single position estimate of the target, or (ii) a second set of position estimates associated with a smaller dispersion than the given set of a plurality of position estimates; (iii) a position estimate of the target associated with an uncertainty which is smaller than an uncertainty associated with the given set of a plurality of position estimates;
- xviii. the processing includes at least one of: (i) determining data informative of a symmetry of at least part of the given set of a plurality of position estimates; (ii) determining data informative of a center of at least part of the given set of a plurality of position estimates; (iii) determining data informative of an average of at least part of the plurality of the position estimates of said given set;
- xix. the system is configured to perform target detection at different positions of the marine vehicle relative to the target, based on magnetic detection data of the magnetic detection system and on first position data of the detection system, thereby obtaining a plurality of sets of position estimates, and process at least part of the plurality of sets of position estimates to obtain tracking data informative of the target;
- xx. the system is configured to perform at least one of: (i) determining data informative of an average of at least part of the plurality of the position estimates of each of set of said of plurality of sets, (ii) determining data informative of a center of at least part of each set of the plurality of sets of position estimates, (iii) determining data informative of a symmetry of at least part of each set of the plurality of sets of position estimates, and using data obtained at (i), (ii) or (iii) to generate the tracking data;

- xxi. the system is configured to compare the tracking data with tracking data provided by the detection system;
- xxii. the system is configured to compare one or more geometrical properties of at least part of the given set of a plurality of position estimates with one or more expected geometrical properties, and use the comparison to determine tracking data of the target;
- xxiii. the system is configured to perform a first target detection based on the magnetic detection data, without using first position data of the detection system, to obtain a set of target position estimates, use the set to orient a field of view of the detection system, thereby obtaining the first position data, and use the first position data and the magnetic detection data to perform said target detection;
- xxiv. the system is configured use said estimate of the position of the target to perform at least one of: (i) controlling the marine vehicle to avoid a collision with the target; (ii) performing an ascension of the marine vehicle to periscope depth; (iii) obtaining a map of one or more surface targets; (iv) obtaining a map of one or more seabed targets; (v) performing underwater mine detection; (vi) determining position of the marine vehicle, said determining using a priori knowledge of the position of the target.
- xxv. the system is configured to perform (1) to (4) for different positions of the marine vehicle: (1) obtain first position data informative of one or more first areas determined by the at least one detection system, (2) obtain magnetic detection data of the at least one magnetic detection system, and (3) use the first position data to determine a set of one or more three-dimensional search areas, and (4) use at least part of the magnetic detection data to perform a target detection in the set of one or more three-dimensional search areas to obtain one or more position estimates of the target.
- xxvi. the marine vehicle is an underwater vehicle, wherein the detection system and the magnetic detection system are mounted on the underwater vehicle;
- xxvii. the marine vehicle is an underwater vehicle, wherein the detection system and the magnetic detection system are towed by underwater vehicle;

xxviii. the marine vehicle is an underwater vehicle, wherein at least part of a system comprising the detection system and the magnetic detection system is mounted on the underwater vehicle, and another part of said system is towed by the underwater vehicle; and

5 xxix. the marine vehicle is a ship, wherein the detection system and the magnetic detection system are towed by the ship.

In accordance with other aspects of the presently disclosed subject matter, there is provided a system comprising one or more processing circuitries configured to obtain first position data informative of one or more first areas determined by at least one
10 underwater detection system associated with a marine vehicle, obtain magnetic detection data of at least one underwater magnetic detection system associated with the marine vehicle, use the first position data to determine a set of one or more three-dimensional search areas, and use at least part of the magnetic detection data to perform at least one target detection within the set of one or more three-dimensional search areas, enabling
15 estimating position of at least one target within said set of one or more three-dimensional search areas.

In addition to the above features, the system according to this aspect of the presently disclosed subject matter can optionally comprise one or more of features (xxx) to (xxxv) below, in any technically possible combination or permutation:

20 xxx. the first position data comprise range and azimuth of each of the one or more first areas, but do not comprise elevation of each of the one or more first areas;

 xxxi. said at least one target detection includes using the magnetic detection data to search for one or more targets within a plurality of sub-areas of each
25 three-dimensional search area of the set:

 xxxii. the target detection is limited within a space corresponding to said set of one or more three-dimensional search areas;

 xxxiii. the system is configured to use the first position data to determine, for at least one given first area of the one or more first areas, a given three-
30 dimensional search area comprising the given first area, with a larger volume than the given first area, thereby obtaining a set of one or more three-dimensional search areas, and feed the magnetic detection data to a magnetic detection algorithm to perform a target detection within a space,

wherein said space is defined based on the set of one or more three-dimensional search areas;

xxxiv. the target detection is performed in a period of time comprising a relative motion between the marine vehicle and at least one target, in which the marine vehicle has not passed over the at least one target; and

xxxv. the system is configured to perform (1) to (4) for different positions of the marine vehicle relative to a target: (1) obtain first position data informative of one or more first areas determined by the at least one detection system, (2) obtain magnetic detection data of the at least one magnetic detection system, (3) use the first position data to determine a set of one or more three-dimensional search areas, and (4) use at least part of the magnetic detection data to perform a target detection in the set of one or more three-dimensional search areas to obtain one or more position estimates of the target.

In addition to the above features, the system according to this aspect of the presently disclosed subject matter can optionally comprise one or more of features (i) to (xxix) above, in any technically possible combination or permutation:

In accordance with other aspects of the presently disclosed subject matter, there is provided a system comprising one or more processing circuitries configured to obtain first position data informative of one or more first areas determined by at least one underwater detection system associated with a marine vehicle, obtain magnetic detection data of at least one underwater magnetic detection system associated with the marine vehicle, use at least part of the first position data and at least part of the magnetic detection data to perform at least one target detection enabling obtaining a set of a plurality of position estimates of at least one target, and process at least part of the set of a plurality of position estimates to determine an estimate of the position of the target.

In addition to the above features, the system according to this aspect of the presently disclosed subject matter can optionally comprise one or more of features (xxvi) to (xli) below, in any technically possible combination or permutation:

xxxvi. said processing enables obtaining at least one of: (i) a single position estimate of the target, or (ii) a second set of position estimates associated with a smaller dispersion than the set of a plurality of position estimates; (iii) a position estimate of the target associated with an uncertainty which

is smaller than an uncertainty associated with the set of a plurality of position estimates;

5 xxxvii. said processing includes at least one of: (i) determining data informative of a symmetry of at least part of the given set of a plurality of position estimates; (ii) determining data informative of a center of at least part of the given set of a plurality of position estimates; (iii) determining data informative of an average of at least part of the plurality of the position estimates of said given set.

10 xxxviii. the system is configured to perform target detection at different positions of the marine vehicle relative to a target, based on magnetic detection data of the magnetic detection system and on first position data of the detection system, thereby obtaining a plurality of sets of position estimates, and process at least part of the plurality of sets of position estimates to obtain tracking data informative of the target:

15 xxxix. the system is configured to perform at least one of (i), (ii) or (iii): (i) determining data informative of an average of at least part of the plurality of the position estimates of each of set of said of plurality of sets; (ii) determining data informative of a center of at least part of each set of the plurality of sets of position estimates; (iii) determining data informative of a symmetry of at least part of each set of the plurality of sets of position estimates; and using data obtained at (i), (ii) or (iii) to generate the tracking data;

20 xl. the system is configured to compare the tracking data with tracking data provided by the detection system;

25 xli. the system is configured to compare one or more geometrical properties of at least part of the set of a plurality of position estimates with one or more expected geometrical properties, and use the comparison to determine tracking data of the target.

30 In addition to the above features, the system according to this aspect of the presently disclosed subject matter can optionally comprise one or more of features (i) to (xxxv) above, in any technically possible combination or permutation:

 In accordance with other aspects of the presently disclosed subject matter, there is provided a marine vehicle associated with at least one underwater detection system, an underwater magnetic detection system, and a system according to one or more of the

aspects described above. In some examples, the marine vehicle can correspond to an underwater vehicle such as an autonomous underwater or to a surface vehicle such as a ship. In some examples, the marine vehicle is an underwater vehicle, wherein the detection system and the magnetic detection system are mounted on the underwater vehicle. In some examples, the marine vehicle is an underwater vehicle, wherein the detection system and the magnetic detection system are towed by underwater vehicle. In some examples, the marine vehicle is an underwater vehicle, wherein at least part of a system comprising the detection system and the magnetic detection system is mounted on the underwater vehicle, and another part of said system is towed by the underwater vehicle. In some examples, the marine vehicle is a ship, wherein the detection system and the magnetic detection system are towed by the ship.

In accordance with other aspects of the presently disclosed subject matter, there is provided a method comprising performing, by one or more processing circuitries, in a period of time comprising a relative motion between a marine vehicle and at least one target, in which the marine vehicle has not passed over the at least one target, obtaining first position data informative of one or more first areas determined by at least one underwater detection system associated with the marine vehicle, obtaining magnetic detection data of at least one underwater magnetic detection system associated with the marine vehicle, and using at least part of the first position data and at least part of the magnetic detection data to perform at least one target detection enabling estimating position of the at least one target.

In addition to the above features, the method according to this aspect of the presently disclosed subject matter can optionally comprise one or more of features (xlii) to (xli) below, in any technically possible combination or permutation:

- xlii. the method comprises using the first position data to determine a set of one or more three-dimensional search areas, and using at least part of the magnetic detection data to perform a target detection within the set of one or more three-dimensional search areas:
- xliii. the method comprises using the first position data to determine, for at least one given first area of the one or more first areas, a given three-dimensional search area comprising the given first area, with a larger volume than the given first area, thereby obtaining a set of one or more three-dimensional search areas, and feeding the magnetic detection data to a magnetic detection algorithm to perform a target detection within a space, wherein

said space is defined based on the set of one or more three-dimensional search areas:

- xliv. the first position data comprise range and azimuth of each of the one or more first areas, but do not comprise elevation of each of the one or more first areas.

In addition to the above features, the method according to this aspect of the presently disclosed subject matter can optionally comprise or implement one or more of features (i) to (xli) above, in any technically possible combination or permutation.

In accordance with other aspects of the presently disclosed subject matter, there is provided a method comprising performing, by one or more processing circuitries, obtaining first position data informative of one or more first areas determined by at least one underwater detection system associated with a marine vehicle, obtaining magnetic detection data of at least one underwater magnetic detection system associated with the marine vehicle, using the first position data to determine a set of one or more three-dimensional search areas, and using at least part of the magnetic detection data to perform at least one target detection within the set of one or more three-dimensional search areas, enabling estimating position of at least one target within said set of one or more three-dimensional search areas.

In addition to the above features, the method according to this aspect of the presently disclosed subject matter can optionally comprise or implement one or more of features (i) to (xli) above, in any technically possible combination or permutation.

In accordance with other aspects of the presently disclosed subject matter, there is provided a method comprising obtaining first position data informative of one or more first areas determined by at least one underwater detection system associated with a marine vehicle, obtaining magnetic detection data of at least one underwater magnetic detection system associated with the marine vehicle, using at least part of the first position data and at least part of the magnetic detection data to perform at least one target detection enabling obtaining a set of a plurality of position estimates of at least one target, and processing at least part of the set of a plurality of position estimates to determine an estimate of the position of the target.

In addition to the above features, the method according to this aspect of the presently disclosed subject matter can optionally comprise or implement one or more of features (i) to (xli) above, in any technically possible combination or permutation.

In accordance with other aspects of the presently disclosed subject matter, there is provided a non-transitory computer readable medium comprising instructions that, when executed by one or more processing circuitries, cause the one or more processing circuitries to perform, in a period of time comprising a relative motion between a marine vehicle and at least one target, in which the marine vehicle has not passed over the at least one target, obtaining first position data informative of one or more first areas determined by at least one underwater detection system associated with the marine vehicle, obtaining magnetic detection data of at least one underwater magnetic detection system associated with the marine vehicle, and using at least part of the first position data and at least part of the magnetic detection data to perform at least one target detection enabling estimating position of the at least one target.

In addition to the above features, the non-transitory computer readable medium comprises instructions that, when executed by one or more processing circuitries, cause the one or more processing circuitries to perform or include one or more of the operations of features as described above (features (i) to (xliv)).

In accordance with other aspects of the presently disclosed subject matter, there is provided a non-transitory computer readable medium comprising instructions that, when executed by one or more processing circuitries, cause the one or more processing circuitries to perform obtaining first position data informative of one or more first areas determined by at least one underwater detection system associated with a marine vehicle, obtaining magnetic detection data of at least one underwater magnetic detection system associated with the marine vehicle, using the first position data to determine a set of one or more three-dimensional search areas, and using at least part of the magnetic detection data to perform at least one target detection within the set of one or more three-dimensional search areas, enabling estimating position of at least one target within said set of one or more three-dimensional search areas.

In addition to the above features, the non-transitory computer readable medium comprises instructions that, when executed by one or more processing circuitries, cause the one or more processing circuitries to perform or include one or more of the operations of features as described above (features (i) to (xliv)).

In accordance with other aspects of the presently disclosed subject matter, there is provided a non-transitory computer readable medium comprising instructions that, when executed by one or more processing circuitries, cause the one or more processing circuitries to perform obtaining first position data informative of one or more first areas

determined by at least one underwater detection system associated with a marine vehicle, obtaining magnetic detection data of at least one underwater magnetic detection system associated with the marine vehicle, using at least part of the first position data and at least part of the magnetic detection data to perform at least one target detection enabling
5 obtaining a set of a plurality of position estimates of at least one target, and processing at least part of the set of a plurality of position estimates to determine an estimate of the position of the target.

In addition to the above features, the non-transitory computer readable medium comprises instructions that, when executed by one or more processing circuitries, cause
10 the one or more processing circuitries to perform or include one or more of the operations of features as described above (features (i) to (xliv)).

According to some examples, the proposed solution relies on a synergy between one or more magnetic sensors and one or more acoustic sensors (or other sensors, as explained hereinafter). In particular, the proposed solution benefits from the synergy
15 between acoustic sensor(s) and magnetic sensor(s) to overcome inherent drawbacks of each type of sensor used independently.

According to some examples, the proposed solution enables target detection in advance, while the underwater vehicle is approaching the target. In particular, the target can be detected even if the underwater vehicle has not passed over the target (and even
20 if the underwater vehicle will not pass over the target).

According to some examples, the proposed solution enables accurate target detection.

According to some examples, the proposed solution enables target tracking.

According to some examples, the proposed solution enables both accurate
25 underwater target detection and surface target detection.

According to some examples, the proposed solution enables improved collision avoidance for underwater vehicles, such as autonomous underwater vehicles (AUV).

According to some examples, the proposed solution improves efficiency of missions performed by underwater vehicles, such as AUVs.

30 According to some examples, the proposed solution proposes a fully automatic collision detection solution for underwater vehicles, such as AUVs.

According to some examples, the proposed solution does not require complex manoeuvres of the underwater vehicle for target detection.

According to some examples, the proposed solution can be used to facilitate ascension to periscopic depth of an underwater vehicle. In particular, it enables autonomous and safe ascension to periscopic depth of an underwater vehicle. In some examples, a fully autonomous ascent of an AUV is ensured.

5 According to some examples, the proposed solution can be used to perform a seabed scan.

 According to some examples, the proposed solution can be used to perform a surface scan.

 According to some examples, the proposed solution can be used for situational
10 awareness.

 Note that the proposed solution can be used for various applications (some of which are listed hereinafter the specification). However, the proposed solution is not limited to these applications.

15 **BRIEF DESCRIPTION OF THE DRAWINGS**

 In order to understand the invention and to see how it can be carried out in practice, embodiments will be described, by way of non-limiting examples, with reference to the accompanying drawings, in which:

- 20 - **Fig. 1** illustrates an embodiment of a system usable to detect underwater and/or surface target(s);
- **Fig. 2** illustrates a non-limitative example of an underwater vehicle embedding the system of **Fig. 1**;
- **Fig. 3** illustrates a method allowing estimating position of a target, using the system of **Fig. 1**;
- 25 - **Figs. 4A to 4C** illustrate properties of an acoustic detection system;
- **Fig. 5A** and **5B** illustrate a method allowing estimating position of a target, using the system of **Fig. 1**;
- **Figs. 6A to 6C** illustrate a method of limiting the space in which a target detection is performed, based on data provided by a detection system (such as
30 an acoustic detection system);
- **Figs. 7A** and **7B** illustrate a method allowing estimating position of a target, using the system of **Fig. 1**;
- **Figs. 8A** and **8B** illustrate a method allowing estimating position of a target, before the underwater vehicle passes over the target, using the system of **Fig. 1**;

- **Fig. 8C** illustrates a situation in which the underwater vehicle has passed over the target;
- **Figs. 9A and 9B** illustrate a method allowing estimating position of a target, in which a plurality of target detections is performed over time, using the system of **Fig. 1**;
- **Fig. 9C** illustrates a method in which dimension(s) of a 3D search is dynamically modified over time;
- **Figs. 10A, 10B, 11A, 11B, 12A and 12B** illustrate different methods of using different magnetic detection data acquired over time;
- **Fig. 13A** illustrates a non-limitative example of a method which uses different target position estimates provided at a given position of the underwater vehicle relative to a target, to estimate position of the target;
- **Fig. 13B** illustrates a non-limitative example of a method which uses different target position estimates provided for different positions of the underwater vehicle relative to a target, to estimate position of the target;
- **Fig. 14** illustrates a non-limitative example of different target position estimates provided at different positions of the underwater vehicle relative to a target;
- **Fig. 15** illustrates a non-limitative example of processing a plurality of sets of position estimates obtained at different positions of the underwater vehicle, to determine data informative of a target;
- **Fig. 16A** illustrates a non-limitative example of a method which uses different target position estimates provided at a given position of the underwater vehicle relative to a target, to estimate position of the target;
- **Fig. 16B** illustrates a non-limitative example of a method which uses different target position estimates provided for different positions of the underwater vehicle relative to a target, to estimate position of the target;
- **Fig. 17A** illustrates a non-limitative example of the method of **Fig. 16B**;
- **Fig. 17B** illustrates another non-limitative example of the method of **Fig. 16B**;
- **Fig. 17C** illustrates another non-limitative example of the method of **Fig. 16B**;
- **Fig. 18A** illustrates a non-limitative example of a method which uses different target position estimates provided for different positions of the underwater vehicle relative to a target, to track the target;
- **Fig. 18B** illustrates a non-limitative example of the method of **Fig. 18A**;

- **Figs. 19A to 19D** illustrate a non-limitative example of a method using one or more geometrical properties of a plurality of sets of position estimates to track a target;
- **Fig. 20A** illustrates a method of controlling operation of an acoustic detection system;
- **Fig. 20B** illustrates another method of controlling operation of an acoustic detection system; and
- **Figs. 21 to 25** illustrate various non-limitative applications of the various methods described herein.

DETAILED DESCRIPTION

Attention is now drawn to **Fig. 1**, which describes a system **100**. System **100** can be used to perform various methods, such as, but not limited to, one or more of the methods described hereinafter. System **100** is operative to operate underwater.

System **100** includes at least one detection system **110**. The at least one detection system **110** operates underwater. For example, it can be mounted on an underwater vehicle (see e.g., **Fig. 2**), or towed by an underwater vehicle or a ship. The detection system **110** can operate underwater in order to provide detection data and/or localization data and/or tracking data informative of one or more underwater targets and/or one or more surface targets.

In the present description, the detection system **110** will mainly be referred to as an acoustic detection system **110**. This is however not limitative, and the detection system **110** can correspond to a laser detection system (such as, but not limited to, a laser light detection and ranging system (LIDAR), a green laser light detection and ranging system, etc.), or to another target detection system which can operate underwater, and which does not correspond to a magnetic sensor.

The acoustic detection system **110** can receive ambient sound in order to detect the presence of sound-generating objects such as (but not limited to) an engine, a ship in motion, etc. The acoustic detection system **110** can determine data informative of targets which are located underwater, and/or (with a smaller accuracy) of surface targets based on the detection of acoustic waves.

The acoustic detection system **110** can be a passive system or an active system. In some examples, the acoustic detection system **110** can switch from a passive mode to an active mode, or conversely.

5 The acoustic detection system **110** can include one or more passive sonars and/or one or more active sonars. In some examples, the one or more sonars can be tilted. In some examples, the acoustic detection system **110** can include one or more Flank Array Sonar(s) (FAS) and/or one or more Tiltable Forward Looking Sonar(s) (FLS – which corresponds to an active sonar located on the front of an underwater vehicle).

10 The acoustic detection system **110** typically includes one or more array(s) **113** of microphones operative to sense acoustic waves (sound).

If the acoustic detection system **110** includes an active sonar, it can include a transducer **112** operatively coupled to the one or more arrays of microphones.

Note that the acoustic sensing system **110** can include, or can be operatively coupled to a processing circuitry **105** which can process data sensed by the array **113** of microphones. The processing circuitry **105** can determine data informative of targets based on the acoustic data sensed by the array **113** of microphones, such as range, azimuth, tracking data of targets, etc.

20 System **100** further includes at least one magnetic detection system **120**. The magnetic detection system **120** can operate underwater in order to detect underwater targets and/or surface targets, based on magnetic data informative of the targets. The magnetic detection system **120** can be mounted on an underwater vehicle (in particular, on the same underwater vehicle as the acoustic detection system **110**), or towed by an underwater vehicle or a ship.

25 The magnetic detection system **120** includes one or more magnetic sensor(s) **121**. The one or more magnetic sensor(s) **121** can measure a magnetic field (e.g., field strength and/or field direction). In some examples, the magnetic sensors **121** are part of a gradiometer (not represented). The gradiometer can evaluate the difference between two measurements of different magnetic sensors.

30 The magnetic sensing system **120** can include or can be operatively coupled to a processing circuitry **106** which can process data sensed by the magnetic sensor(s) **121**.

In some examples, the acoustic detection system **110** and the magnetic detection system **120** are synchronized, using the same synchronization clock (not represented).

System **100** includes at least one (or more) processing circuitry **104**, which each includes one or more processors and one or more memories. The processing circuitry

104 can be operatively coupled to the acoustic detection system **110** and to the magnetic detection system **120**.

In particular, the processing circuitry **104** can receive data from the acoustic detection system **110** and/or from the magnetic detection system **120**.

5 In some examples, processing of the data sensed by the array **113** of microphones and/or by the magnetic sensor(s) **121** can be performed by the processing circuitry **104**.

In some examples, the processing circuitry **104** can control operation of the acoustic detection system **110** and/or of the magnetic detection system **120**.

10 The processing circuitries **104**, **105** and **106** can correspond to distinct processing circuitries, or can correspond to a common processing circuitry. As explained hereinafter, system **100** can be mounted on an underwater vehicle. In some examples, at least some of the operations performed by the processing circuitries **104**, **105** and/or **106** can be performed on-board, and/or can be performed remotely by one or more remote processing
15 circuitries (such as a remote server, cloud, etc.) operative to communicate with the system **100**.

System **100** enables executing at least one magnetic detection algorithm **130**. As explained hereinafter, the magnetic detection algorithm **130** is operative to estimate the position (three-dimensional position) of one or more (underwater and/or surface)
20 targets based on magnetic detection data **161** of the magnetic detection system **120** (in particular of the magnetic sensors **121**) and based on data **160** provided by the acoustic detection system **110**. The magnetic detection algorithm **130** can correspond e.g., to an optimization algorithm which is able to determine position of targets based on magnetic detection data. It will be explained hereinafter how the first position data can be used
25 by the magnetic detection algorithm **130**. Note that the estimated position of the target(s) can be expressed relative to the underwater vehicle (range, azimuth, elevation), and/or as an absolute position. The data **160** provided by the acoustic detection system **110** can include a first indication of areas in which targets may be located according to the acoustic detection system **110**, which can be used by the magnetic detection
30 algorithm **130** to facilitate processing of the magnetic detection data in order to determine the position of the target(s) by the magnetic detection algorithm **130**. This will be further discussed hereinafter.

In some examples, the magnetic detection algorithm **130** can be implemented by the processing circuitry **106** and/or by the processing circuitry **104** and/or by another

processing circuitry. Instructions stored in a computer readable medium can be executed by one or more processing circuitries to operate the magnetic detection algorithm **130**.

5 Elements of the system **100** depicted in **Fig. 1** can be made up of any combination of software and hardware and/or firmware. Elements of the system depicted in **Fig. 1** may be centralized in one location or dispersed over more than one location. In other examples of the presently disclosed subject matter, the system of **Fig. 1** may comprise fewer, more, and/or different elements than those shown in **Fig. 1**. Likewise, the specific division of the functionality of the disclosed system to specific parts, as described below, is provided by way of example, and other various alternatives
10 are also construed within the scope of the presently disclosed subject matter. For example, the processing circuitry **104** can be part of the acoustic sensing system **110** and/or of the magnetic sensing system **120**.

System **100** is usable to detect targets, such as underwater target(s) (e.g.,
15 underwater vehicles, autonomous underwater vehicles, sunk ships, mines, or any other underwater object which has a magnetic moment) and/or surface target(s) (e.g., ships, autonomous ships, buoys, or any other surface object which has a magnetic moment). Note that a surface object generally includes a portion thereof which is immersed underwater – most of the surface object is however located above the sea level. Each
20 target includes one or more components associated with a magnetic moment. The magnetic moment enables the target to modify the Earth's magnetic field lines. This property can be used to detect and localize the target, by measuring the variation of magnetic fields, as explained hereinafter.

A target detected by system **100** generally corresponds to a target for which
25 there is a relative motion between system **100** and the target. This can be due to the fact that the underwater vehicle **200** moves relative to the target, or because the target moves relative to the underwater vehicle **200**, or because both the underwater vehicle **200** and the target are both in motion.

System **100** can be also used to track one or more targets over time.

30 Target(s) can include objects with which an interaction has to be performed (such as, but not limited to, collection of the object(s), destruction of the objects, mapping of the object(s), measurement of properties of the object(s), etc.), and/or objects corresponding to obstacles that need to be avoided (e.g., by an underwater

vehicle during its mission). This is however not limitative, and different types of targets can be detected.

As visible in **Fig. 2**, system **100** can be associated with a marine vehicle (such as an underwater vehicle - see e.g., the non-limitative example of underwater vehicle **200** depicted in **Fig. 2**) or a ship.

This association includes various possible configurations, as explained hereinafter.

The system **100** can be mounted on the underwater vehicle **200** and/or a at least part (such as the acoustic detection system **110** and the magnetic detection system **120**), or all of the underwater system **100** is towed by the underwater vehicle **200** (using e.g., a cable coupled to the underwater vehicle **200**, on which the acoustic detection system **110** and the magnetic detection system **120** are mounted). When the detection system **110** and the magnetic detection system **120** are towed by an underwater vehicle, they are located underwater. In some examples, a single cable is used, on which both the acoustic detection system **110** and the magnetic detection system **120** are mounted. In other examples, the acoustic detection system **110** is mounted on a first cable and the magnetic detection system **120** is mounted on a second cable, both towed by the underwater vehicle **200**. In some examples, part of the acoustic detection system **110** and part of the magnetic detection system **120** are mounted on a first cable, and another part of the acoustic detection system **110** and another part of magnetic detection system **120** are mounted on a second cable.

In some examples, the acoustic detection system **110** is towed by the underwater vehicle **200** and the magnetic detection system **120** is mounted on the underwater vehicle **200**. In other examples, the acoustic detection system **110** is mounted on the underwater vehicle **200** and the magnetic detection system **120** is towed by the underwater vehicle **200**.

In some examples, system **100** (or at least the acoustic detection system **110** and the magnetic detection system **120**) can be towed by a surface object, such as a ship which tows system **100** (system **100** being located underwater while being towed). When the detection system **110** and the magnetic detection system **120** are towed by the ship, they are located underwater. The acoustic detection system **110** and the magnetic detection system **120** can be mounted on a same cable towed by the ship. Note that one or more of the processing circuitries of system **100** can be mounted on the cable

and/or on the underwater vehicle. When the detection system **110** and the magnetic detection system **120** are towed by a ship, they are located underwater.

In some examples, a single cable towed by the ship is used, on which both the acoustic detection system **110** and the magnetic detection system **120** are mounted. In other examples, the acoustic detection system **110** is mounted on a first cable and the magnetic detection system **120** is mounted on a second cable, both towed by the ship. In some examples, part of the acoustic detection system **110** and part of the magnetic detection system **120** are mounted on a first cable, and another part of the acoustic detection system **110** and another part of magnetic detection system **120** are mounted on a second cable, both towed by the ship.

Note that in these various configurations, one or more of the processing circuitries of system **100** can be mounted on the cable and/or on the marine vehicle (underwater vehicle or ship). The cable can transmit data between one or more systems of the marine vehicle and one or more systems located on the cable.

Note that in these various configurations, it is possible to mount the magnetic sensors and the acoustic sensors on the cable such as there is an alternance between subset(s) of one or more magnetic sensors with subset(s) of one or more acoustic sensors/microphones (e.g. a magnetic sensor, then an acoustic sensor, then another magnetic sensor, etc. – this is not limitative and other types of alternance can be used).

Although the specification mainly mentions hereinafter operation of system **100** in association with an underwater vehicle, the teaching of the specification applies similarly to a system **100** associated with a surface object such as a ship.

In some other examples, system **100** can be mounted on an underwater platform which is stationary, such as the immersed portion of an oil platform, etc., in order to detect targets which are mobile relative to the underwater platform.

The underwater vehicle includes e.g., a submarine, an autonomous underwater vehicle (or AUV in short), or another underwater platform.

The term autonomous underwater vehicle can include an unmanned, self-propelled, untethered underwater vehicle capable of carrying out underwater tasks with little or no human intervention. Such activities may include, for example, surveying the seabed (e.g., for the purpose of ocean cartography studies), characterizing physical or chemical properties of the water, underwater biological research, etc. These activities are not limitative, and other activities can be performed.

Different underwater vehicles are known today to have various degrees of autonomous capabilities, with varying levels of a need for human supervision and interference during operation.

As shown in **Fig. 2**, the underwater vehicle **200** can embed, in addition to system **100**, various additional modules, such as (but not limited to): a navigation controller **210** (which can include one or more processing circuitries usable to determine the route of the underwater vehicle, and to control the various actuators of the underwater vehicle in order to comply with this route), additional sensors **220** (e.g., localization sensor, cameras, etc.), etc. System **100** can communicate data with the navigation controller **210** and/or with the other modules of the underwater vehicle **200**. This enables, for example, implementing a collision avoidance method, in which system **100** detects one or more obstacles and transmits information on these one or more obstacles to the navigation controller **210**, which adapts the route of the underwater vehicle **200** accordingly (for example by controlling the underwater vehicle **200** along a route which enables avoiding these one or more obstacles). This will be further discussed hereinafter.

In some examples, the underwater vehicle **200** is composed of a non-magnetic material (such as, but not limited to, aluminium or fiberglass), so as to reduce the magnetic signature of the underwater vehicle **200** and facilitate use of magnetic sensors **121**. This is however not limitative.

In some examples, system **100** (or at least the acoustic detection system **110** and the magnetic detection system **120**) can be towed by an underwater vehicle. The acoustic detection system **110** and the magnetic detection system **120** can be mounted on a same cable towed by the underwater vehicle.

Attention is now drawn to **Fig. 3**, which depicts a method of detecting targets according to some examples of the invention, using e.g., system **100**. As mentioned above, system **100** is located underwater and is typically mounted on an underwater platform, such as an underwater vehicle.

The method includes obtaining (operation **300**) first position data **160** obtained based on at least one detection performed by the at least one detection system **110**. Hereinafter, the detection system **110** will be referred to as corresponding to an acoustic detection system **110** – however, as mentioned above, this is not limitative.

The first position data **160** is informative of one or more first areas determined by the acoustic detection system **110**. The first areas correspond to areas identified/detected

by the acoustic detection system **100**, based on sensed acoustic data, as including one or more targets. Note that the first areas are informative of candidate targets, since some of the first areas can correspond to areas in which no actual target is present (false positive). As mentioned in the background section, incorrect target detections can be due to noise
5 such as (but not limited to) reverberation effects.

The first position data **160** are transmitted to the magnetic detection algorithm **130**. The first position data **160** can be transmitted directly by the acoustic detection system **110** to the magnetic detection system **120**, or can be communicated to the processing circuitry **104** which forwards these data (in their original state, or after some pre-
10 processing) to the magnetic detection system **120**. Other paths of communication can be used to transmit the first position data **160** to the magnetic detection algorithm **130**.

Figs. 4A to 4C provide diagrams which are beneficial to further understand some properties of the first position data **160**, according to some examples of the invention. Note that the first position data are not limited to the description provided
15 with reference to **Figs. 4A to 4C**.

In the acoustic detection system **110** (which can be e.g., a sonar), a processing circuitry receives acoustic data sensed by the one or more array(s) **113** of microphones, and processes the acoustic data to provide data informative of one or more first areas detected as comprising (with a certain likelihood) one or more candidate targets. The data
20 provides certain information on the position of the one or more first areas. Note that the processing circuitry can include the processing circuitry **105** of the acoustic sensing system **110** itself and/or can correspond to the processing circuitry **104** and/or another processing circuitry operatively coupled to the acoustic detection system **110**.

As visible in **Fig. 4A**, the first position data **160** generally includes, for each given
25 first area of the one or more first areas (see e.g., first areas **410₁** and **410₂**): the range (generally noted R and corresponding to the distance between the acoustic detection system **110** and the given first area) and the azimuth (generally noted φ – if one defines a Cartesian referential XYZ, in which the Z axis corresponds to the gravity axis and the plane XY is orthogonal to the Z axis, the angle φ defines the angular deviation in the
30 XY plane).

However, in at least some examples, the acoustic sensing system **110** cannot provide the elevation angle (also called height angle) of the one or more first areas, or may provide it with a high level of uncertainty.

Indeed, at least some sonars cannot provide the elevation angle of the candidate targets. These kinds of sonars are generally selected to be mounted on underwater vehicles such as AUV, because of their cost. Note that it exists sonars which can provide an estimate of the elevation angle. These sonars are generally very costly and are therefore not adapted to be mounted on underwater vehicles such as AUV. Their high cost is prohibitive for a usage on small platforms such as AUV. Although various methods are described hereinafter with sonars which do not provide the elevation angle of the candidate targets, it has to be understood that these various methods can be used (*a fortiori*) similarly with sonars which provide the elevation angle of the candidate targets. Indeed, these (expensive) sonars also suffer from reverberation effects, and other sources of noise, which make them provide various false positives – therefore, the various methods described hereinafter can be used to improve target detection.

As visible in **Figs. 4B** and **4C**, assume that a sound-producing target **420** is located at a position with a range R , azimuth angle ϕ , and elevation angle β . The acoustic detection system **110** of the underwater vehicle **200** can estimate R and ϕ , but cannot estimate β . As a consequence, the first area **430** detected by the acoustic detection system **110** in the example of **Fig. 4C** corresponds to a slice of the space which has a range R , an azimuth angle ϕ , for all (possible) values of the elevation angle β . The slice can correspond to a 2D surface or to a 3D area. It can be understood from these diagrams that prior art systems, which rely on the sole usage of sonars for detecting targets (which do not provide elevation angle), suffer from a high level of uncertainty. Indeed, the uncertainty of the sonar on the elevation angle of the target(s) is such that it prevents from determining the 3D position of the target(s). In prior art systems, it can occur for example that a target is present at the seabed, which is not an obstacle for the AUV, but the sonar will consider that the whole slice including this target (from the seabed up to the surface of the sea) has to be avoided by the underwater vehicle.

The method of **Fig. 3** further includes obtaining (operation **310**) magnetic detection data **161** of the at least one magnetic sensing system **120**.

The magnetic detection data **161** can include magnetic signals (e.g., magnetic fields) measured by the magnetic sensor(s) **121**. The magnetic signals can typically include magnetic field strength and magnetic field direction, or these data can be derived from the magnetic signals. The magnetic detection data **161** can correspond, e.g., to data output by

the magnetic sensor(s) **121**, or to data derived (after a pre-processing, such as filtering) from the data output by the magnetic sensor(s) **121**.

The method of **Fig. 3** further includes (operation **320**) using at least part of the first position data and at least part of the magnetic detection data to perform a target detection, in which the position (3D position) of one or more targets is determined.

As illustrated with reference to **Figs. 5A** and **5B**, the first position data **160** (which includes data informative of the position of the first areas detected by the acoustic detection system **110**) and the magnetic detection data **161** (corresponding to, or derived from the magnetic signals detected by the magnetic sensor(s) **121**) can be fed (operation **510**) to the magnetic detection algorithm **130**, which attempts to determine the 3D position of target(s) in the space. The magnetic detection algorithm **130** estimates the three components of the 3D position of the target(s). Note that depending on the range to the target, the magnetic detection algorithm **130** can output different estimates of the position of the target: the spatial dispersion of these estimates is reduced as the range to the target is reduced. As explained hereinafter, the magnetic detection algorithm **130** can search for targets based on the magnetic detection data. This search can be constrained within a limited volume of the space, which is defined based on the first position data. All of the target search (also called target detection), or most of the search, or at least part thereof can be limited to this limited volume of the space. The estimated 3D position of the target can be expressed in any relevant coordinate system, such as Cartesian coordinates (X, Y, Z), polar/spherical coordinates (range, azimuth, elevation), etc. Localization of the target(s) is therefore obtained. As explained hereinafter, the method of **Fig. 3** can be performed in a period of time in which there is a relative motion between the underwater vehicle and at least one target. Localization of the (at least one) target can be performed during this period of time, even if the underwater vehicle has not passed over the target. An in-advance target detection is therefore performed.

Attention is now drawn to **Figs. 6A** and **6B**.

The first position data **160** (which results from the acoustic detection system **110**) can be used to limit the size/volume of the space in which the magnetic detection algorithm **130** has to search for targets. The first position data **160** can be used to define (operation **610**) one or more 3D areas (search areas), which correspond to volume(s) of the space in which the magnetic detection algorithm **130** searches for targets based on the magnetic detection data. The magnetic detection algorithm **130** can be configured to search for targets based on the magnetic detection data only in the 3D areas. In some examples, for

each given first area of the first areas, a (corresponding) given 3D search area is defined. The given 3D area can include the given first area but covers a larger volume. Indeed, the acoustic detection system **110** may be inaccurate in its determination of each given first area. Therefore, generation of a given 3D area, which is larger than the given first area, enables to take into account this possible inaccuracy. In addition, the target may be mobile, and it is therefore beneficial to use a given 3D area which is larger than the given first area. Lastly, the target is not a point (but rather covers a certain volume), and this has to be taken into account in the definition of the 3D areas. Note that the dimensions of the 3D area, the position of the 3D area with respect to the corresponding first area, the shape of the 3D area, and other parameters of the 3D area, can be defined by a user, and/or can be pre-defined, and/or can be set according to some rules. It is possible to generate one or more 3D search areas with different geometrical properties (shape, dimension) than one or more other 3D search area(s), but this is not mandatory.

Fig. 6B illustrates a non-limitative example of operation **610**. **Fig. 6B** illustrates an underwater vehicle **200** (which embeds the system **100**, not represented) and a target **620**. The acoustic detection system **110** has detected a first area **630** around the target **620**. The acoustic detection system **110** provides an estimate of the range and azimuth of the target **620**, but cannot determine the elevation of the target **620** (or with high uncertainty), which is why the acoustic detection system **110** can only provide the first area **630** (slice) located around the target **620** as an estimate of its position. In accordance with operation **610**, the first area **630** is used to generate a 3D area **640**. In this example, the 3D area **640** is a cube, but this is not limitative (other shapes can be used, such as spheres, etc.).

The magnetic detection algorithm **130** uses the magnetic signals (magnetic detection data **161**) to perform a target detection within the one or more 3D areas determined at operation **610**. In some examples, the magnetic detection algorithm **130** searches mainly (or only) for targets within the one or more 3D areas. All of the target search (also called target detection), or most of the search, or at least part thereof can be limited to this limited volume of the space corresponding to the one or more 3D areas.

This target detection is facilitated by generation of the one or more 3D areas, since the size of the space in which the magnetic detection algorithm **130** attempts to detect targets is limited to the one or more 3D areas only. In other words, instead of being forced to search for targets in the whole space based on the sensed magnetic signals, this search is confined to the one or more 3D areas generated based on the first areas provided by the acoustic detection system **110**. Note that searching for targets in

the whole space (and not in the limited set of one or more 3D search areas) would be complex. This is further emphasized in scenarios in which only partial magnetic information is obtained from the target (see examples hereinafter e.g., in **Fig. 8B**, in which the underwater vehicle does not pass over the target, and therefore obtains only a partial magnetic signature of the target). Smart usage of the one or more 3D search areas reduces the complexity of target detection, and enables determining the position of the target even in scenarios in which only a partial magnetic signature of the target is available. The computation time is reduced, and the number of solutions (which correspond to position estimates) output by the algorithm is reduced. Accuracy is therefore improved.

The magnetic detection algorithm **130** outputs (operation **615**) at least one estimate of the 3D position of at least one target. This 3D position is located within the limited set of the one or more 3D search areas. As explained hereinafter, even for a single target, the magnetic detection algorithm **130** can output a plurality of estimates for the position of the target – as the range to the target decreases, the number and the spatial dispersion of these estimates is reduced.

Fig. 6C illustrates that the magnetic detection algorithm **130** outputs a plurality of target position estimates of the target **620**, which are located in the volume **650**. At this stage, the magnetic detection algorithm **130** has estimated that the target is located in this volume. As the range to the target decreases, the method can be repeated, and the size of the volume decreases until accurate location of the target is obtained, before the underwater vehicle passes over the target.

The methods of **Figs. 3** and **6A** can be repeated over time, for different positions of the underwater vehicle relative to the target(s). At each relative position, one or more estimates of the 3D position of the target(s) can be provided. Generally, the uncertainty associated with the estimate decreases as the range to the target decreases, and therefore the volume in which the estimate(s) provided by the magnetic detection algorithm **130** decreases over time, as visible in **Fig. 9B**.

As explained above, the first areas correspond to slices with a high level of uncertainty on the height/elevation. The output of the magnetic detection algorithm **130** reduces this uncertainty, or even cancels this uncertainty when sufficient magnetic detection data has been acquired, and/or when the underwater vehicle has approached the target at a certain distance (without requiring the underwater vehicle to pass over the target). It provides, for each target, an estimate of its position (e.g., range, azimuth,

and elevation – or using any other convention enabling expressing the 3D position of object). Note that depending on the distance between the underwater vehicle and the target, the output of the magnetic detection algorithm **130** can include different estimates of the position of the target, which are dispersed. However, it has to be noted
5 that the more the underwater vehicle approaches the target, the smaller the number of estimates (and the smaller their dispersion).

Note that the one or more estimates of the position of the at least one target output by the magnetic detection algorithm **130** can differ from the first position data, and one or more of these estimates can be located outside of the first areas detected by the acoustic
10 detection system **110**. Indeed, the first position data are mainly used as a “starting point” to generate 3D search areas which limit the volume of the space in which the magnetic detection algorithm **130** is searching for targets based on the magnetic data, but the magnetic detection algorithm **130** can determine one or more 3D positions of the at least one target which differ from the first position data. This is due to the fact that the 3D search
15 areas are larger than the first areas, and therefore it can occur that the magnetic detection algorithm **130** detects targets outside of the first areas. It can refine/modify/improve the initial “guess” of the acoustic detection system **110**.

Attention is now drawn to **Figs. 7A and 7B**.

As mentioned above, the magnetic detection algorithm **130** receives both the first
20 position data **160** and the magnetic detection data **161** and uses them to estimate the 3D position of target(s). The first position data **160** is used as a constraint (spatial constraint) which enables limiting the space in which the magnetic detection algorithm **130** searches for targets based on the magnetic detection data **161**.

Various existing magnetic detection algorithms can be used as a basis to generate
25 the magnetic detection algorithm **130**. However, the magnetic detection algorithm **130** is modified with respect to these existing magnetic detection algorithms at least in that it receives a new input (the first position data **160**) which is used to limit the 3D volume in which the magnetic detection algorithm **130** searches for targets to one or more specific 3D areas derived from the first position data **160**.

30 Any magnetic detection algorithm which searches for targets in space based on magnetic detection data (magnetic signals) can be modified with the additional constraint that the targets are searched for only in the 3D areas derived from the first position data **160**, in order to obtain the magnetic detection algorithm **130**. In some examples, the magnetic detection algorithm **130** searches for targets within a plurality of sub-areas of at

least one 3D area (this corresponds to a sampling of the 3D area), or of each 3D sub-area. Note that the sampling (number of samples, dispersion of the samples) can be different for each 3D search area, but this is not mandatory.

In some examples, the magnetic detection algorithm **130** can be based on the PSO (Particle Swarm Optimization) algorithm, which is modified such that its area of search is limited to one or more specific 3D areas derived from the first position data **160**, as explained above. This is however not limitative, and other existing magnetic detection algorithms, which search for targets in space based on magnetic detection data (e.g., magnetic signatures), can be used: Monte Carlo method (which uses e.g., data of a magnetometer array), Unscented Kalman filter for target tracking, Simulated annealing (a global search method usable to solve optimization problems), Shading filter (usable to estimate full track trajectory). As explained in the various methods described herein, these algorithms can be modified such that the area(s) of search of the targets (target detection/localization) is limited (e.g., only or mostly) to one or more specific 3D areas derived from the first position data **160**.

Attention is now drawn to **Figs. 7A** and **7B** which illustrate principles which can be used by the magnetic detection algorithm **130** to detect target(s), according to some examples of the invention.

When a metallic/ferromagnetic object is present at a given location, it gives rise to detectable local disturbances in the Earth's magnetic field. The magnetic signature of a given target can correspond to these detectable local disturbances. Note that the magnetic signature can differ, depending on the type of target, the relative position (range, azimuth, elevation) of the target, and/or the direction of motion (orientation) of the target with respect to the magnetic sensors detecting the magnetic signals.

It is possible to build a database **740** of magnetic signatures. This database can be built using simulation data and/or using experimental data. In some examples, this database can store corresponding magnetic signature(s) for each type of target (e.g., different types of AUV, different types of magnetic obstacles, etc.), for different positions (range/elevation/azimuth) of the target and/or for different orientations (directions of motion of the target) at each position. Non-limitative examples of types of targets include different types of submarines, different types of AUVs, sunk ships, metallic mines, etc. This type of database is used in at least some implementations of the conventional PSO algorithm.

Although the database can be built in advance, it may be built (at least partially) on-board, by performing simulations (this reduces, however, the speed of the algorithm).

The magnetic detection data **161** obtained by the magnetic detection algorithm **130** can correspond to raw data provided by the magnetic sensors **121**, which can be pre-processed. The pre-processing can include operations such as filtering, or other adapted operations. This enables obtaining measured magnetic signatures, which reflect modification of the Earth's magnetic field by the various magnetic targets present in outer space. In some examples, the magnetic signatures are directly obtained by the magnetic detection algorithm **130**.

In a conventional PSO algorithm (which relies only on magnetic detection data, and does not receive information from an acoustic detection system), the whole space is randomly sampled into a plurality of points or sub-areas distributed along a dense grid. Assume that the underwater vehicle is located at a given current position. For each given point (sample point) in the outer space, the conventional PSO algorithm determines whether the measured magnetic signature, measured for the given current position of the underwater vehicle, matches a given magnetic signature of the database, if a target with this given magnetic signature has been located at this given point. In other words, the algorithm compares various candidate magnetic signatures (extracted from a database such as the database **740**) with the measured magnetic signatures. If a match according to an optimization criterion is obtained, this can correspond to detection of a target. Note that these principles are provided for illustration only, and the PSO algorithm can use more processing steps and/or different processing steps to detect magnetic targets based on magnetic detection data.

According to some examples of the approach proposed herein, the first position data **160** provided by the acoustic sensing system **110** is used to determine a limited subset **770** of one or more 3D areas (operation **710**). If the magnetic detection algorithm **130** relies on the principles of the PSO algorithm outlined above, it searches for targets based on the measured magnetic signatures only in the limited subset **770** of one or more 3D areas. Each 3D area can be sampled into a plurality of points (or sub-areas within the 3D area, containing one or more points). For each given point (or each given sub-area) of each 3D area, the magnetic detection algorithm **130** determines whether the measured magnetic signature measured for a given position of the underwater vehicle matches a given magnetic signature of the database **740**, if a target with this

given magnetic signature has been located at this given point or at this given sub-area (operation **720**). In other words, several magnetic signatures of the database are tested to determine whether one of them would match the measured magnetic signature(s), for one or more of the different sub-areas sampled within the 3D areas. Detection of a target
5 can be performed for the point(s) or sub-area(s) of the 3D areas for which the best match is obtained.

Note that these principles are provided for illustration only, and the magnetic detection algorithm **130** can use more processing steps and/or different processing steps to detect magnetic targets based on magnetic detection data within the limited subset of
10 one or more 3D areas. In addition, the magnetic detection algorithm **130** does not necessarily rely on the principles of the PSO algorithm.

Attention is now drawn to **Fig. 8A** and **Fig. 8B** which illustrate a non-limitative example of a scenario in which the proposed solution can be used, according to some examples of the invention.

15 Assume that there is a relative motion between an underwater vehicle **200**, which embeds system **100** operative to perform one or more of the various methods described herein, and a target **850** (underwater target or surface target). For example, this relative motion can be such that the range between the underwater vehicle and the target **850** decreases over time. The relative motion can be due to the fact that the
20 underwater vehicle is in relative motion with respect to the target, and/or that the target is in relative motion with respect to the underwater vehicle.

The method of **Fig. 8A** corresponds to the usage of the method of **Fig. 3**, (or of any of the other methods described herein, such as **Fig. 6A**) during a period of time in which a relative motion occurs between the underwater vehicle and the target.

25 The method of **Fig. 8A** enables in-advance detection of the target **850** by the system **100**. In particular, it enables detection of the target **850** in a situation in which the underwater vehicle **200** has not passed over the target **850**. Note that detection of the target **850** is enabled even if the underwater vehicle **200** never passes over the target **850**. In other words, the method enables detecting target **850** (this includes estimating
30 the 3D position of the target **850**) without requiring the underwater vehicle **100** to pass over the target.

Passing over a target **850** corresponds to a situation (see **Fig. 8C**) in which the system **100** (or the magnetic detection system **120**, or equivalently the marine vehicle such as the underwater vehicle **200**, when the system **100** is mounted on the marine

vehicle) crosses a direction **880** which passes through the target **850** and is orthogonal to the trajectory of the marine vehicle, such as the underwater vehicle **200** (or when the target crosses a direction which passes through system **100**, or through the magnetic detection system **120**, or through a marine vehicle on which the system **100** is mounted, and which is orthogonal to the trajectory of the target).

Passing over a target is assessed in a 3D space. Note that passing over a surface target by an underwater vehicle can be performed by passing below the target (at a vertical direction of the target), or on the sides of the target. Passing over an underwater target by an underwater vehicle can be performed by passing below the target, on the sides of the target, or above the target. Passing over an underwater target by a ship can be performed by passing above the target or on the sides of the target. Passing over a surface target by a ship can be performed by passing on the sides of the target.

In the non-limitative example of **Fig. 8B**, target **850** is detected by system **100** when the underwater vehicle **200** is located at location **830**. Note that before reaching location **830**, system **100** can determine a plurality of initial target position estimates of the location of the target **850** (which can include false positive detection(s)), for different positions of the underwater vehicle **200** relative to the target **850**. At each position of the underwater vehicle **200** relative to the target **850**, first position data are provided by the acoustic detection system **110**, which are used together with magnetic detection data of the magnetic detection system **120**, to estimate the 3D position of the target **850**.

At location **830**, the target **850** is detected with the required accuracy. Such required accuracy can depend on the type of mission, type of targets, requirements of the operator, etc.

It can be understood from **Fig. 8B** that the proposed solution(s) enables an in-advance and accurate detection of targets (without requiring passing over the target), which is crucial for several applications, such as collision avoidance, automatic control of underwater vehicles, etc. Although the magnetic detection system **120** of system **100** measures only a partial magnetic signature of the target **850** (since the underwater vehicle **200** does not pass over the target **850**), system **100** is able to determine the (3D) position of the target **850**, using the various methods described herein. The method benefits *inter alia* from the smart usage of the first position data which enables generating one or more 3D search areas, limiting the space in which the magnetic detection algorithm **130** searches for targets based on the magnetic detection data

(which, in at least some scenarios, enable generating only a partial magnetic signature of each target). As a consequence, although only partial magnetic signatures are available, the magnetic detection algorithm **130** can solve accurately the target detection problem.

5 In addition to the ability of performing in advance detection, the method enables real time or quasi real time detection of the target(s), while the underwater vehicle approaches the target (or conversely). Indeed, the 3D search area limits the space in which the magnetic detection algorithm **130** has to search for targets, which therefore improves accuracy of the detection, and also reduces the processing time/amount of
10 computation.

Fig. 8C illustrates a configuration in which the underwater vehicle **200** passes over the target **850** (since it has the vertical plane **880**). In this configuration, a full magnetic signature of the target **850** is measured by the magnetic detection system **120**, and therefore localization of the target **850** is facilitated. The various methods described
15 herein do not require the underwater vehicle to pass over the target to localize the target. It is obvious that the method(s) described herein also operate in this configuration, which is less complex, since a full magnetic signature of the target is obtained.

 The method of **Fig. 8A** includes operations **801**, **810**, and **820**, which are performed in a period of time in which there is a relative motion between the underwater
20 vehicle **200** and at least one target, such that the underwater vehicle **200** has not passed over the at least one target.

 Operation **801** includes obtaining first position data informative of one or more first areas detected by the acoustic sensing system **110** of the underwater vehicle, while the underwater vehicle is approaching the target. Operation **801** is similar to operation
25 **300** and is not described again.

 Operation **810** includes obtaining magnetic detection data of the magnetic detection system **120** of the underwater vehicle **200**. The magnetic detection data are obtained while the underwater vehicle is approaching the target. Operation **810** is similar to operation **310** and is not described again.

30 Operation **820** includes using at least part of the first position data and at least part of the magnetic detection data to determine (3D) position of the at least one target. This can include using the magnetic detection data to search for targets only in 3D search areas generated based on at least part of the first position data. Operation **820** is similar to operation **320** and is not described again.

Detection of the target **850** is performed even if the underwater vehicle **200** has not passed (and will not pass) over the target **850**.

Note that the methods described herein enable detection and localization of a target in real time or in quasi-real time, while the underwater vehicle approaches the
5 target(s).

Attention is now drawn to **Figs. 9A** and **9B**.

Assume that during at least part of a given period of time, there is a relative motion between the underwater vehicle **200** and the target **905**. In some non-limitative examples, the range between the underwater vehicle and the target decreases over time.
10 One or more of the method(s) described herein can be used repetitively at different instants of time of this given period of time, to estimate the 3D location of the target. The level of inaccuracy of the estimate of the 3D location of the target decreases over time, since the range between the underwater vehicle and the target decreases (and it is therefore easier to localize the target). Another reason for this improvement of the
15 localization accuracy can be due to the fact that more magnetic data are acquired, which, in turn, enable obtaining a more comprehensive picture of the magnetic signature of the target (although this magnetic signature remains partial, since the underwater vehicle does not need to pass over the target to enable detection of the target).

In a sub-period of time T_i of the given period of time, first position data
20 (indicative of first areas detected by the acoustic detection system **110**) and magnetic detection data are obtained.

The method of **Fig. 9A** includes (operation **910**), in the sub-period of time T_i , using the first position data (indicative of first areas detected by the acoustic detection system **110**) to define one or more 3D areas (search areas). Operation **910** is similar to
25 operations **610** and **710** and is not described again.

The method of **Fig. 9A** further includes (operation **915**), using the magnetic detection data to determine the 3D position of one or more targets by the magnetic detection algorithm **130**, within the one or more 3D areas. As explained above, the target detection according to which the magnetic detection algorithm **130** searches for
30 target can be limited to a space corresponding to the one or more 3D areas. As mentioned above, this can include sampling the 3D areas into a plurality of sub-areas, and comparing, for each sub-area, the measured magnetic signatures to one or more expected magnetic signatures of one or more targets, if the one or more targets were present in the one or more sub-areas.

In the sub-period of time T_i , the magnetic detection algorithm **130** outputs a plurality of target position estimates, which are located within an area/volume **950₁**.

In a sub-period of time T_{i+1} (posterior to the sub-period of time T_i), operations **910** and **915** can be repeated.

5 Note that in the sub-period of time T_{i+1} , the position of the underwater vehicle and/or the position of the target has changed.

10 In the sub-period of time T_{i+1} , first position data (indicative of first areas detected by the acoustic detection system **110**) and magnetic detection data are obtained. Note that the first position data obtained at T_{i+1} can differ from the first position data obtained at T_i . Similarly, that the magnetic detection data obtained at T_{i+1} differ from the magnetic detection data obtained at T_i .

This is due to the fact that at time T_{i+1} additional data have been sensed, both by the acoustic detection system **110** and by the magnetic detection system **120**.

15 There are various ways to handle the data accumulated over time, which will be described hereinafter.

In the sub-period of time T_i , the magnetic detection algorithm **130** outputs a plurality of target position estimates, which are located within an area/volume **950₂**.

20 The process can be repeated for different times. In some examples, the process can be stopped when the dispersion of the candidate targets is below a threshold (one or more dimensions of the area, in which the candidate targets are located, are below a threshold), or when the underwater vehicle is located at a certain range from the target (which can be estimated using the acoustic detection system **110**). For example, in **Fig. 9B**, the dispersion of the candidate targets in the volume **950_N** is below a threshold.

25 As is visible in **Fig. 9B**, the closer the target to the underwater vehicle, the smaller the volume of the area in which the candidate targets are output by the system **100**. In other words, accuracy of detection of the target is improved over time. The dimensions of the area **950₂** are smaller than the dimensions of the area **950₁**, since the uncertainty on the location of the target decreases when the range to the target decreases.

30 Attention is now drawn to **Fig. 9C**.

It has been mentioned that the first position data provided by the acoustic detection system **110** are used to generate 3D search areas in which the magnetic detection algorithm **130** searches for targets. The 3D search areas can be generated for different positions of the underwater vehicle (or for different instants of time). In some examples, the method

of **Fig. 9C** includes, for a given position of the underwater vehicle (or for a given time), using 3D search areas which are associated with a size (or more generally dimensions(s)) which differs from a size (or more generally dimension(s)) of 3D search areas which are used at a previous position of the underwater vehicle (or at a previous time). In some examples, the size of the 3D search areas at a given position (or at a given time) of the underwater vehicle is selected based on the range between the underwater vehicle and the target.

The size of the 3D search areas can be selected to be smaller at a first range between the underwater vehicle and the target than at a second range between the underwater vehicle and the target, wherein the first range is smaller than the second range. In other words, as the range between the underwater vehicle and the target decreases, the dimensions (and/or the size) of the 3D search areas can be reduced. This is not limitative.

Figs. 10A and 10B describe a first approach of processing the data output by the acoustic detection system **110** and the magnetic detection system **120** over time.

Assume that there is a relative motion between the underwater vehicle **200** and the target **1060** during a given period of time starting at time T_1 . T_1 can correspond e.g., to an instant at which the target **1060** is within the detection range of both the acoustic detection system **110** and the magnetic detection system **120**.

At each of a plurality of different instants of time T_i of the given period of time (corresponding to a different position of the underwater vehicle **200** and/or to a different position of the target **1060**), new data is obtained both from the magnetic detection system **120** and the acoustic detection system **110**.

As a consequence, over time, a set of a plurality of magnetic detection data is obtained, wherein each given magnetic detection data of the set has been acquired at a different position of the underwater vehicle **200** and/or at a different position of the target **1060** (at a different instant of time).

The method of **Fig. 10A** includes waiting until the range between the underwater vehicle **200** and the target **1060** has reached a threshold **1020** in order to determine 3D position of the target **1060**. Assume that this threshold is reached at time T_{end} . The threshold can be defined as a minimal distance between the underwater vehicle **200** and the target **1060**, which can be either predefined or set by a user/operator.

Responsive to detection that the range between the underwater vehicle **200** and the target **1060** meets the threshold (the range to the target can be estimated using the first position data output by the acoustic detection system **110**), the method of **Fig. 10A** can

include using the set of magnetic detection data, or most of it (collected from the beginning of the given period of time, up to the time T_{end} at which the range to the target meets a minimal threshold) and first position data (output by the acoustic detection system **110** within the given period of time) to perform a target detection enabling
5 estimating three-dimensional position of the at least one target, using the various methods described herein. The target detection is performed as explained in the various methods described herein.

In other words, this method waits until a sufficient amount of magnetic detection data has been obtained, and only then performs a detection using the whole set of magnetic
10 detection data collected over time, or most of this set.

For example, T_1 corresponds to a configuration in which the distance between the underwater vehicle **200** and the target **1060** is 200 meters and T_{end} corresponds to a configuration in which the distance between the underwater vehicle **200** and the target **1060** is 50 meters. These values are not limitative. The magnetic detection data
15 collected between T_1 and T_{end} , together with the first position data provided by the acoustic detection system **110** (within the given period of time – it is possible to use the latest updated first position data which are the most accurate), can be fed to the magnetic detection algorithm **130** to determine the 3D position of one or more targets, as explained in the various methods described herein.

Figs. 11A and 11B describe another approach of processing the data output by the acoustic detection system **110** and the magnetic detection system **120**.

Assume that there is a relative motion between the underwater vehicle **200** and the target **1160** during a given period of time starting at time T_1 .

At each instant of time T_i in which a target detection is performed, it is possible
25 to use the last magnetic detection data **1150** collected in a sub-period of time ending at T_i and with a predetermined duration (for example, the last N seconds), or associated with a predetermined distance travelled by the underwater vehicle up to time T_i (for example, the last 25 meters travelled by the underwater vehicle), together with previous magnetic detection data **1155** collected before said sub-period of time (for example,
30 from the last 25 meters up to the last 50 meters). The target detection takes into account the previous magnetic detection data with a lower weight than the last magnetic detection data. This can be performed by assigning a weight to the previous detection data and/or the last detection data which reduces the importance of the previous magnetic detection data with respect to the last magnetic detection data. Regarding the

first position data, it is possible to use the last first position data obtained in the last period of time. This is not limitative.

Target detection is performed as explained in the various methods described herein.

5 Indeed, it is expected that the last period of time of fixed duration (or corresponding to a fixed distance travelled by the underwater vehicle) will include the most accurate and updated detection data. However, the historical data acquired beforehand can be also taken into account, with a lower weight, which indicates that the target detection will rely less on these historical data.

10 For example, every 25 meters, a target detection is performed using the magnetic detection data collected in the last 25 meters, together with magnetic detection data collected from the last 25 meters up to the last 50 meters, with a lower weight. This is repeated over time.

Figs. 12A and 12B describe another approach of processing the data output by the acoustic detection system **110** and the magnetic detection system **120**.

15 Assume that there is a relative motion between the underwater vehicle **200** and the target **1260** during a given period of time starting at time T_1 .

 At each instant of time T_i in which a target detection is performed, it is possible to use the last magnetic detection data corresponding only to the magnetic detection data obtained in a period of time **1250** ending at T_i or at a time preceding T_i and associated with a predetermined duration (for example, the last N seconds), or associated with a predetermined distance travelled by the underwater vehicle up to time T_i (for example, the last 25 meters travelled by the underwater vehicle). Regarding the first position data, it is possible to use the last first position data obtained in this same period of time. This is not limitative.

25 Target detection is performed as explained in the various methods described herein.

 In other words, each time target detection is performed, the method of **Fig. 12A** uses only the magnetic detection data obtained in a recent past period of time, and ignores magnetic detection data obtained beforehand. Indeed, it is expected that the last period of time of fixed duration (or fixed distance) will include the most accurate and updated detection data.

30

For example, every 25 meters (or every 5 seconds), target detection is performed using only the magnetic detection collected in the last 25 meters (or in the last 5 seconds). This is repeated over time.

Note that one or more of the methods described with reference to **Figs. 10A, 10B, 11A, 11B, 12A and 12B** can be performed in parallel.

Attention is now drawn to **Fig. 13**.

As explained in the various methods described herein, the magnetic detection algorithm **130** is fed with magnetic detection data provided by the magnetic detection system **120** and first position data provided by the acoustic detection system **110**. These data are used to provide one or more estimates of the position of the target(s).

At a given position of the underwater vehicle with respect to the target, a target detection performed based on the first position data and the magnetic detection data (using the various methods described herein) can provide a plurality of position estimates (target position estimates). As mentioned with reference to **Fig. 8A**, target detection can be performed even if the underwater vehicle did not (and will not) pass over the target. As a consequence, a set of different estimates of the 3D position of the given target is generated (operation **1300**). This set of position estimates includes a plurality of different estimates of the position of the target. This set is output by the magnetic detection algorithm **130** (as solutions to the magnetic problem solved by the magnetic detection algorithm **130** based on the magnetic detection data). As mentioned above, when the range to the target is large, this set of position estimates has a larger spatial dispersion than when the range to the target is small. This set of position estimates is also called a “cloud” of position estimates.

Applicant has discovered that this set of position estimates can be further processed (operation **1310**) in order to provide an estimate of the position of the target and/or to track the target. In particular, one or more properties (such as one or more geometrical properties) of the set of position estimates, or at least part of it, can be used to provide an estimate of the 3D position of the target. Although the set of position estimates has a certain spatial dispersion, this additional processing enables providing a single position estimate (instead of a cloud of different position estimates), or a second set of position estimates with a smaller dispersion (along each axis X, Y and Z). The dispersion can be measured as the distance between extreme points of the set (along each axis X, Y and Z). In other words, a new estimate with an uncertainty smaller than the original set of a plurality of position estimates is obtained.

The method of **Fig. 13A** can be performed repeatedly over time. This is illustrated in **Fig. 13B**.

During a period of time in which a motion between the underwater vehicle and a target occurs (which can include a configuration in which the range of the target decreases over time), the magnetic detection algorithm **130** can provide various sets of position estimates, provided at different instants of time and/or for different relative positions of the underwater vehicle with respect to the given target. As mentioned with reference to **Fig. 8A**, target detection can be performed even if the underwater vehicle did not (and will not) pass over the target.

For each given position of a plurality of different positions of the underwater vehicle relative to the target, the magnetic detection algorithm **130** can provide a given set of target position estimates (which correspond e.g., to areas in which the magnetic detection algorithm has evaluated that a magnetic signature of the database corresponds to the magnetic detection data). Therefore, a plurality of different sets of target position estimates is obtained (operation **1320**).

The plurality of sets of position estimates can be processed (one after the other, or simultaneously) to provide a plurality of position estimates of the target. As explained hereinafter, this enables tracking the position of the target over time.

A non-limitative example of a plurality of sets of position estimates (obtained by performing different target detections at different positions of the underwater vehicle relative to the target) is provided in **Fig. 14**, in which the range between the underwater vehicle (moving along trajectory **1440**) and the target **1410** decreases over time along the X axis. The Z axis corresponds to the height axis and the Y axis (lateral axis) is orthogonal to the X and Z axes. Note that the representation of **Fig. 14** is not limitative and different sets of estimates can be obtained.

Attention is drawn to **Fig. 15**, in which the pattern (according to which the set of position estimates of the target is distributed) is represented in a two-dimensional plane. **Fig. 15** illustrates the pattern of 3D estimates provided for different positions of the underwater vehicle **1500** relative to the target **1510** (see references (1), (2), etc. corresponding to different positions over time of the underwater vehicle **1500**), projected in a 2D plane (XY plane).

It is expected that the more the range between the underwater vehicle and the target reduces, the lower the uncertainty, and, therefore, the smaller the dispersion of the estimates. As a consequence, it is expected that the 2D representation of the pattern

(e.g., in the XY plane, and/or in the XZ plane) is such that the dispersion of the estimates decreases when the range to the target decreases. The shape of the projected pattern is therefore expected to correspond to a “funnel” (this is not limitative), in a scenario in which the target does not move with respect to the underwater vehicle. It can be clearly
5 seen that the width of the pattern reduces as the underwater vehicle **1500** approaches the target **1510**, since the estimate of the 3D position becomes more accurate.

Fig. 15 shows an interesting property: the position of the target can be estimated by determining the axis of symmetry (center) of the pattern of estimates (projected in a 2D plane). In particular, for each slice of the set of estimates along a given direction
10 (e.g., direction Y in the example of **Fig. 15**), the center of the different target position estimates corresponds to an estimate of the position of the direction along the given direction. **Fig. 15** illustrates this property for different ranges between the underwater vehicle and the target: at range 200 meters, the center of the set of estimates obtained by the system **100** along the Y direction corresponds to reference **1550**, at range 175
15 meters, the center of the set of estimates along the Y direction corresponds to reference **1551**, etc. The accuracy of the estimate obtained using this method increases as the range to the target decreases.

As visible in **Fig. 15**, this enables tracking the position of the target over time (see line **1560** which corresponds to a track of the target).

20 Note that this property can be used to estimate the position of the target in each direction (X, Y and Z).

The method of **Fig. 16A** uses this property to determine an estimate of the position of the target. The method includes obtaining (operation **1600**) a set of a plurality of position estimates of the position of the target provided by the magnetic
25 detection algorithm **130**, wherein the set has been provided at a given range between the underwater vehicle and the target.

The method further includes (operation **1610**) determining at least one of: data informative of a center of at least part of the set of position estimates, data informative of an axis of symmetry of at least part of the set of position estimates, data informative
30 of an average value at least part of the set of position estimates. This data can be computed for each direction of the 3D space (X, Y and Z directions). For example, the average value (or center/axis of symmetry) of the position estimates of the set along the X axis (range to the target) can be determined to estimate the position of the target along the X axis. The average value (or center/axis of symmetry) of the position estimates of

the set along the Y axis (lateral axis) can be determined to estimate the position of the target along the Y axis. The average value (or center/axis of symmetry) of the position estimates of the set along the Z axis (height axis) can be determined to estimate the position of the target along the Z axis.

5 Note that determination of data informative of the average value of the position estimates along each axis is not limited to an average calculation. Various additional/different processing operations can be performed.

 In some examples, the magnetic detection algorithm **130** outputs, for each position estimate, a confidence value, indicative of the level of confidence of the
10 position estimate. When computing data informative of the average value of the position estimates, it is possible to take into account the level of confidence of the position estimates. A higher weight can be assigned to position estimates with a high level of confidence, whereas a lower weight can be assigned to position estimates with a low level of confidence.

15 In some examples, for a given position of the underwater vehicle with respect to the target, the target detection is performed several times by the magnetic detection algorithm **130**. It therefore outputs several sets of position estimates. It is possible to take into account the number of times each position estimate is present in the several sets. Position estimates which are more frequently present in the several sets can be
20 assigned a higher weight than other position estimates, when determining data informative of the average value of the position estimates along each axis.

 Different/additional processing operations can be performed to determine data informative of the average value of the position estimates along each axis.

 Data informative of the average value of the position estimates can be used to
25 estimate the position of the target. This enables obtaining, for a given set of position estimates, a single position estimate (instead of a cloud of different position estimates), or a second set of position estimates with a smaller dispersion (along each axis X, Y and Z).

 The method of **Fig. 16A** can be repeated over time. This is illustrated in **Fig.**
30 **16B**.

 During a period of time in which a motion between the underwater vehicle and a target occurs (which can include a configuration in which the range of the target decreases over time), the magnetic detection algorithm **130** can provide various sets of position estimates, provided at different instants of time and/or for different relative

positions of the underwater vehicle with respect to the given target. As mentioned with reference to **Fig. 8A**, target detection can be performed even if the underwater vehicle did not (and will not) pass over the target.

For each given position of a plurality of different positions of the underwater vehicle relative to the target, the magnetic detection algorithm **130** can provide a given set of target position estimates (which correspond e.g., to areas in which the magnetic detection algorithm has evaluated that a magnetic signature of the database corresponds to the magnetic detection data). Therefore, a plurality of different sets of target position estimates is obtained (operation **1620**).

The plurality of sets of position estimates can be processed (one after the other, or simultaneously) to provide a plurality of position estimates of the target over time. This enables tracking the position of the target over time. This processing can include determining at least one of: data informative of a center of at least part of each set of position estimates, data informative of an axis of symmetry of at least part of each set of position estimates, data informative of an average value at least part of each set of position estimates. This enables obtaining, for each set of position estimates, a single position estimate (instead of a cloud of different position estimates), or a second set of position estimates with a smaller dispersion (along each axis X, Y and Z).

The method of **Figs. 16A** and **16B** enables estimating the position of a given target in advance, even if the range to the given target is large. In other words, an advance rough estimate of the position (3D) is obtained. For example, in **Fig. 15**, at a range of 200 meters to the target, although the spread of the estimates provided by the magnetic detection algorithm **130** is around 175 meters along the Y axis, determination of the center **1550** of the pattern of estimates (in the XY plane) already provides an estimate of the position of the given target with an error of around 30 meters. Note that the center (or axis of symmetry) is only an example of a geometrical property which can be used to estimate the position of the target, and other geometrical properties can be used.

Fig. 17A illustrates the same principles for estimating the height of the target **1700**. The respective center (see **1710**, **1711**, etc.) of the group of position estimates obtained for respective positions of the underwater vehicle is determined along the height direction. Each center is an estimate of the height position of the target **1700**. A line **1760** joining the different centers correspond to a track of the target **1700**. As the

range to the target decreases, the center tends to be close to the sea level, since the target is a surface target.

Fig. 17B illustrates the same principles for estimating the range of the target **1700**. The respective center (average) of each set of position estimates obtained for
5 respective positions of the underwater vehicle is determined along the range/longitudinal direction. This provides different estimates of the range of the target, for different positions of the underwater vehicle relative to the target.

Another example is illustrated in **Fig. 17C** in which the set **1760** of estimates is projected in the 2D plane XY in a configuration in which the underwater vehicle is still
10 at a long distance from the target **1750**. At this distance, there is still an uncertainty on the lateral position (Y axis) of the target. It is possible to determine the axis **1780** of symmetry of the set **1760**, which provides a first estimate of the lateral position of the target **1750**. The same method can be used to provide a first estimate of the height position of the target **1750**.

15 **Fig. 18A** illustrates a method in which the different sets of position estimates can be used to determine data informative of the motion of the target and/or to track the target.

Target detection is performed using the various methods described herein, for different positions of the underwater vehicle relative to the target.

20 During a period of time in which a motion between the underwater vehicle and a target occurs (which can include a configuration in which the range of the target decreases over time), the magnetic detection algorithm **130** can provide various sets of position estimates, provided at different instants of time and/or for different relative positions of the underwater vehicle with respect to the given target. As mentioned with
25 reference to **Fig. 8A**, target detection can be performed even if the underwater vehicle did not (and will not) pass over the target.

For each given position of a plurality of different positions of the underwater vehicle relative to the target, the magnetic detection algorithm **130** can provide a given set of target position estimates (which correspond e.g., to areas in which the magnetic
30 detection algorithm has evaluated that a magnetic signature of the database corresponds to the magnetic detection data). Therefore, a plurality of different sets of target position estimates is obtained (operation **1820**).

The plurality of sets of position estimates can be processed (one after the other, or simultaneously) to provide a plurality of position estimates of the target over time

(operation **1830**). This enables tracking the position of the target over time. This processing can include determining at least one of: data informative of a center of at least part of each set of position estimates, data informative of an axis of symmetry of at least part of each set of position estimates, data informative of an average value at least part of each set of position estimates. This enables obtaining, for each set of position estimates, a single position estimate (instead of a cloud of different position estimates), or a second set of position estimates with a smaller dispersion (along each axis X, Y and Z).

The different position estimates constitute estimate of the position of the target over time. In other words, tracking data of the target is obtained over time. This is visible in the non-limitative example of **Fig. 18B**, in which the underwater vehicle **1801** is moving along the X axis towards the target, and the target **1802** is moving laterally along the Y axis. **Fig. 18B** illustrates the set of position estimates projected in the 2D plane XY, obtained using the method of **Fig. 18A**.

Fig. 18B illustrates the tracking data **1803** (estimated tracking data) obtained using the method of **Fig. 18A**, and the real tracking data **1804** of the target.

The estimated tracking data can be compared (operation **1840**) to the tracking data of the acoustic detection system **110**. Indeed, the acoustic detection system (e.g., sonar) **110** provides tracking data of the target. This comparison can be performed to determine whether the estimates provided by the magnetic detection algorithm **130** can be relied upon.

If there is a match, this can be used to confirm that the estimates provided by the magnetic detection algorithm **130** are accurate.

If there is a mismatch, this can be used to detect that that the estimates provided by the magnetic detection algorithm **130** cannot be relied upon. An alarm can be raised for the operator and/or systems of the underwater vehicle.

Attention is drawn to **Fig. 19A**.

In some examples, it is possible to determine whether one or more geometrical properties of the plurality of sets of positions estimates (or of a pattern derived thereof, such as a projection of the set in a 2D plane) deviate from the one or more expected geometrical properties (see operations **1900**, **1910**). The one or more expected geometrical properties can correspond to a configuration in which there is no relative motion between the underwater vehicle and the target (or a relative motion below a predefined threshold) along at least one direction.

When this deviation is identified, this can be used to track the target. In particular, this can be used to detect that there is a relative motion between the underwater vehicle and the target along this direction. The direction and the sense of the motion can be estimated. Therefore, the method can use this deviation to track the target over time.

An example of a set **1940** of estimates (projected in a 2D plane), associated with expected geometrical properties, is illustrated in **Fig. 19B**. In this example, the target **1950** does not move relative to the underwater vehicle along the lateral Y axis. Assume that the range between the underwater vehicle and the target **1950** decreases over time, e.g., along the axis X. Assume that there is no relative lateral motion (along the Y axis) between the underwater vehicle and the target **1950**. It is expected that the uncertainty on the estimate along the Y axis will decrease over time. As a consequence, the width of the expected pattern of estimates (in the XY plane) will decrease as the range to the target decreases. The geometrical shape of the expected pattern can therefore be similar to a funnel (this shape is not limitative and is provided as an example only).

A non-limitative example of the usage of the method of **Fig. 19A** is provided in **Fig. 19C**.

From time T_0 to T_1 , the underwater vehicle has moved from position X_0 to position X_1 along the X axis. During this interval of time, there is no relative motion between the underwater vehicle and the given target **1950** along the Y axis. System **100** of the underwater vehicle provides estimates for the position of the given target **1950** for different positions of the underwater vehicle. This enables obtaining a set of estimates which are distributed according to the pattern **1960**. In accordance with operation **1910**, it is possible to determine geometrical properties of the pattern **1960** and to compare them with expected geometrical properties. In particular, it is possible to determine the evolution of the width of the pattern, and to determine whether it matches with the expected evolution. At this stage, the evolution of the width of the pattern **1960** matches with the evolution of the width of the expected pattern **1940**.

Assume that from time T_1 up to time T_2 , in which the underwater vehicle moves from position X_1 to X_2 , the target **1950** starts to move relative to the underwater vehicle along the Y axis (lateral displacement), from position Y_1 to Y_2 .

System **100** determines estimates of the position of the target **1950** between T_1 and T_2 . The set of estimates (projected in a 2D plane) which is obtained, corresponds to the pattern **1980**.

In particular, it can be seen in **Fig. 18D** that although the width of the pattern **1980** of estimates decreases over time (as the range to the target decreases), the center of the pattern **1980** determined for each slice along the X axis tends to move laterally in the Y direction, with respect to the expected position of the center of the expected pattern **1940**.

In other words, the pattern **1980** of estimates provided by system **100** does not comply with the expected pattern **1940**. This can be used to provide tracking data of the target. In particular, this can be used to determine that the given target is moving laterally along the Y direction, such that the distance between the underwater vehicle and the target increases along the Y axis. The direction and the sense of the motion of the target can be determined along the Y axis (lateral axis).

Note that the same principles can be used to determine the direction and the sense of motion along the X axis and the Z axis (height axis).

Attention is now drawn to **Fig. 20A**.

It has been mentioned above that the first position data provided by the acoustic detection system **110** can be used, together with the magnetic detection data, as an input of the magnetic detection algorithm **130**, in order to determine one or more estimates of the position of the target.

In some examples, the output (one or more estimates of the position of the target) of the magnetic detection algorithm **130** can be used as feedback for controlling (operation **2010**) of the acoustic detection system **110**. In particular, the output of the magnetic detection algorithm **130** can be used to orient the field of view of the acoustic detection system **110** towards the areas detected by the magnetic detection algorithm **130**.

By virtue of this feedback with the acoustic detection system **110**, more accurate first position data are obtained from the acoustic detection system **110**, which can be used the next time a target detection is performed, together with the magnetic data of the magnetic detection algorithm **120**, according to the various methods described herein.

For example, assume that the magnetic detection algorithm **130** has been first fed with initial first position data and magnetic detection data, and indicates that a target is located on the right side of the underwater vehicle. The method of **Fig. 20A** can include controlling the acoustic detection system **110** to acquire data only on the right side of the underwater vehicle. New first position data are then acquired, which can be

fed together with magnetic detection data to the magnetic detection algorithm **130**, in order to perform a new target detection.

Attention is now drawn to **Fig. 20B**.

In some examples, at an initial stage, the magnetic detection algorithm **130** can be fed only with magnetic detection data (operation **2030** – without the first position data). As mentioned above, when the underwater vehicle does not pass over the target, this cannot provide an estimate of the 3D position of the target. However, this can provide an inaccurate estimate of some areas in which the presence of target(s) is suspected. The acoustic detection system **110** can be controlled such that its field of view is oriented toward these detected areas (operation **2040**). First position data are obtained which can be fed together with magnetic detection data to the magnetic detection algorithm **130**, in order to perform target detection, as explained in the various methods described herein (operation **2050**).

Attention is now drawn to **Fig. 21**, which provides an application of the various methods described herein.

The method of **Fig. 21** includes (see operation **2110**), in a period of time in which there is a relative motion between an underwater vehicle and a target, estimating (at least once, or repetitively over time) the 3D position of the target, using the magnetic detection data and the first position data provided by the acoustic detection system **110**, according to the various methods described herein. As mentioned above, estimating the 3D position of the target is enabled without requiring the underwater vehicle to pass over the target.

The method further includes using (operation **2120**) the estimated 3D position of the target to control the route of the underwater vehicle. In particular, this can include controlling the route of the underwater vehicle to avoid a collision between the underwater vehicle and the target. The estimated 3D position of the target can be transmitted to a navigation controller (see reference **210** in **Fig. 2A**) of the underwater vehicle, which can determine an updated route enabling avoiding collision with the target.

In some examples, the method can include waiting until an accurate estimate of the target has been obtained (that is to say that the dispersion of the estimates provided by the magnetic detection algorithm **130** is below some threshold) and then modifying the route of the underwater vehicle accordingly, to avoid a collision with the target.

Note that the method enables efficient collision avoidance, since it can predict in advance the position of the target, even if the underwater vehicle has not passed over the target. The method can be used *a fortiori* when the underwater vehicle has passed over the target.

5 Attention is now drawn to **Fig. 22**, which provides another application of the various methods described herein.

 While having many different autonomous capabilities, when a AUV intends to ascend toward the water surface and exits the water, a man in the loop is required (for example on a nearby vessel) for the purpose of monitoring the ascent and ensuring that
10 there is no obstacle that could collide, impede, and/or endanger in any way, the underwater vehicle while ascending towards the water surface or exiting from the water.

 For example, when ascending at a harbor area, monitoring of the ascent is required in order to avoid collision of the AUV with other vessels which normally occupy the harbor.

15 The method of **Fig. 22** enables a completely autonomous ascent of the AUV to the water surface or while operating at periscope depth (PD).

 The method of **Fig. 22** includes, in a period of time in which there is a relative motion between an underwater vehicle and a surface target, estimating (at least once, or repetitively over time) the 3D position of the surface target, using (operation **2210**)
20 the magnetic detection data and the first position data provided by the acoustic detection system **110** (as explained in the various methods described herein). As mentioned above, estimating the 3D position of the surface target is enabled without requiring the underwater vehicle to pass over the target.

 The method further includes using (operation **2220**) the estimated 3D position
25 of the surface target to perform an ascension of the underwater vehicle to periscope depth. This ascension is performed in an area which avoids collision between the underwater vehicle and the surface target, by virtue of the accurate knowledge of the 3D position of the surface target. The method does not require performing complex maneuvers in which the underwater vehicle needs to pass over the surface target one or
30 more times. To the contrary, it enables in-advance prediction of the position of the target, which enables determining an efficient ascension of the underwater vehicle to periscope depth. The method can be used *a fortiori* when the underwater vehicle has passed over the target.

Attention is now drawn to **Fig. 23**, which provides another application of the various methods described herein.

The method of **Fig. 23A** includes using the various methods described herein to detect targets located on the seabed. In other words, a seabed scan is performed, which
5 can be used to generate a map of targets located on the seabed (see operations **2310** and **2320**).

Attention is now drawn to **Fig. 23B**, which provides another application of the various methods described herein.

The method of **Fig. 23B** includes using the various methods described herein to
10 detect surface targets. In other words, a surface scan is performed, which can be used to generate a map of targets located on the surface (see operations **2330** and **2340**).

Attention is now drawn to **Fig. 24**, which provides another application of the various methods described herein.

The method of **Fig. 24** includes using the various methods described herein to
15 detect underwater mines (naval mines). A map of underwater mines can be obtained. This can be used to control the route of the underwater vehicle (see operations **2410** and **2420**), in order to avoid that the underwater vehicle will enter an interaction area of the underwater mines, in which activation of the mine could damage the underwater vehicle.

20 Attention is now drawn to **Fig. 25**, which provides another application of the various methods described herein.

The method of **Fig. 25** proposes a new way to determine position of the underwater vehicle. This estimated position can be used e.g., for navigation purposes, such as by the navigation controller of the underwater vehicle.

25 Assume that a plurality of magnetic objects is dispersed underwater at known locations. These magnetic objects can be used as references to determine the position of the underwater vehicle.

The method includes determining (operation **2510**) position of one or more of these magnetic objects using the various methods described herein. The position of one
30 or more of these magnetic objects is determined with respect to the underwater vehicle (range, azimuth, elevation with respect to the underwater vehicle).

In particular, the position of each given magnetic object can be determined in a situation in which the underwater vehicle has not passed over the given magnetic object. Determination of the position of one or more of the magnetic objects can then be used

to determine the position of the underwater vehicle itself. Indeed, the method enables determining the relative position of the magnetic objects with respect to the underwater vehicle (range, azimuth, elevation). Since the position of these magnetic objects is *a priori* known, it is possible to deduce the position of the underwater vehicle (operation
5 **2520**).

In the detailed description, numerous specific details have been set forth in order to provide a thorough understanding of the disclosure. However, it will be understood by those skilled in the art that the presently disclosed subject matter may be practiced without these specific details. In other instances, well-known methods, procedures,
10 components, and circuits have not been described in detail so as not to obscure the presently disclosed subject matter.

Unless specifically stated otherwise, as apparent from the aforementioned discussions, it is appreciated that throughout the specification discussions utilizing terms such as "obtaining", "determining", "performing", "using", "controlling",
15 "estimating", or the like, refer to the action(s) and/or process(es) of a computer that manipulate and/or transform data into other data, said data represented as physical, such as electronic, quantities and/or said data representing the physical objects.

The terms "computer" or "computer-based system" should be expansively construed to include any kind of hardware-based electronic device with a data
20 processing circuitry (e.g., digital signal processor (DSP), a GPU, a TPU, a field programmable gate array (FPGA), an application specific integrated circuit (ASIC), microcontroller, microprocessor etc.), including, by way of non-limiting example, the computer-based system **100** of **Fig. 1** and respective parts thereof disclosed in the present application. The data processing circuitry (designated also as processing
25 circuitry) can comprise, for example, one or more processors operatively connected to computer memory, loaded with executable instructions for executing operations, as further described below. The data processing circuitry encompasses a single processor or multiple processors, which may be located in the same geographical zone, or may, at least partially, be located in different zones, and may be able to communicate
30 together. The one or more processors can represent one or more general-purpose processing devices such as a microprocessor, a central processing unit, or the like. More particularly, a given processor may be one of: a complex instruction set computing (CISC) microprocessor, a reduced instruction set computing (RISC) microprocessor, a very long instruction word (VLIW) microprocessor, a processor implementing other

instruction sets, or a processor implementing a combination of instruction sets. The one or more processors may also be one or more special-purpose processing devices such as an application specific integrated circuit (ASIC), a field programmable gate array (FPGA), a digital signal processor (DSP), a network processor, or the like. The one or
5 more processors are configured to execute instructions for performing the operations and steps discussed herein.

The memories referred to herein can comprise one or more of the following: internal memory, such as, e.g., processor registers and cache, etc., main memory such as, e.g., read-only memory (ROM), flash memory, dynamic random access memory
10 (DRAM) such as synchronous DRAM (SDRAM), or Rambus DRAM (RDRAM), etc.

The terms "non-transitory memory" and "non-transitory storage medium" used herein should be expansively construed to cover any volatile or non-volatile computer memory suitable to the presently disclosed subject matter. The terms should be taken to include a single medium or multiple media (e.g., a centralized or distributed database,
15 and/or associated caches and servers) that store the one or more sets of instructions. The terms shall also be taken to include any medium that is capable of storing or encoding a set of instructions for execution by the computer and that cause the computer to perform any one or more of the methodologies of the present disclosure. The terms shall accordingly be taken to include, but not be limited to, a read only memory ("ROM"),
20 random access memory ("RAM"), magnetic disk storage media, optical storage media, flash memory devices, etc.

It is to be noted that while the present disclosure refers to the processing circuitry **104** (or other processing circuitries **105**, **106**) being configured to perform various functionalities and/or operations, the functionalities/operations can be
25 performed by the one or more processors of the processing circuitry **104** in various ways. By way of example, the operations described hereinafter can be performed by a specific processor, or by a combination of processors. The operations described hereinafter can thus be performed by respective processors (or processor combinations) in the processing circuitry **104** (or other processing circuitries **105**, **106**), while,
30 optionally, at least some of these operations may be performed by the same processor. The present disclosure should not be limited to be construed as one single processor always performing all the operations.

It is appreciated that, unless specifically stated otherwise, certain features of the presently disclosed subject matter, which are described in the context of separate

embodiments, can also be provided in combination in a single embodiment. Conversely, various features of the presently disclosed subject matter, which are described in the context of a single embodiment, can also be provided separately or in any suitable sub-combination. It is to be noted that the various features described in the
5 various embodiments or examples can be combined according to all possible technical combinations.

In embodiments of the presently disclosed subject matter, fewer, more, and/or different stages than those shown in the methods described in the appended figures may be executed. In embodiments of the presently disclosed subject matter, one or more
10 stages illustrated in the methods described in the appended figures may be executed in a different order, and/or one or more groups of stages may be executed simultaneously.

It will also be understood that the system according to the invention may be, at least partly, implemented on a suitably programmed computer. Likewise, the invention contemplates a computer program being readable by a computer for executing the
15 method of the invention. The invention further contemplates a non-transitory computer-readable memory tangibly embodying a program of instructions executable by the computer for executing the method of the invention.

The invention is capable of other embodiments and of being practiced and carried out in various ways. Hence, it is to be understood that the phraseology and
20 terminology employed herein are for the purpose of description and should not be regarded as limiting. As such, those skilled in the art will appreciate that the conception upon which this disclosure is based may readily be utilized as a basis for designing other structures, methods, and systems for carrying out the several purposes of the presently disclosed subject matter.

It is to be understood that the invention is not limited in its application to the details set forth in the description contained herein or illustrated in the drawings. The invention is capable of other embodiments and of being practiced and carried out in various ways. Hence, it is to be understood that the phraseology and terminology
25 employed herein are for the purpose of description and should not be regarded as limiting. As such, those skilled in the art will appreciate that the conception upon which this disclosure is based can readily be utilized as a basis for designing other structures, methods, and systems for carrying out the several purposes of the presently disclosed
30 subject matter.

Those skilled in the art will readily appreciate that various modifications and changes can be applied to the embodiments of the invention as hereinbefore described without departing from its scope, defined in and by the appended claims.

CLAIMS

1. A system comprising one or more processing circuitries configured to:
 - in a period of time comprising a relative motion between a marine vehicle and at least one target, in which the marine vehicle has not passed over the at least one target:
 - obtain first position data informative of one or more first areas determined by at least one underwater detection system associated with the marine vehicle,
 - obtain magnetic detection data of at least one underwater magnetic detection system associated with the marine vehicle, and
 - using at least part of the first position data and at least part of the magnetic detection data to perform at least one target detection enabling estimating position of the at least one target.
2. The system of claim 1, wherein the at least one detection system comprises:
 - (i) an acoustic detection system, or
 - (ii) a laser detection system.
3. The system of claim 1 or of claim 2, wherein said target detection outputs at least one target position estimate which is outside of said one or more first areas.
4. The system of any one of claims 1 to 3, wherein said target detection comprises using a magnetic detection algorithm which searches for one or more targets in space based on the magnetic detection data, wherein the first position data is used to limit at least part of said space.
5. The system of any one of claims 1 to 4, configured to:
 - use the first position data to determine a set of one or more three-dimensional search areas, and
 - use at least part of the magnetic detection data to perform a target detection within the set of one or more three-dimensional search areas.

6. The system of claim 5, wherein said target detection is limited within a space corresponding to said set of one or more three-dimensional search areas.
7. The system of claim 5 or of claim 6, wherein said target detection includes using the magnetic detection data to search for one or more targets within a plurality of sub-areas of each three-dimensional search area of the set.
8. The system of any one of claims 5 to 7, configured to select one or more dimensions of the one or more three-dimensional search areas based on an estimated range between the marine vehicle and the target.
9. The system of any one of claims 1 to 8, configured to:
 - use the first position data to determine, for at least one given first area of the one or more first areas, a given three-dimensional search area comprising the given first area, with a larger volume than the given first area, thereby obtaining a set of one or more three-dimensional search areas, and
 - feed the magnetic detection data to a magnetic detection algorithm to perform a target detection within a space, wherein said space is defined based on the set of one or more three-dimensional search areas.
10. The system of any one of claims 1 to 9, wherein the first position data comprise range and azimuth of each of the one or more first areas, but do not comprise elevation of each of the one or more first areas.
11. The system of any one of claims 1 to 10, configured to:
 - use the first position data to determine a set of one or more three-dimensional search areas, and
 - use at least part of the magnetic detection data to perform a target detection within a space constrained by said set of one or more three-dimensional search areas, said target detection comprising, for each given sub-area of a plurality of sub-areas of each given three-dimensional search area:
 - comparing the magnetic detection data, or data derived thereof, with one or more expected magnetic signatures of one or more targets.

12. The system of any one of claims 1 to 11, configured to:
- obtain magnetic detection data for different positions of the marine vehicle relative to the target, thereby obtaining a set of a plurality of magnetic detection data,
 - responsive to detection that a range between the marine vehicle and the target meets a threshold, use at least part of the first position data and at least part of the set of magnetic detection data to perform a target detection enabling estimating position of the at least one target.
13. The system of any one of claims 1 to 12, configured to:
- perform a target detection with last magnetic detection data obtained in a given sub-period of time together with previous magnetic detection data obtained before said given sub-period of time, wherein the target detection takes into account the previous magnetic detection data with a lower weight than the last magnetic detection data.
14. The system of any one of claims 1 to 13, configured to:
- perform a target detection at a given instant time with last magnetic detection data obtained only in a sub-period of time of the period of time ending at this given instant of time.
15. The system of any one of claims 1 to 14, configured to perform at least one of (i) or (ii):
- (i) using the estimate of the position of the target to control operation of the at least one detection system, or
 - (ii) controlling the at least one detection system to orient its field of view based on the estimate of the position of the target.
16. The system of any one of claims 1 to 15, configured to:
- perform target detection at a given position of the marine vehicle relative to the target, based on magnetic detection data of the magnetic detection system and on first position data of the detection system, thereby obtaining a given set of a plurality of position estimates, and
 - process at least part of the given set of a plurality of position estimates to determine an estimate of the position of the target.

17. The system of claim 16, wherein said processing enables obtaining at least one of:

- (i) a single position estimate of the target, or
- (ii) a second set of position estimates associated with a smaller dispersion than the given set of a plurality of position estimates;
- (iii) a position estimate of the target associated with an uncertainty which is smaller than an uncertainty associated with the given set of a plurality of position estimates.

18. The system of claim 16 or of claim 17, wherein said processing includes at least one of:

- (i) determining data informative of a symmetry of at least part of the given set of a plurality of position estimates;
- (ii) determining data informative of a center of at least part of the given set of a plurality of position estimates;
- (iii) determining data informative of an average of at least part of the plurality of the position estimates of said given set.

19. The system of any one of claims 1 to 18, configured to:

perform target detection at different positions of the marine vehicle relative to the target, based on magnetic detection data of the magnetic detection system and on first position data of the detection system, thereby obtaining a plurality of sets of position estimates, and

process at least part of the plurality of sets of position estimates to obtain tracking data informative of the target.

20. The system of claim 19, configured to:

perform at least one of (i), (ii) or (iii):

- (i) determining data informative of an average of at least part of the plurality of the position estimates of each of set of said of plurality of sets,
- (ii) determining data informative of a center of at least part of each set of the plurality of sets of position estimates;
- (iii) determining data informative of a symmetry of at least part of each set of the plurality of sets of position estimates;

use data obtained at (i), (ii) or (iii) to generate the tracking data.

21. The system of claim 19 or to claim 20, configured to compare the tracking data with tracking data provided by the detection system.
22. The system of claim 16, configured to:
compare one or more geometrical properties of at least part of the given set of a plurality of position estimates with one or more expected geometrical properties,
use the comparison to determine tracking data of the target.
23. The system of any one of claims 1 to 22, configured to:
perform a first target detection based on the magnetic detection data, without using first position data of the detection system, to obtain a set of target position estimates,
use the set to orient a field of view of the detection system, thereby obtaining the first position data, and
use the first position data and the magnetic detection data to perform said target detection.
24. The system of any one of claims 1 to 23, configured to use said estimate of the position of the target to perform at least one of:
(i) controlling the marine vehicle to avoid a collision with the target;
(ii) performing an ascension of the marine vehicle to periscope depth;
(iii) obtaining a map of one or more surface targets;
(iv) obtaining a map of one or more seabed targets;
(v) performing underwater mine detection;
(vi) determining position of the marine vehicle, said determining using a priori knowledge of the position of the target.
25. The system of any one of claims 1 to 24, configured to perform (1) to (4) for different positions of the marine vehicle:
(1) obtain first position data informative of one or more first areas determined by the at least one detection system,
(2) obtain magnetic detection data of the at least one magnetic detection system,

- (3) use the first position data to determine a set of one or more three-dimensional search areas, and
- (4) use at least part of the magnetic detection data to perform a target detection in the set of one or more three-dimensional search areas to obtain one or more position estimates of the target.

26. The system of any one of claims 1 to 25, wherein:

(i) the marine vehicle is an underwater vehicle, wherein the detection system and the magnetic detection system are mounted on the underwater vehicle, or

(ii) the marine vehicle is an underwater vehicle, wherein the detection system and the magnetic detection system are towed by the underwater vehicle; or

(iii) the marine vehicle is an underwater vehicle, wherein at least part of a system comprising the detection system and the magnetic detection system is mounted on the underwater vehicle, and another part of said system is towed by the underwater vehicle; or

(iv) the marine vehicle is a ship, wherein the detection system and the magnetic detection system are towed by the ship.

27. A system comprising one or more processing circuitries configured to:

obtain first position data informative of one or more first areas determined by at least one underwater detection system associated with a marine vehicle,

obtain magnetic detection data of at least one underwater magnetic detection system associated with the marine vehicle,

use the first position data to determine a set of one or more three-dimensional search areas, and

use at least part of the magnetic detection data to perform at least one target detection within the set of one or more three-dimensional search areas, enabling estimating position of at least one target within said set of one or more three-dimensional search areas.

28. The system of claim 27, wherein the first position data comprise range and azimuth of each of the one or more first areas, but do not comprise elevation of each of the one or more first areas.

29. The system of claim 27 or claim 28, wherein said at least one target detection includes using the magnetic detection data to search for one or more targets within a plurality of sub-areas of each three-dimensional search area of the set.

30. The system of any one of claims 27 to 29, wherein the target detection is limited within a space corresponding to said set of one or more three-dimensional search areas.

31. The system of any one of claims 27 to 30, configured to:

use the first position data to determine, for at least one given first area of the one or more first areas, a given three-dimensional search area comprising the given first area, with a larger volume than the given first area, thereby obtaining a set of one or more three-dimensional search areas, and

feed the magnetic detection data to a magnetic detection algorithm to perform a target detection within a space, wherein said space is defined based on the set of one or more three-dimensional search areas.

32. The system of any one of claims 27 to 31, performed in a period of time comprising a relative motion between the marine vehicle and at least one target, in which the marine vehicle has not passed over the at least one target.

33. The system of any one of claims 27 to 32, configured to perform (1) to (4) for different positions of the marine vehicle relative to a target:

- (1) obtain first position data informative of one or more first areas determined by the at least one detection system,
- (2) obtain magnetic detection data of the at least one magnetic detection system,
- (3) use the first position data to determine a set of one or more three-dimensional search areas, and
- (4) use at least part of the magnetic detection data to perform a target detection in the set of one or more three-dimensional search areas to obtain one or more position estimates of the target.

34. A system comprising one or more processing circuitries configured to:

obtain first position data informative of one or more first areas determined by at least one underwater detection system associated with a marine vehicle,

obtain magnetic detection data of at least one underwater magnetic detection system associated with the marine vehicle,

use at least part of the first position data and at least part of the magnetic detection data to perform at least one target detection enabling obtaining a set of a plurality of position estimates of at least one target, and

process at least part of the set of a plurality of position estimates to determine an estimate of the position of the target.

35. The system of claim 34, wherein said processing enables obtaining at least one of:

- (i) a single position estimate of the target, or
- (ii) a second set of position estimates associated with a smaller dispersion than the set of a plurality of position estimates;
- (iii) a position estimate of the target associated with an uncertainty which is smaller than an uncertainty associated with the set of a plurality of position estimates.

36. The system of claim 34 or of claim 35, wherein said processing includes at least one of:

- (i) determining data informative of a symmetry of at least part of the given set of a plurality of position estimates;
- (ii) determining data informative of a center of at least part of the given set of a plurality of position estimates;
- (iii) determining data informative of an average of at least part of the plurality of the position estimates of said given set.

37. The system of any one of claims 34 to 36, configured to:

perform target detection at different positions of the marine vehicle relative to a target, based on magnetic detection data of the magnetic detection system and on first position data of the detection system, thereby obtaining a plurality of sets of position estimates, and

process at least part of the plurality of sets of position estimates to obtain tracking data informative of the target.

38. The system of claim 37, configured to:
perform at least one of (i), (ii) or (iii):
(i) determining data informative of an average of at least part of the plurality of the position estimates of each of set of said of plurality of sets,
(ii) determining data informative of a center of at least part of each set of the plurality of sets of position estimates;
(iii) determining data informative of a symmetry of at least part of each set of the plurality of sets of position estimates;
use data obtained at (i), (ii) or (iii) to generate the tracking data.
39. The system of claim 37 or to claim 38, configured to compare the tracking data with tracking data provided by the detection system.
40. The system of claim 37, configured to:
compare one or more geometrical properties of at least part of the set of a plurality of position estimates with one or more expected geometrical properties,
use the comparison to determine tracking data of the target.
41. A method comprising performing, by one or more processing circuitries:
in a period of time comprising a relative motion between a marine vehicle and at least one target, in which the marine vehicle has not passed over the at least one target:
obtaining first position data informative of one or more first areas determined by at least one underwater detection system associated with the marine vehicle,
obtaining magnetic detection data of at least one underwater magnetic detection system associated with the marine vehicle, and
using at least part of the first position data and at least part of the magnetic detection data to perform at least one target detection enabling estimating position of the at least one target.
42. The method of claim 41, comprising:
using the first position data to determine a set of one or more three-dimensional search areas, and

using at least part of the magnetic detection data to perform a target detection within the set of one or more three-dimensional search areas.

43. The method of claim 41 or of claim 42, comprising:

using the first position data to determine, for at least one given first area of the one or more first areas, a given three-dimensional search area comprising the given first area, with a larger volume than the given first area, thereby obtaining a set of one or more three-dimensional search areas, and

feeding the magnetic detection data to a magnetic detection algorithm to perform a target detection within a space, wherein said space is defined based on the set of one or more three-dimensional search areas.

44. The method of any one of claims 40 to 43, wherein the first position data comprise range and azimuth of each of the one or more first areas, but do not comprise elevation of each of the one or more first areas.

45. A method comprising performing, by one or more processing circuitries:

obtaining first position data informative of one or more first areas determined by at least one underwater detection system associated with a marine vehicle,

obtaining magnetic detection data of at least one underwater magnetic detection system associated with the marine vehicle,

using the first position data to determine a set of one or more three-dimensional search areas, and

using at least part of the magnetic detection data to perform at least one target detection within the set of one or more three-dimensional search areas, enabling estimating position of at least one target within said set of one or more three-dimensional search areas.

46. A method comprising performing, by one or more processing circuitries:

obtaining first position data informative of one or more first areas determined by at least one underwater detection system associated with a marine vehicle,

obtaining magnetic detection data of at least one underwater magnetic detection system associated with the marine vehicle,

using at least part of the first position data and at least part of the magnetic detection data to perform at least one target detection enabling obtaining a set of a plurality of position estimates of at least one target, and

processing at least part of the set of a plurality of position estimates to determine an estimate of the position of the target.

47. A marine vehicle associated with:
at least one underwater detection system,
an underwater magnetic detection system, and
the system of any one of claims 1 to 40.

48. A non-transitory computer readable medium comprising instructions that, when executed by one or more processing circuitries, cause the one or more processing circuitries to perform:

in a period of time comprising a relative motion between a marine vehicle and at least one target, in which the marine vehicle has not passed over the at least one target:

obtaining first position data informative of one or more first areas determined by at least one underwater detection system associated with the marine vehicle,

obtaining magnetic detection data of at least one underwater magnetic detection system associated with the marine vehicle, and

using at least part of the first position data and at least part of the magnetic detection data to perform at least one target detection enabling estimating position of the at least one target.

49. A non-transitory computer readable medium comprising instructions that, when executed by one or more processing circuitries, cause the one or more processing circuitries to perform:

obtaining first position data informative of one or more first areas determined by at least one underwater detection system associated with a marine vehicle,

obtaining magnetic detection data of at least one underwater magnetic detection system associated with the marine vehicle, using the first position data to determine a set of one or more three-dimensional search areas, and

using at least part of the magnetic detection data to perform at least one target detection within the set of one or more three-dimensional search areas, enabling estimating position of at least one target within said set of one or more three-dimensional search areas.

50. A non-transitory computer readable medium comprising instructions that, when executed by one or more processing circuitries, cause the one or more processing circuitries to perform:

obtaining first position data informative of one or more first areas determined by at least one underwater detection system associated with a marine vehicle,

obtaining magnetic detection data of at least one underwater magnetic detection system associated with the marine vehicle,

using at least part of the first position data and at least part of the magnetic detection data to perform at least one target detection enabling obtaining a set of a plurality of position estimates of at least one target, and

processing at least part of the set of a plurality of position estimates to determine an estimate of the position of the target.