



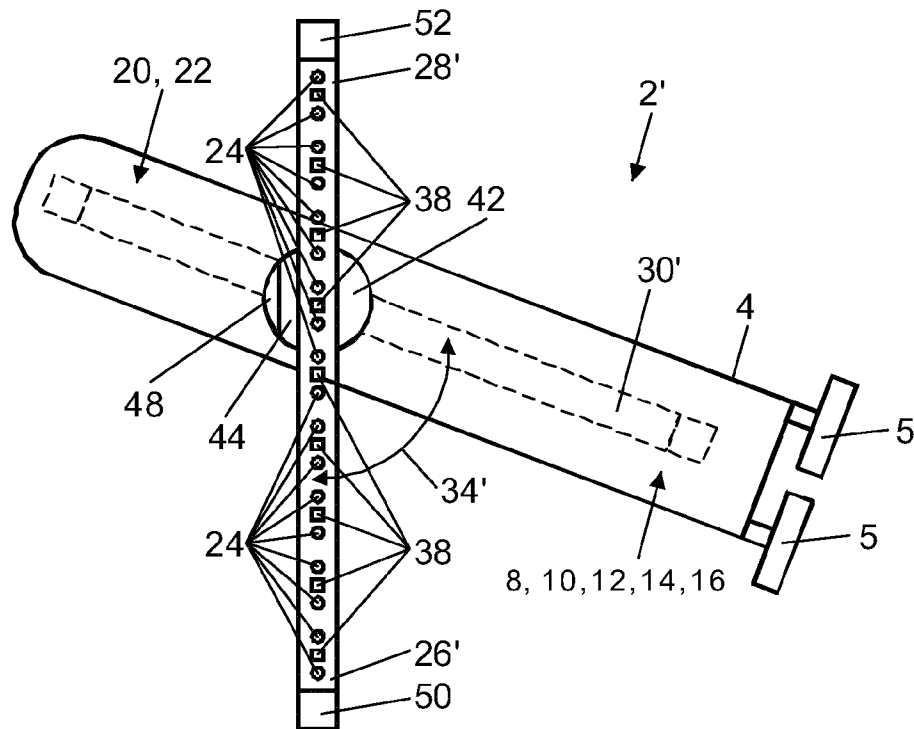
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**Cierpka et al.**(10) **Pub. No.: US 2014/0165898 A1**(43) **Pub. Date: Jun. 19, 2014**(54) **UNMANNED UNDERWATER VEHICLE AND  
METHOD FOR LOCALIZING AND  
EXAMINING AN OBJECT ARRANGED AT  
THE BOTTOM OF A BODY OF WATER AND  
SYSTEM HAVING THE UNMANNED  
UNDERWATER VEHICLE****Publication Classification**(51) **Int. Cl.**  
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USPC ..... **114/312**(75) Inventors: **Kai Cierpka**, Bremen (DE); **Bernd  
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(57) **ABSTRACT**

The invention relates to an unmanned underwater vehicle for localizing and examining an object, for example a pipeline, arranged at the bottom of a body of water. For this purpose, the underwater vehicle has object localization means and object examination means. The underwater vehicle has a sonar device with 3D underground sonar for collecting measurement data. The object localization means are designed for three-dimensional acoustic localization of local sections of the object which are arranged both above and below the surface of the bottom of the body of water by means of these measurement data while the underwater vehicle is simultaneously moving away over these local sections for the purpose of examining local sections of the object by means of the object examination means. As a result, the invention allows a pipeline to be simultaneously surveyed and inspected as it is traversed once. The invention also relates to a system having the underwater vehicle and also to a method for localizing and examining the object.



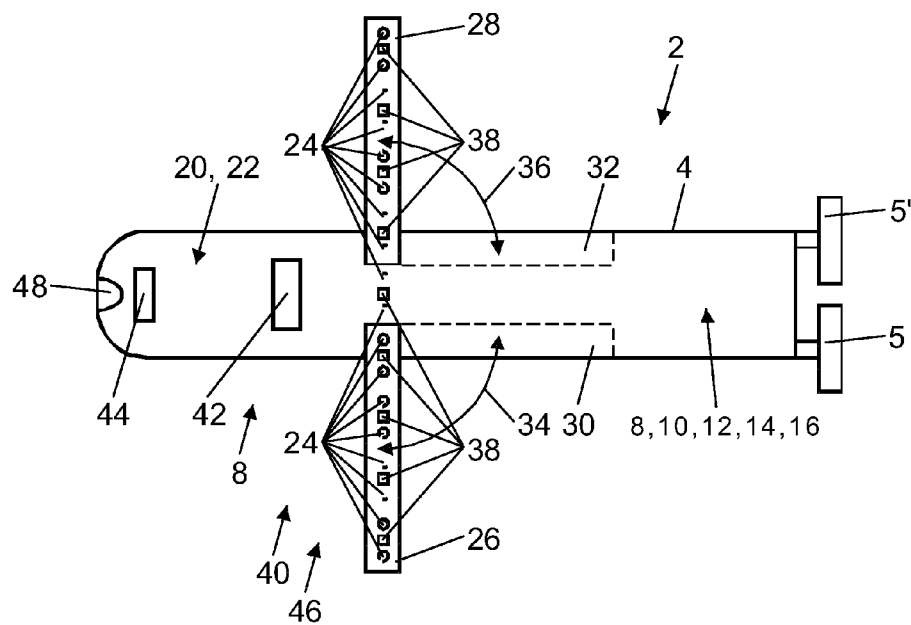


Fig. 1

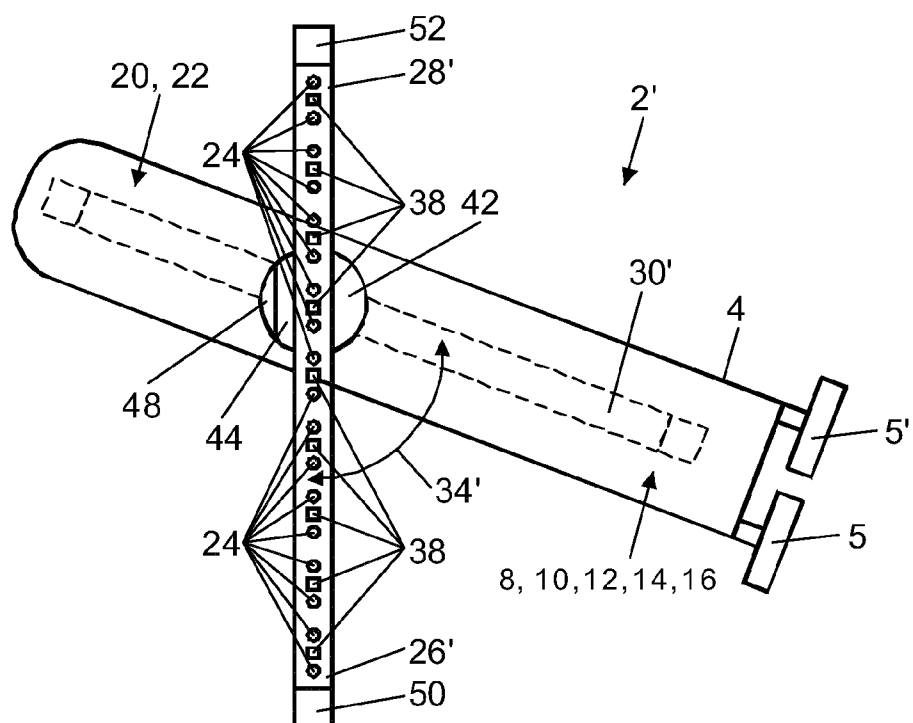


Fig. 2

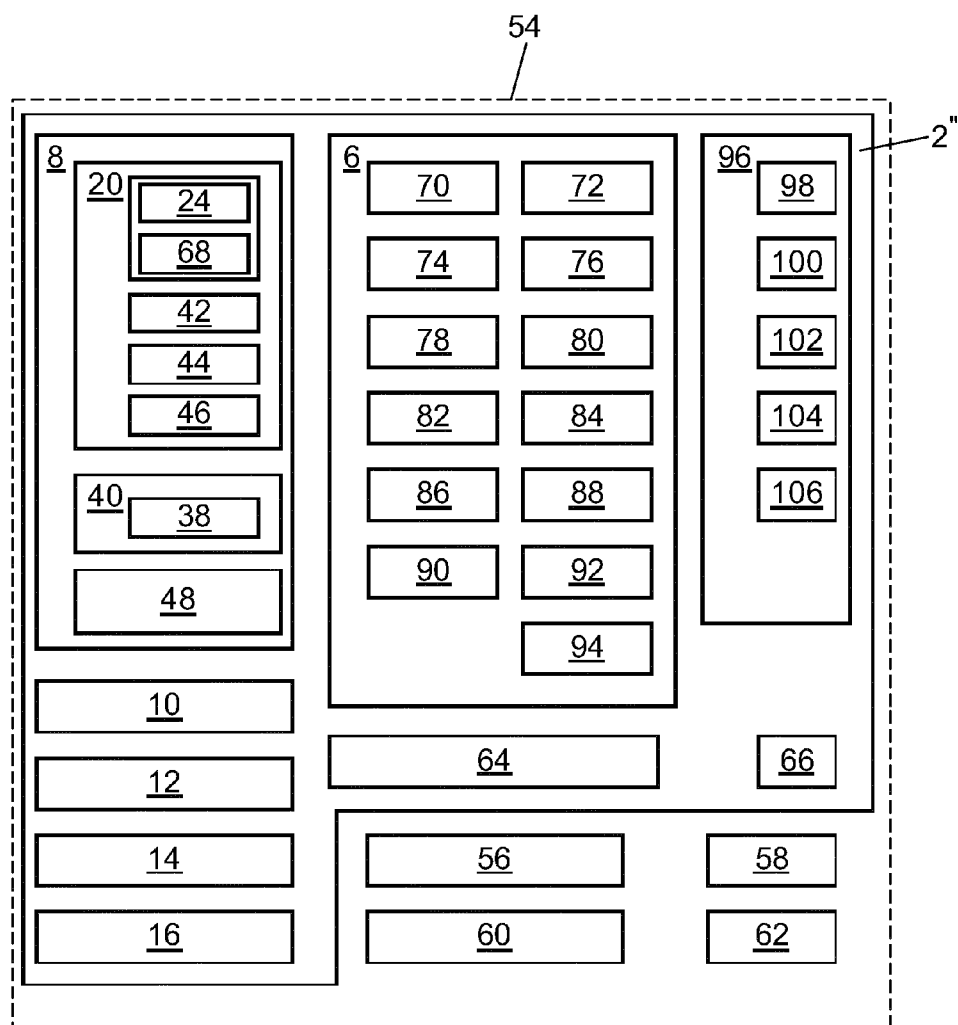


Fig. 3

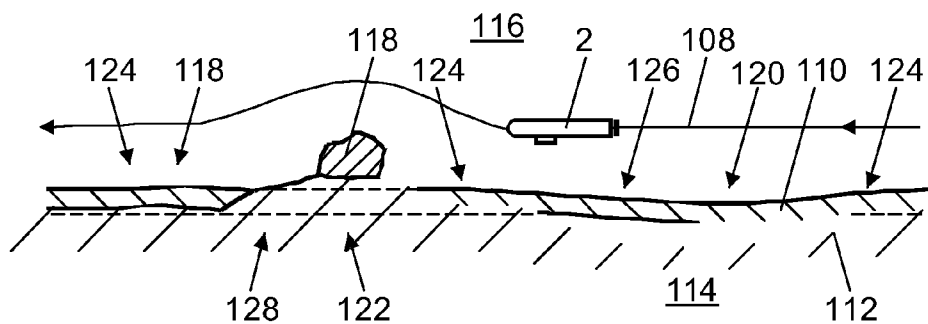


Fig. 4

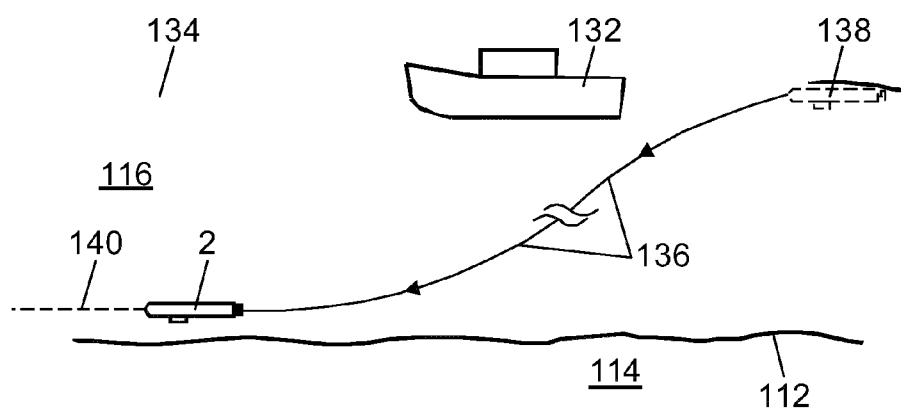


Fig. 5

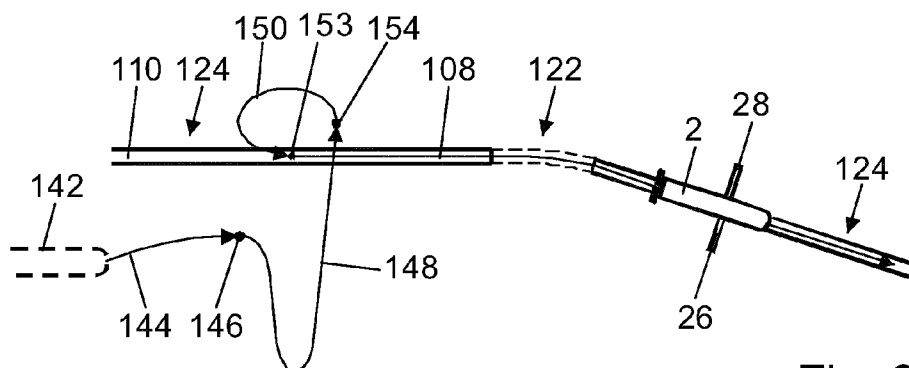


Fig. 6

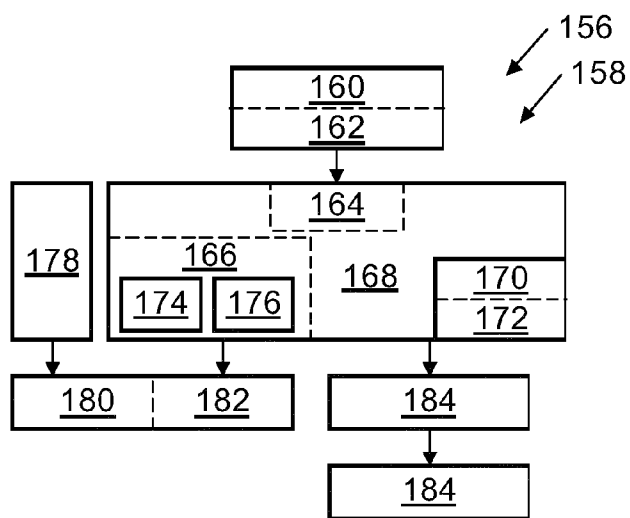


Fig. 7

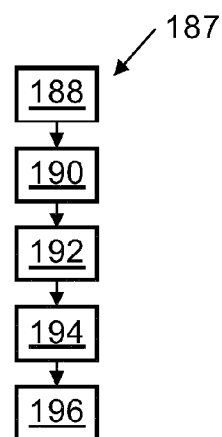


Fig. 8

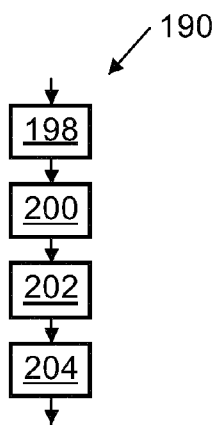


Fig. 9

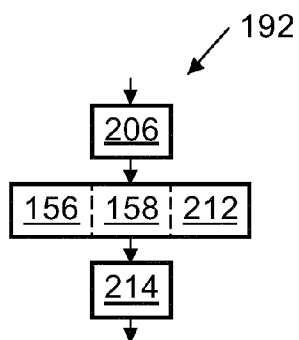


Fig. 10

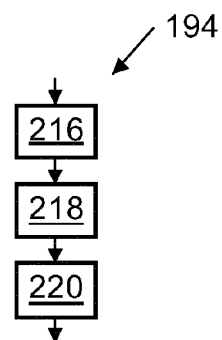


Fig. 11

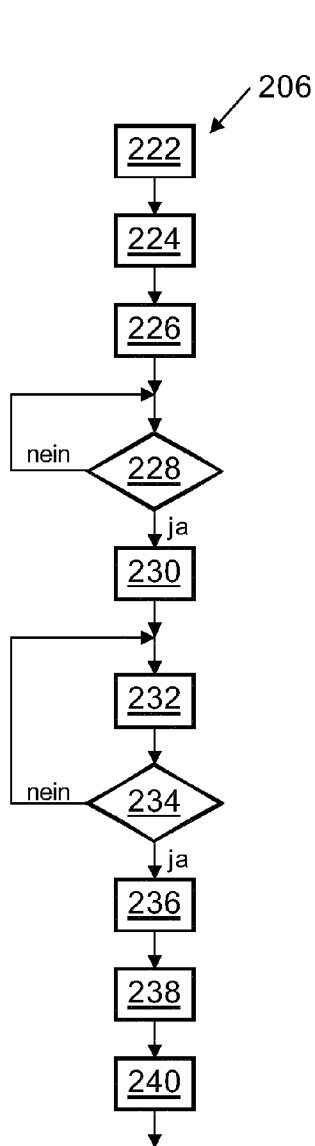


Fig. 12

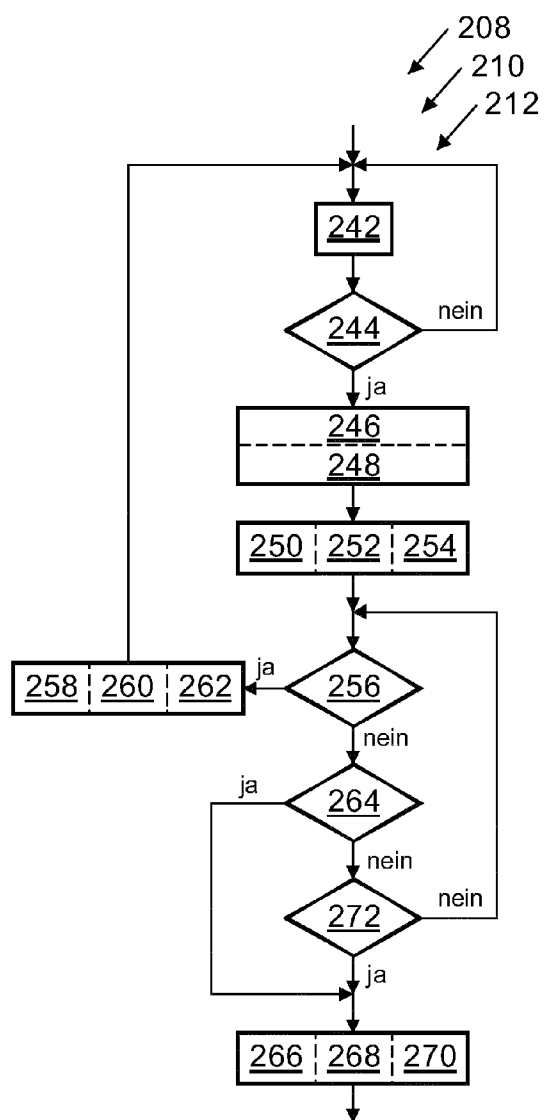


Fig. 13

**UNMANNED UNDERWATER VEHICLE AND  
METHOD FOR LOCALIZING AND  
EXAMINING AN OBJECT ARRANGED AT  
THE BOTTOM OF A BODY OF WATER AND  
SYSTEM HAVING THE UNMANNED  
UNDERWATER VEHICLE**

**CROSS-REFERENCE TO RELATED  
APPLICATIONS**

**[0001]** The present invention is the US national stage under 35 U.S.C. §371 of International Application No. PCT/EP2012/067623, which was filed on Sep. 10, 2012 and which claims the priority of application DE 10 2011 116 613.4 filed on Oct. 20, 2011 the content of which (text, drawings and claims) are incorporated here by reference in its entirety.

**FIELD**

**[0002]** The invention relates to an unmanned underwater vehicle for localizing and examining an object arranged at the bottom of a body of water. The invention further relates to a corresponding method and a system having the unmanned underwater vehicle.

**BACKGROUND**

**[0003]** In various embodiments, an object arranged at the bottom of a body of water can be a pipeline or a marine cable which is to be detected, surveyed and examined, following the path thereof. However, mines may also be detected, for example, by means of the invention. By means of an arrangement of the object at the bottom of the body of water, it is to be understood in the present case that the object is in direct contact with the bottom of the body of water or is connected at least fixedly, optionally even indirectly for example via pipe connectors, to the bottom of the body of water. In this case, sections of the object may rest against the bottom of the body of water and/or be buried in the bottom of the body of water and/or be completely covered over by sediment and/or be exposed and/or underwashed.

**[0004]** For localizing and examining such an object, in a first step it is known to localize and/or to detect and to survey the object and in a second step to examine and/or to inspect the object by means of sensors, for example by means of a camera. At least for locating and surveying and/or for localizing the object, it is known to use an unmanned underwater vehicle. In particular, it is known to use an autonomous underwater vehicle (Autonomous Underwater Vehicle=AUV) or a cable-operated underwater vehicle (Remotely Operated Vehicle=ROV) as the unmanned underwater vehicle for localizing an object arranged at the bottom of the body of water.

**[0005]** The AUV is able to be launched from a support platform, in particular a support vessel, for example a supply vessel, then independently carry out its mission and subsequently be retrieved and/or accommodated again by the support platform. The supply carrier does not have to accompany the AUV while the AUV carries out its mission. However, in this case the AUV is not able to be supplied with electrical energy by the supply carrier so that its operating time is limited by the storage capacity of accumulators carried on-board. The ROV is connected to the carrier platform by means of a cable via which it is supplied, for example, with electrical energy and/or control data, the carrier platform thus having to accompany the underwater vehicle during the localization and/or during an entire mission comprising the localization.

Moreover, the operating time of the ROV is also limited when it is not supplied with electrical energy via its cable.

**[0006]** For locating and surveying the object, known underwater vehicles have a side scan sonar device which permits a downward, substantially oblique side view. It is, therefore, known to track the path of a pipeline which has been located once or the path of a further object and to survey the pipeline and/or the object by the underwater vehicle travelling with a lateral offset over the pipeline and/or the object.

**[0007]** Due to ocean currents, the bottom of the body of water is usually constantly in motion so that sections of the object may be covered with sediment and/or buried in sediment. In this case, such buried sections of the object are no longer able to be identified by the side scan sonar device. Known underwater vehicles, therefore, follow an assumed object path and search for the object there which may be time-consuming, in particular when the assumed object path does not coincide with the actual object path, for example due to the pipeline kinking to the side.

**[0008]** For examining the localized object, it is known to carry out a manual inspection by means of divers. It is also known to carry out [an inspection of] the object by means of a further ROV or AUV or even by means of the ROV or AUV previously used for localizing. In this case, the underwater vehicle traverses the now localized object once again but now without a lateral offset in order to be able to inspect the object from a close distance, for example directly from above by means of a camera.

**[0009]** The known method for localizing and examining an object arranged at the bottom of a body of water thus has a several drawbacks. In particular, in the limited operating period of the AUV or ROV without an external energy supply only an extremely limited region of the object may be actually localized and examined as the underwater vehicle has to traverse the object twice for the localization and examination and also as the object has to be located again beneath buried sections during a mission which is sometimes time-consuming. In this case it also has to be taken into account that, in particular when used at great depths, merely the submersion and surfacing of the underwater vehicle when used at increasing operating depths, uses up an increasingly greater proportion of the limited operating time of the underwater vehicle.

**SUMMARY**

**[0010]** The object of the invention, therefore, is to improve the localizing and examining of an object, in particular a pipeline and/or a marine cable at the bottom of a body of water.

**[0011]** In various embodiments, this object is achieved by an unmanned underwater vehicle according to claim 1, having a system according to claim 8 and having a method according to claim 9.

**[0012]** The unmanned underwater vehicle has object localization means for localizing the object and object examination means for examining the object. Moreover, the autonomous underwater vehicle has a sonar device with 3D underground sonar for collecting measurement data. The sonar device can also have further sonar devices. The object localization means are designed for three-dimensional acoustic localization of local sections of the object which are arranged both above and below the surface of the bottom of the body of water, by means of at least the measurement data, while the underwater vehicle is simultaneously moving along the local sections for the purpose of examining the sections or



adjacent sections of the object by means of the object examination means. The measurement data are at least partially generated by 3D underground sonar. The underwater vehicle, therefore, only has to follow the path of the object once and at the same time is able to localize and/or survey the object and examine and/or inspect the object. As a result, during an equally long time period, or during a mission, a considerably larger region of the object can be localized and examined, or an object can be localized and examined in a shorter time, relative to the prior art.

**[0013]** The use of the sonar device with 3D underground sonar in this case permits the localizing of the object with a small lateral offset of the underwater vehicle relative to the object when tracking the object path, in particular from a position in which the object is arranged at a lateral angle of less than 20 degrees, e.g., less than 10 degrees, relative to the vertical from the underwater vehicle. The localizing of the object takes place with the reduced risk of losing the object locally and having to locate the object again. Thus, the necessity in the prior art of moving the underwater vehicle in a first process for localizing the object, with a lateral offset, and subsequently moving the underwater vehicle in a second process for examining the object, without a lateral offset to the object, is dispensed with.

**[0014]** In this case, the risk of losing the object when following the object path is reduced as the sonar device with 3D underground sonar enables local sections of the object to be localized irrespective of whether the local sections are arranged below the surface of the bottom of the body of water or above the surface of the bottom of the body of water.

**[0015]** According to the method according to the invention, the sonar device with the 3D underground sonar collects measurement data and the object localization means determine, by means of the measurement data, the local sections of the object in a three-dimensional acoustic manner, while the underwater vehicle is moving along the local sections of the object and simultaneously the object examination means examine the object, irrespective of whether the local sections are arranged above or below the surface of the bottom of the body of water.

**[0016]** In various embodiments, the unmanned underwater vehicle is configured for fully autonomous use as an AUV. The underwater vehicle configured as an AUV is provided according to a development of the invention with a data link (hub) for providing data online via the data link. In a further embodiment, the underwater vehicle is an ROV. According to a development of the invention, the underwater vehicle is able to be used both as an AUV and also an ROV, and equipped for both purposes. In this case, for example, the underwater vehicle can be cable-connected in shallow water and operate fully autonomously in the deep ocean.

**[0017]** In various embodiments, the unmanned underwater vehicle has object path identification means for identifying the local object path and/or for identifying structures of the object by means of the localized local sections, irrespective of whether the local sections rest on the surface, are buried or exposed. In this case it is assumed that the object has a size and/or a diameter of 0.05 to 0.25 meters for a marine cable and/or 0.60 to 0.81 meters for a pipeline and additionally comprises a ferromagnetic material. The pipeline is in this case buried up to a depth of a maximum of 2 meters in the seabed. Due to its very small thickness, it is possible for the marine cable to be buried less deeply, for example up to a depth of 0.5 meters or up to a depth of 1 meter. According to

the method, the object path identification means identify the local object path of the object by means of the localized sections irrespective of whether the localized sections rest on the surface, are buried or exposed. As a result, this counteracts the underwater vehicle temporarily losing the object and/or sections of the object and having to locate the object again, while it follows the object path.

**[0018]** In various embodiments, the unmanned underwater vehicle has object path tracking means for adapting the trajectory of the underwater vehicle by means of the identified object path such that a lateral offset of the trajectory relative to the identified object path is kept as small as possible, in particular below a specific threshold value, and/or as constant as possible, in particular in the event of a deviation from a constant lateral offset which is below a specific threshold value. As a result, the invention makes it possible to follow the object path substantially without a lateral offset, in particular with a horizontal lateral offset of less than half a meter and/or with a substantially constant lateral offset, for example of half a meter, so that examining the object is already possible within the same process and/or already when localizing the object.

**[0019]** The unmanned underwater vehicle in various embodiments comprises a multi-sensor system. The multi-sensor system has the 3D underground sonar as a first sensor. Moreover, the multi-sensor system has at least one further sensor. All these sensors are configured for collecting measurement data for localizing and/or for examining the object by means of the measurement data. The further sensors include at least one camera, a side scan sonar device, a multi-beam sonar device, a front scan sonar device and/or at least one magnetic sensor and/or gradiometer probes and/or a magnetometer, in particular a vector magnetometer, of a magnetic field detection device. According to the method, the multi-sensor system combines the measurement data of at least two of the sensors of the multi-sensor system together and/or amalgamates the measurement data. The object localization means identify and/or examine the object by means of the combined and/or amalgamated measurement data. In various embodiments, measurement data of at least one optical, at least one acoustic and at least one magnetic sensor are combined together and/or amalgamated, in particular for localizing the object, particularly for tracking the object path.

**[0020]** The combining of the measurement data permits autonomous operation during the localization with the greatest degree of precision and when examining the object and ensures at the same time a high degree of reliability of the results. In particular, errors when interpreting the measurement data are minimized, as the measurement data from different sensors are used.

**[0021]** In this case, the camera permits a visual inspection of the object so that for the examination procedure, for example, external damage to the object can be identified. At the same time, the optical sensor data of the camera can also be evaluated for identifying the object path and/or for identifying underwashing.

**[0022]** The side scan sonar device not only permits initial locating of the pipeline but, similar to the multibeam sonar, an examination of the surroundings of the object. As a result, in particular the object path can be estimated more accurately relative to the surroundings. The front scan sonar device permits, in particular, early identification of a potential kink in the object path and the detection of possible obstacles.

**[0023]** In various embodiments, the underwater vehicle does not pass around the side of obstacles in the desired trajectory above the object path but passes over the obstacles by a deviation in the vertical direction. As a result, uninterrupted localizing and examining of the object is facilitated. Finally, the object, in particular the pipeline when it comprises a ferromagnetic material, is advantageously detected by means of the magnetic sensors and/or by means of the magnetometer of the gradiometer probes. Also, the path of the object can be advantageously identified, in particular in combination with the 3D underground sonar, assisted by the magnetic field detection device. The magnetometer can be a passive and/or an active magnetometer, wherein in the case of a configuration as an active magnetometer, a device for producing a magnetic field is provided on the underwater vehicle.

**[0024]** In various embodiments, the multi-sensor system is designed to collect measurement data which are suitable for surveying the local surface of the bottom of the body of water below the underwater vehicle, for identifying the position of the detected local sections of the object relative to the local surface of the bottom of the body of water and for classifying by means of the identified position whether the local sections are sections of the object which rest on the surface, are buried or exposed, in particular underwashed. According to the method, corresponding measurement data are collected. Thus, both the object and the surroundings of the surface of the bottom of the body of water are surveyed, wherein the measurement data collected thereby are supplied for common evaluation and, as a result, permit the interpretation of how the individual sensor data can be evaluated and whether the detected local sections of the object rest on the bottom of the body of water, are buried in the bottom of the body of water or are exposed. For example, in optical terms the object is not visible by means of the camera but can be located by means of the 3D underground sonar at a specific depth. In this case, the distance from the seabed to the underwater vehicle can be detected, for example, by the multibeam sonar.

**[0025]** Advantageously, the unmanned underwater vehicle has navigation means which provide navigation data for independent navigation of the underwater vehicle. In various embodiments, the navigation means are used for determining the respective position of the respectively localized section of the object and for assigning measurement data to the respective position. The navigation means permit highly accurate navigation initially from the water surface to a submerged position, the object being assumed to be in the surroundings thereof. The navigation means further permit the highly accurate tracking of the object path and the allocation of coordinates to sections of the object and/or the localizing of sections of the object. To this end, the navigation means comprise a plurality of navigation devices for determining the navigation data.

**[0026]** In various embodiments the unmanned underwater vehicle has and/or the navigation means have a pitch sensor for determining the rotational movement of the underwater vehicle about its transverse axis. As a result, the operating depth of the underwater vehicle can be maintained and, in combination with further sensors, in particular for determining the speed, the submersion speed and/or surfacing speed of the underwater vehicle can be determined.

**[0027]** Furthermore, a roll sensor can be provided as a navigation means for determining the rotational movement of the underwater vehicle about its longitudinal axis. This assists

with identifying tilting to the side and/or stabilizing the underwater vehicle against tilting to the side.

**[0028]** In addition, in various embodiments, the unmanned underwater vehicle has and/or the navigation means have a magnetic compass for determining the direction and orientation of the underwater vehicle relative to the field lines of the earth's magnetic field. As a result, it is possible to determine the course in the water.

**[0029]** In various embodiments the navigation means comprise an aneroid barometer or a further barometer for determining the water pressure at the depth of the underwater vehicle below the water surface, wherein the water pressure is determined in order to be able to determine the depth using the determined water pressure. In particular, when submerging or when surfacing, the unmanned underwater vehicle automatically determines the current submerged depth by means of the navigation system and/or by means of the aneroid barometer.

**[0030]** Moreover, the unmanned underwater vehicle, in particular when submerging, navigates by means of a so-called "ultra short baseline" underwater navigation system, wherein the navigation means comprise a device of the underwater navigation system which, by at least one further device, carries out travel time measurements between the device and the further device and uses the travel time measurements for determining the position. The further device can be positioned, for example, on the seabed, wherein the position is fixed at least during the navigation. Moreover, the further device can also be fastened to the support platform or to a further vessel. The underwater navigation system permits the position of the underwater vehicle to be determined with a high degree of accuracy, in particular during submersion.

**[0031]** In various embodiments, the navigation means comprise at least one waterborne sound speed sensor for determining the sound speed in water, in particular for assisting the navigation by means of travel time measurements.

**[0032]** Furthermore, the navigation means of the unmanned underwater vehicle can have a so-called transponder and/or a so-called responder. The transponder and the responder are devices which receive signals and return signals in response thereto. The transponder is in this case a movable device whereas the responder is a fixed device. The transponder and/or the responder permit travel time measurements which are carried out, for example, from the support platform. Results of the travel time measurements can then be transmitted from the support platform to the autonomous underwater vehicle, for example by means of waterborne sound signals.

**[0033]** In various embodiments, the unmanned underwater vehicle has and/or the navigation means have an ultrasonic doppler profile flowmeter for determining the water flow relative to the underwater vehicle. According to the method, therefore, the water flow relative to the underwater vehicle is determined and in various embodiments used for controlling the underwater vehicle, so that it is possible for example to counteract the drifting of the underwater vehicle away from a designated course.

**[0034]** In various embodiments, the navigation means comprise acceleration sensors for determining the acceleration of the underwater vehicle, in particular in an inertial reference system, provided in particular by means of the underwater vehicle. Thus inertial navigation and/or navigation is assisted, even without reference to the external environment.

[0035] Moreover, the navigation means can comprise a measuring probe for determining the salt content and/or for determining the temperature of the surrounding water and/or for determining the depth of the measuring probe below the water surface. The measuring probe accordingly determines the salt content and/or the temperature and/or the depth of the measuring probe below the water surface and provides corresponding measurement results. The measurement results are in various embodiments used when determining measurement results of the remaining devices or during the interpretation thereof, as measurements using the remaining devices and/or measurement results are at least partially dependent, for example, on the salt content of the surrounding water.

[0036] In various embodiments the navigation means also comprise a receiver device for receiving satellite signals of a satellite-assisted navigation system, for example of a Global Positioning System (GPS). The satellite-assisted navigation system is used for determining the position of the underwater vehicle by means of the satellite signals, in particular when the underwater vehicle is located on the surface of the body of water on which it is able to receive the satellite signals. On the surface of the body of water the satellite-assisted navigation system permits a very accurate determination of the position, for example before submersion. By means of one or by means of a plurality of the remaining devices, further navigation is carried out when submerged, which however is in various embodiments able to be carried out accurately at least such that at a submerged depth of 1500 meters a submersion error of a maximum of 10 meters is achieved. In various embodiments, a navigation accuracy of 0.1 per cent of the path covered during submersion is achieved relative to the start position.

[0037] Moreover, the navigation means can comprise a turbidity sensor for determining the turbidity of the surrounding water. The turbidity determined by the turbidity sensor is in various embodiments taken into consideration when using further measurement results, similar to the measurement results of the measuring probe for determining the salt content. Also, the turbidity can falsify the measurement results or even make visual navigation impossible, which is thus able to be taken into account.

[0038] In various embodiments, the navigation means take into account knowledge about the path of the object, for example a straight or curved path of the object, during navigation. The knowledge is stored prior knowledge or knowledge detected by means of sensors.

[0039] In various embodiments, the navigation means also comprise an electronic navigation system and/or algorithms for image processing and/or for providing artificial intelligence and/or for providing statistical signal processing, wherein the electronic navigation system assists the navigation and, in particular, permits accurate navigation.

[0040] In various embodiments, the unmanned underwater vehicle has a single and/or generic data interface and/or sensor interface for the different sensors and/or for the different devices, in particular navigation devices, such that different sensors and/or devices can be optionally connected via the data interface and used for localizing and/or examining the object. In this manner, it is possible to provide the underwater vehicle for different purposes with a different number of sensors or even with different sensors and/or devices, without having to provide a different computer or control electronics therefor, or having to undertake other costly adaptations. According to the method, measurement data from at least one

of the sensors and/or devices, in particular after reconfiguration of the underwater vehicle or when sensors deliver no measurement data or falsely identified measurement data, are used for the localizing and/or examining, alternatively or additionally to the measurement data of at least one further sensor and/or devices. The respective measurement data are transmitted via the respective single data interface so that the sensors and/or devices can be used in a redundant manner. In particular, therefore, a functional redundancy is permitted when navigating and/or when tracking and/or when examining the object.

[0041] For communication, the unmanned underwater vehicle can have a communication means which receive and/or transmit signals and/or information for communication. In this case, the communication means can comprise an acoustic underwater communication device and/or a satellite communication device and/or a WLAN (Wireless Local Area Network) communication device and/or a network device and/or a radio connection device.

[0042] The acoustic underwater communication device communicates acoustically by means of waterborne sound signals and/or with a further underwater communication device which is arranged on the support platform. The satellite communication device communicates via radio via at least one satellite. The WLAN communication device also permits communication via radio, but only in the immediate vicinity, via a wireless local network, for example in order to transmit measurement data after the end of the mission wirelessly from the underwater vehicle to a stationary device. This transmission of the measurement data can also take place by means of the network device, which permits an electrical communication via a wired network. Also, it is possible to transmit measurement data during the execution of a mission, in particular when the underwater vehicle is configured as an ROV. Finally, the radio connection device permits communication via radio by using a transmission method which minimizes transmission losses by identification and repeated transmission of incompletely transmitted data packets, for example of the so-called "Radio Link Protocol" (RLP).

[0043] In various embodiments, the 3D underground sonar comprises a plurality of waterborne sound transducers, arranged in particular in series, and an artificial aperture for spanning an observation plane permitting the three-dimensional localization of the object by means of repeatedly determined sensor data of the waterborne sound transducers. As a result, the movement of the underwater vehicle is utilized in order to minimize the number of waterborne sound transducers to be physically provided.

[0044] In various embodiments, the unmanned underwater vehicle has at least one sensor carrier which is pivotable relative to the longitudinal axis of the underwater vehicle. The waterborne sound transducers are fastened to the sensor carrier at a plurality of different intervals, in each case relative to a common reference point on the longitudinal axis, at least in their majority. Individual waterborne sound transducers can be fastened, for example, directly to the hull of the underwater vehicle. In particular, the waterborne sound transducers are fastened at a plurality of different intervals relative to the respective pivot axis of the respective sensor carrier. The pivot axis can in this case be a materially configured axis or an imaginary axis, which is either fixedly fastened to the underwater vehicle or in turn can even be displaced and/or pivoted, in particular when retracting or extending the sensor carrier.

**[0045]** The underwater vehicle is thus able to travel towards its start position at its mission depth with the sensor carriers pivoted-in, so that the sensor carriers do not provide any unnecessary resistance to the movement and the maneuvering in the water during submersion. According to the method, before the start of the measurements the underwater vehicle pivots at least one sensor carrier relative to the longitudinal axis of the underwater vehicle. In particular, the underwater vehicle pivots the sensor carrier out. The waterborne sound transducers are accordingly arranged over a width of at least two meters and can be distributed uniformly over the width. Subsequently, sensor data is determined repeatedly, wherein the sensor data determined at different time periods is considered, as is sensor data determined at different locations, which is possible by considering the inherent movement of the underwater vehicle and with the assumption that the bottom of the body of water remains at least substantially unaltered during this short time period. Thus, the so-called artificial aperture is spanned. By means of the artificial aperture, it is possible to detect the seabed three-dimensionally.

**[0046]** In an advantageous development, the waterborne sound transducers which determine the sensor data are arranged asymmetrically to the longitudinal axis of the underwater vehicle, such that the centre of a scanning region which is able to be scanned by means of the waterborne sound transducers has a lateral offset, in various embodiments of at least half a meter, to the longitudinal axis of the underwater vehicle. Optionally, in this case the waterborne sound transducers fastened physically to the sensor carrier can be symmetrical to the longitudinal axis of the underwater vehicle, wherein the sensor data from all of the underwater sound transducers is not exclusively used for localizing the object. The asymmetrical arrangement permits an improved localization directly below the underwater vehicle and/or in the region of the object.

**[0047]** In various embodiments, magnetic sensors are fastened to the sensor carrier with the waterborne sound transducers or to a further sensor carrier or extension arm, for locating the object, wherein the object is located by detecting magnetic anomalies which are caused by the object. The object, in particular the pipeline and/or the marine cable, has a ferromagnetic material which is detected by means of the magnetic sensors, even when the object is buried in the seabed. The magnetic sensors facilitate the locating of the object but can also permit the object and/or the object path to be tracked, either alone or by assisting other devices.

**[0048]** In various embodiments, the unmanned underwater vehicle can have a control device. The control device is configured for maneuvering the underwater vehicle to an operating depth defined by a submerged position. Moreover, the control device is configured for maneuvering the underwater vehicle to the submerged position after reaching the operating depth. Moreover, the control device is configured for carrying out a search routine after reaching the submerged position, wherein available prior knowledge about the position of the object is taken into consideration by the search routine. Finally, the control device is configured for calculating and traversing a start-up trajectory to a position defined as a function of the determined position of the object and for following the trajectory located above a determined object path. The control device has respective means for these purposes.

**[0049]** According to the method, initially a mission is planned, in various embodiments by means of a mission

planning device. In a development of the invention, prior knowledge about the position of the object is considered here. The mission planning device produces control data suitable for carrying out the mission which are transmitted to the underwater vehicle via radio, via a wired connection or by means of a data storage device, which is connected to the underwater vehicle. Subsequently, in particular after putting the underwater vehicle to water, the underwater vehicle navigates independently and carries out a submersion maneuver by independent navigation. In this case, the underwater vehicle maneuvers to the operating depth defined by the submerged position, wherein it repeatedly or continuously determines its position. In particular, the position determination takes place during submersion by means of the above-mentioned "ultra short baseline" system. In this case, the position of the underwater vehicle from the surface vessel is determined and transmitted to the underwater vehicle.

**[0050]** After reaching the operating depth, the underwater vehicle can perform a so-called "navigation alignment navigation maneuver" to reach the submerged position. In this case, a potential submersion error which is established by means of sensors and/or navigation devices is compensated.

**[0051]** In various embodiments, the underwater vehicle subsequently performs a search routine to search for the object. In particular, the underwater vehicle travels in a meandering manner for locating the object at a defined distance above the bottom of the body of water. If prior knowledge about the position of the object is available, this prior knowledge is in various embodiments taken into consideration when performing the search routine. After locating the object, a start-up trajectory to a start position is calculated and traversed by the underwater vehicle. In various embodiments, the underwater vehicle subsequently repeatedly determines the object path and in this case follows the determined object path on its trajectory located thereabove. The underwater vehicle at the same time examines the object and stores measurement data detected during the examination, in particular from the sensors but in various embodiments also the navigation devices, in a memory device and/or transmits the measurement data via a cable, for example, to the support platform. The measurement data stored in the memory device are read and evaluated, in particular after the end of the mission. In this case, the measurement data are evaluated so as to classify whether sections of the object are sections which rest on the surface, are buried or exposed, in particular underwater. Alternatively or additionally, the condition of the object is determined by means of the measurement data. The classification and the determination of the condition takes place entirely, or at least substantially, automatically.

**[0052]** The system according to the invention has the autonomous underwater vehicle as well as a mission planning device for producing control data for controlling the mission. Moreover, the system comprises a control data transmission device for transmitting the control data from the mission planning device to the underwater vehicle. Furthermore, the system has a measurement data reading device for reading measurement data stored during the mission and a measurement data evaluation device for classifying sections of the object as sections which rest on the surface, are buried or exposed, and/or for determining the condition of the object.

#### DRAWINGS

**[0053]** Further embodiments are revealed from the claims and from the exemplary embodiments described in more detail with reference to the drawings, in which:

[0054] FIG. 1 shows an autonomous underwater vehicle according to various exemplary embodiments of the invention in a simplified schematic view from below.

[0055] FIG. 2 shows an autonomous underwater vehicle according to various other exemplary embodiments of the invention in a simplified schematic view from below.

[0056] FIG. 3 shows a system with an autonomous underwater vehicle according to still other exemplary embodiments of the invention in a simplified schematic side view.

[0057] FIG. 4 shows the autonomous underwater vehicle according to the exemplary embodiments of FIG. 1 in an arrangement when localizing and examining a pipeline in a side view.

[0058] FIG. 5 shows the autonomous underwater vehicle according to the exemplary embodiments of FIG. 1 in an arrangement during submersion with its trajectory in a side view.

[0059] FIG. 6 shows the autonomous underwater vehicle according to the exemplary embodiments of FIG. 1 in an arrangement when localizing and examining a pipeline with the trajectory travelled for adopting a submerged position, for searching for the pipeline, for travelling towards a start position and when tracking the path of the pipeline, in a plan view.

[0060] FIG. 7 shows a schematic view of method steps when localizing and examining an object arranged on the bottom of the body of water according to various exemplary embodiments of the invention.

[0061] FIG. 8 shows a schematic view of a method for localizing and examining an object assigned to the bottom of the body of water according to various exemplary embodiments of the invention.

[0062] FIG. 9 shows method steps for preparing the mission of the method of the exemplary embodiments according to FIG. 8.

[0063] FIG. 10 shows method steps for carrying out the mission of the method of the exemplary embodiments according to FIG. 8.

[0064] FIG. 11 shows method steps for following up the mission of the method of the exemplary embodiments according to FIG. 8.

[0065] FIG. 12 shows method steps for submersion when carrying out the mission according to FIG. 10.

[0066] FIG. 13 shows method steps for localizing and examining the object when carrying out the mission according to FIG. 10.

#### DETAILED DESCRIPTION

[0067] FIG. 1 shows an unmanned underwater vehicle 2 according to various exemplary embodiments for localizing and examining an object arranged at the bottom of a body of water. The object is, for example, a pipeline or a marine cable which is laid at the bottom of the body of water. The bottom of the body of water and thus the object can be arranged at a depth of up to 1500 or even up to 2000 meters below the surface of the body of water and/or below sea level. The autonomous underwater vehicle 2 is configured to be correspondingly pressure-tight so that it is able to operate at this depth.

[0068] The unmanned underwater vehicle is configured as an autonomous underwater vehicle (AUV=Autonomous Underwater Vehicle), as a cable operated underwater vehicle (ROV=Remotely Operated Vehicle) or such that it can optionally be used as an AUV or ROV.

[0069] The underwater vehicle 2 has at least one pressure casing 4 within which different devices are accommodated, protected from the water and protected from the pressure of the water. For moving forward, the underwater vehicle 2 comprises drives 5 and 5' which, similar to other electrical devices of the underwater vehicle 2, are also supplied with electrical energy by an accumulator accommodated in the pressure casing 4. In various embodiments, further drives, not shown here, such as for example a horizontal and/or a vertical thruster are provided for assisting a height alteration and/or a lateral movement or steering counter to lateral currents on the underwater vehicle 2.

[0070] For independent navigation, the underwater vehicle 2 comprises navigation means 6 with a plurality of navigation devices and/or sensors as well as a computer and/or algorithms which assist the navigation. Such algorithms are image-processing algorithms, an algorithm providing artificial intelligence as well as algorithms for statistical signal processing. The navigation means 6 are appropriate and provided, in particular, for determining the absolute position of the underwater vehicle 2 and for specifically moving towards the target coordinates. In particular, by means of the navigation means 6 a targeted submersion is possible to a submerged position which can be located at a great depth of, for example, 1500 meters.

[0071] Moreover, the underwater vehicle 2 comprises a multi-sensor system 8 with a plurality of sensors for collecting measurement data. The underwater vehicle 2 has object localization means 10 for localizing the object, object examination means 12 for examining the object and object path identification means 14 for identifying the local object path, which in each case use single measurement data, a plurality of measurement data or all of the measurement data. The local object path is the direction in which the object extends locally. The object path tracking means 16 are provided in order to follow this object path directly over the object by means of the identified object path and/or to track the object path. The multi-sensor system 8 in this case permits measurement data for localizing the object and measurement data for examining the object to be able to be collected simultaneously. In this case, individual measurement data, a plurality of measurement data or all measurement data can also be used simultaneously to localize and to examine the object. By means of the object localization means 10, the object is surveyed using the measurement data, in particular by additional use of the navigation means 6. In particular, sections of the object are identified and geo-referenced positional data are assigned to the identified sections.

[0072] The multi-sensor system 8 in this case comprises at least one sonar device 20 with 3D underground sonar 22. As a result, it is possible for the object path identification means 14 to identify and to survey sections of the object and/or the object, whilst the underwater vehicle 2 travels on a trajectory which is located substantially without lateral offset above the object path.

[0073] In contrast, a survey solely by using a side scan sonar device would require a lateral offset even if the object were arranged above the surface of the bottom of the body of water. "Sections arranged above the surface of the bottom of the body of water" are to be understood in this case both as sections in contact with and/or resting on the surface of the bottom of the body of water and also exposed and/or underwashed sections of the objects. Sections arranged below the surface of the bottom of the body of water and/or sections of

the object which are completely covered over, buried, covered with sediment or overwashed, however, are also not detected by the side scan sonar device. An underwater vehicle which surveys the object solely by means of its side scan sonar device, therefore, would not detect or insufficiently detect sections of the object arranged below the surface of the bottom of the body of water. If, however, individual sections of the object are not detected, the following sections have to be located again which is costly, necessitating search maneuvers and maneuvering the underwater vehicle, so that the object is not able to be simultaneously localized and examined.

**[0074]** The 3D underground sonar **22** on the underwater vehicle **2** according to various embodiments, however, makes it possible to follow the object path on a trajectory located thereabove and to survey the object in a three-dimensional manner, even when regions of the object are completely covered over. This in turn permits a simultaneous examination and/or inspection of the object. As traversing the object path once is sufficient for localization and examination, larger regions of the object can be localized and/or surveyed and examined during a mission and/or during an operating time of the underwater vehicle **2** provided by the capacity of the accumulator.

**[0075]** The 3D underground sonar in this case can be operated such that it identifies sections of the object arranged below the surface of the bottom of the body of water and/or buried sections of the object, and such that it identifies exposed sections of the object or sections of the object resting on the surface. Moreover, the multi-sensor system surveys the surface of the bottom of the body of water and/or the seabed in the surroundings of the object, in particular by means of the sonar device **20**.

**[0076]** The object path identification means identify, for example, possible kinking of the object path even when the object is kinked in a region which is arranged below the surface of the bottom of the body of water.

**[0077]** The 3D underground sonar comprises a physical aperture and an artificial aperture. The physical aperture is provided by a series of waterborne sound transducers **24** in the lateral direction at right angles to the autonomous underwater vehicle **2** and/or in the lateral direction at right angles to the object path. The artificial aperture extends perpendicular to the physical aperture and/or in the direction of the object path and/or in the direction of the trajectory of the underwater vehicle **2**. Measurement values of the waterborne sound transducers **24** determined in succession are in this case combined together by computer as if they were not provided by the same waterborne sound transducers at different times but provided simultaneously thereby and by further waterborne sound transducers at different locations.

**[0078]** The waterborne sound transducers **24** are arranged on sensor carriers **26** and **28** as well as on the pressure casing **4** of the autonomous underwater vehicle **2**. The sensor carriers **26** and **28** are pivoted horizontally, perpendicular to the longitudinal axis of the underwater vehicle **2**, so that they protrude in the manner of wings to the side of the underwater vehicle **2**. If the underwater vehicle **2** is not used for localizing and/or for examining the object, for example during submersion or surfacing, the sensor carriers **26** and **28** can be folded in and/or are folded in. In this case, they come to rest at positions **30** and **32** indicated by dashed lines. The possibility of pivoting between the positions shown and the positions **30** and **32** of the sensor carriers **26** and **28** are indicated by means of two double arrows **34** and **36**.

**[0079]** Moreover, a plurality of magnetic sensors **38** as part of a magnetic field detection device **40** forming part of the multi-sensor system **8**, are arranged on the sensor carriers **26** and **28** as well as on the pressure casing **4** of the underwater vehicle **2**. The magnetic field detection device is configured as an active magnetometer, which actively generates a magnetic field, the effect thereof on metal objects being able to be determined by means of the magnetic sensors. Alternatively, however, a design is possible as a passive magnetometer which measures an effect of the earth's magnetic field on metal objects in the surroundings. The magnetic field detection device provides measurement data which are suitable for locating, surveying and tracking the object and/or the object path and are used alternatively or additionally to measurement data from the 3D underground sonar **22**.

**[0080]** In addition to the 3D underground sonar **22**, the sonar device **20** also has a multibeam sonar device **42**, in particular for surveying the surface of the bottom of the body of water in the surroundings of the object and a front scan sonar device **44**, in particular for identifying obstacles and/or raised sections on the bottom of the body of water upstream of the underwater vehicle **2**. In addition, the object path upstream of the underwater vehicle **2** is in various embodiments estimated at least by the assistance of the front scan sonar device **44**. Further measurement data are provided by a side scan sonar device **46**. In the exemplary embodiment, the side scan sonar device **46** in this case also uses the waterborne sound transducers **24**. The side scan sonar device **46** serves primarily for locating the object at the side adjacent to the autonomous underwater vehicle **2**. If, however, the region scanned by means of the side scan sonar device **46** is displaced at right angles to the longitudinal axis of the underwater vehicle **2** because, for example, the source of the waterborne sound signals is displaced relative to the longitudinal axis and, for example, is arranged on one of the sensor carriers **26** and **28**, the underwater vehicle is also able to generate measurement data by means of the side scan sonar device which can be used by the object localization means and/or the object examination means for localizing and/or examining the object.

**[0081]** Finally, a camera **48** of the multi-sensor system **8** is arranged on the bow of the autonomous underwater vehicle **2**, the camera permitting visual inspection of the object. Moreover, the object path is navigated and/or identified and followed in this exemplary embodiment at least by the assistance of measurement data from the camera **48** which are evaluated in an image processing device so that the object path is identified.

**[0082]** Alternatively or additionally, further sensors can be provided for navigating, for following the object path and for providing measurement data for the object localization means **10** and/or for the object examination means **12**. Adjustable or rigid rudders **50** and **52** provided for stabilizing the underwater vehicle **2** are arranged at the ends of the sensor carriers **26** and **28**.

**[0083]** FIG. 2 shows an unmanned underwater vehicle **2'** according to a second exemplary embodiment of the invention in a view from below. The underwater vehicle **2'** differs from the underwater vehicle **2** of the first exemplary embodiment according to FIG. 1 by a continuous sensor carrier **26'**, instead of the sensor carriers **26** and **28**, which comprises all of the waterborne sound transducers **24** and all of the magnetic sensors **38**. Moreover, the multibeam sonar device **42**, the front scan sonar device **44** and the camera **48** together with

the sensor carrier 26' are arranged pivotably in the region of the pivot axis of the sensor carrier 26'. Alternatively, differently configured sensor carriers are conceivable in many different forms. The sensor carrier 26', indicated by means of a double arrow 34', can be pivoted into a position 30'. Apart from this, the underwater vehicle 2' is similar to the underwater vehicle 2 of the first exemplary embodiment according to FIG. 1. In particular, the same reference numerals denote the same or similar parts as in all other figures.

[0084] The sensor carrier 26' is arranged at right angles to the object path of an object, not shown, but not at right angles to the longitudinal axis of the underwater vehicle 2'. The underwater vehicle 2' is namely subjected to a current which would result in the underwater vehicle 2' being driven away from a designated trajectory, if the underwater vehicle 2' would not align itself obliquely in the direction of the current. The underwater vehicle 2' is thus aligned obliquely to its trajectory, wherein the front scan sonar device 44 and the camera 48 face in the actual absolute direction of movement of the underwater vehicle 2' and thus some or all sensors are optimally aligned relative to the direction of movement.

[0085] FIG. 3 shows a system 54 with an unmanned underwater vehicle 2" according to a third exemplary embodiment of the invention in a schematic view.

[0086] As a device arranged outside the underwater vehicle 2", the system 54 comprises a mission planning device 56, such as for example a control panel with a computer, by means of which a mission can be planned and control data generated for controlling the mission. The control data are transmitted by means of a control data transmission device 58 from the mission planning device 56 to the underwater vehicle 2", for example by means of a cable, via radio or by means of a storage medium.

[0087] In contrast, the measurement data collected during a mission are transmitted by means of a measurement data reading device 60, also for example by means of a cable, via radio or by means of a storage medium, to a measurement data evaluation device 62. The measurement data evaluation device evaluates the measurement data provided and optionally pre-prepared by the object localization means 10 and/or the object examination means 12, and assigns the measurement data and/or identified branching, valves or damage and/or defects on the object to absolute positions of sections of the object.

[0088] The underwater vehicle 2" comprises the multi-sensor system 8, the navigation means 6, the object localization means 10, the object examination means 12, the object path identification means 14, the object path tracking means 16, a control device 64, and a separately configured data interface 66 for the different sensors. The control device 64 automatically controls the underwater vehicle 2 as a function of navigation data, as a function of the control data for the mission, as a function of prior knowledge transmitted with the control data to the underwater vehicle 2", or contained in the control data about the position of the object, as a function of the current position of the autonomous underwater vehicle 2" and/or as a function of a desired trajectory as well as an actual trajectory potentially deviating slightly therefrom. The control device controls the underwater vehicle in this case accurately such that when following the object path the deviation of the actual trajectory from a desired trajectory is a maximum of half a meter. Moreover, it is possible for the control device 64 in combination with the navigation means 6 to control the underwater vehicle accurately during submersion,

such that the deviation from a submerged position towards which the underwater vehicle travels, located for example at a depth of 1500 meters, is a maximum of 10 meters after submersion.

[0089] The single data interface 66 permits the flexible use of different sensors on the underwater vehicle 2". In this manner, the underwater vehicle 2" can be equipped flexibly with different sensors and use different sensors in a flexible manner during a mission. In particular when, due to environmental influences or defects, individual sensors are not ready for use or provide false measurement results, reference can be made to measurement results of other sensors to be used in a redundant manner. In various embodiments, therefore, the measurement data are prepared such that different sensors, for example, the magnetic sensors 38 and the 3D underground sonar 22, provide prepared measurement data which can be directly compared with one another. A comparison of the measurement data can already take place in the autonomous underwater vehicle 2", for example, by means of the object path identification means 14 at a point which in the case of a design of the unmanned underwater vehicle 2 as an ROV is connected via a cable, for example an optical waveguide, to the underwater vehicle, or alternatively it can take place in the measurement data evaluation device 62 and thus after the end of the mission.

[0090] The multi-sensor system 8 comprises the sonar device 20 with the 3D underground sonar 22, in turn comprising the waterborne sound transducers 24 as well as means for providing the aforementioned artificial aperture and/or an artificial aperture 68, with the multibeam sonar device 42, with the front scan sonar device 44 and with the side scan sonar device 46. Moreover, the multi-sensor system 8 comprises the magnetic field detection device 40 with the magnetic sensors 38 as well as the camera 48.

[0091] The navigation means 6 comprise a pitch sensor 70 and a roll sensor 72 in each case for determining tilting movements of the underwater vehicle. Moreover, the navigation means 6 comprise a magnetic compass 74, a aneroid barometer and/or an expansion chamber 76, an echo sounder 78, a device 80 of a so-called "ultra short baseline" underwater navigation system, a transponder 82, a responder 84, an ultrasound doppler profile flowmeter 86, an acceleration sensor 88, a measuring probe 90 for measuring the salt content, the water temperature and the depth in the water, a receiver device 92 for satellite signals of a satellite-assisted navigation system and a turbidity sensor 94.

[0092] The underwater vehicle 2" also comprises communication means 96 for communicating with other devices, during or after a mission. In particular, the communication means 96 comprise an acoustic underwater sound communication device 98 for communicating through the water by means of waterborne sound signals. For example, during submersion, a mother ship using the transponder 82 and/or the responder 84, determines the position of the underwater vehicle 2" in the water, relative to the mother ship and in absolute terms in connection with, for example, a satellite-assisted position determining system of the mother ship and transmits the established position of the underwater vehicle 2" by means of waterborne sound signals, which can be received by the acoustic underwater communication device 98, to the underwater vehicle 2".

[0093] The communication means 96 further comprise a satellite communication device 100 for communication via a



satellite, when the underwater vehicle 2" has surfaced and/or floats on the surface of the body of water.

[0094] Finally, the communication means 96 comprise a WLAN communication device 102 for wireless communication, in particular for transmitting control data or measurement data, a network device 104 for wired transmission of the data and a radio connection device 106 for communication via radio by means of the so-called "Radio Link Protocol (RLP)" and/or by means of a method which optionally transmits information repeatedly for minimizing transmission losses.

[0095] The system 54, in a variant from the view according to FIG. 3, can have a reduced number of components, in particular sensors. In contrast, the underwater vehicles 2 and 2' according to the first two exemplary embodiments of FIGS. 1 and 2, can have components and/or sensors of the underwater vehicle 2", not shown there.

[0096] FIG. 4 shows the unmanned underwater vehicle 2 of the first exemplary embodiment according to FIG. 1, which moves along its trajectory 108, of which the covered parts and parts yet to be covered are indicated by a line, over a pipeline 110 as the object to be localized and examined, following the path of the pipeline. The navigation means 6 determine in this case the current absolute position of the underwater vehicle 2. The measurement data determined at one respective time are assigned to the position respectively adopted at this time and stored, accordingly assigned. In various embodiments in this case an orientation of the underwater vehicle 2 and/or the respective sensors are part of the position of the underwater vehicle 2, if the orientation of the sensors relative to the orientation of the underwater vehicle 2' is able to be altered as is the case, for example, in the underwater vehicle 2' of the second exemplary embodiment according to FIG. 2.

[0097] The pipeline 110 is laid on the surface 112 of the bottom 114 of a body of water 116. The pipeline 110 has regions 118 and 120 arranged above the surface 112 of the bottom of the body of water as well as a region 122 arranged below the surface 112 of the bottom of the body of water. The region 118 has one or more sections 124 located on the bottom 114 of the body of water, which are directly in contact with the bottom 114 of the body of water but not covered and/or buried in the bottom 114 of the body of water. Also the region 120 has a plurality of sections 124 resting on the surface. Moreover, the region 120 has one or more exposed and/or underwashed sections 126 which are not directly in contact with the bottom 114 of the body of water so that the pipeline 110 sags in the region of the underwashed sections 126. The region 122 arranged below the surface 112 of the bottom of the body of water has one or more buried sections which are completely covered and thus not able to be seen visually from the underwater vehicle 2. Also, the buried sections 128 of the pipeline 110 are not able to be localized and/or surveyed or examined by means of the side scan sonar device 46.

[0098] However, the autonomous underwater vehicle 2 localizes all sections of the pipeline 110 irrespective of whether they are sections 124 which rest on the surface, exposed sections 126 or buried sections 128, and/or irrespective of whether the respective sections and/or the local sections 124, 126, 128 of the pipeline 110 are arranged above or below the surface 112 of the bottom of the body of water.

[0099] The object path identification means 14 identify the local object path of the pipeline 110 and/or the direction in which the pipeline further extends. In particular, in this case

the object path identification means 14 makes use of measurement data of the 3D underground sonar 22 and/or the magnetic field detection device 40, in order to estimate the object path in the region 122 of the pipeline 110 arranged below the surface 112 of the bottom of the body of water.

[0100] A raised section and/or an obstacle 130 is arranged at the bottom 114 of the body of water in order to illustrate that the underwater vehicle 2 does not travel around this obstacle 130 in a traditional manner to the side but, by maintaining a defined minimum distance, travels over the obstacle 130 substantially without a lateral offset to the pipeline 110. Also, this substantially contributes to the underwater vehicle 2 being able to localize and/or survey and examine the pipeline 110 simultaneously. In particular, the object path tracking means 16 are always adapted to the trajectory 108 of the underwater vehicle 2 such that a lateral offset of the trajectory relative to the identified object path is kept below a defined threshold value which, for example, permits a visual inspection of the pipeline 110 in the regions 118 and 120 and/or an inspection by means of sensors from above.

[0101] FIG. 5 shows a support platform 132 configured as a supply vessel and/or support vessel, which floats in the region of the surface 134 of the body of water 116. Moreover, the submerged underwater vehicle 2 of the first exemplary embodiment according to FIG. 1 is shown with its submerged trajectory 136, proceeding from a previous position 138 of the underwater vehicle 2 indicated in dashed lines in the region of the surface 134 of the body of water.

[0102] When submerging and/or when traversing the submerged trajectory 136, the underwater vehicle 2 navigates by means of its navigation means 6. In particular, the underwater vehicle 2, in response to the reception of waterborne sound signals from the support vessel 132, in turn transmits waterborne sound signals which are received by the support vessel 132, which determines the current position of the underwater vehicle 2, using the received waterborne sound signals, by means of travel time measurements, in particular by using its actual position which is determined, for example, by means of satellite signals. The support vessel 132 transmits this determined position of the underwater vehicle 2 by means of further waterborne sound signals to the underwater vehicle 2. The underwater vehicle 2, therefore, is able to identify deviations in its position from the designated submerged trajectory which are optionally present and compensate for the deviations by corresponding steering in the opposite direction, so that the submerged trajectory 136 is substantially the same as the designated submerged trajectory. After submersion, the underwater vehicle 2 is located in the position shown at the designated operating depth 140. This operating depth 140 is either fixed relative to the surface 134 of the body of water or the surface 112 of the bottom of the body of water. In any case, the control device 64 is configured here such that a defined minimum distance and in various embodiments also a defined vertical distance of the underwater vehicle 2 is maintained from the surface 112 of the bottom of the body of water.

[0103] FIG. 6 shows the underwater vehicle 2 when localizing and examining the pipeline 110 above the pipeline 110 in a plan view. A position 142 of the underwater vehicle 2 is indicated in dashed lines which corresponds to the position of the underwater vehicle 2 according to the view in FIG. 5 after submersion and/or after traversing the submerged trajectory 136. The underwater vehicle 2 in the position 142, therefore, has reached its submerged depth and travels on a trajectory 144 toward a submerged position 146 previously stored in the



underwater vehicle 2 or received by means of waterborne sound signals or via a cable. Subsequently, the underwater vehicle 2 performs a search maneuver in which it actively attempts by using the multi-sensor system 8, in particular by using the sonar device 20, to detect the pipeline 110. When traversing a trajectory 148, the underwater vehicle 2 localizes the pipeline 110 and identifies a local path of the pipeline. The underwater vehicle 2 calculates, therefore, a start-up trajectory 150 to a start position 152, which it traverses from a position 154. Subsequently, the trajectory 108 is directly traversed above the pipeline 110 according to the view in FIG. 4.

[0104] The sensor carriers 26 and 28 which are folded in during submersion and/or when traversing the submerged trajectory 136, after reaching the operating depth 140 and/or while traversing the trajectory 144 to the submerged position 146 or at the submerged position 146, are folded out and/or moved into a position in which the waterborne sound transducers 24 and/or the magnetic sensors 38 adopt a suitable position relative to the underwater vehicle 2 in order to locate and/or examine the pipeline 110.

[0105] In the region of the sections of the pipeline 110 arranged below the surface 122 of the bottom of the body of water, the pipeline 110 has a curvature which, however, is identified by the underwater vehicle 2 through the sediment which covers the pipeline 110, so that the underwater vehicle 2 follows the path of the pipeline 110, irrespective of whether the respective sections of the pipeline 110 are arranged above or below the surface 112 of the bottom of the body of water. The trajectory 124 of the underwater vehicle 2 in any case is located substantially vertically above the pipeline 110. In particular, a lateral offset of the underwater vehicle 2 relative to the pipeline 110 is identified, wherein the underwater vehicle 2 is controlled such that an attempt is made to minimize an identified lateral offset.

[0106] FIG. 7 shows method steps when localizing 156 and when examining 158 the object 110 by means of the invention. By means of the multi-sensor system 8, in a step 160 measurement values are produced and/or collected and provided in a step 162. Some or all of the provided measurement values are combined and/or amalgamated in a step 164. For example, the measurement values are compared with one another for consistency and/or average or corrected measurement values are generated from the measurement values provided in step 162. By means of the measurement values, in a step 166 local sections of the object are localized, the local sections are examined in a step 168, in a step 170, the local object path is identified and in a step 172, the identified local object path is tracked.

[0107] Contained within step 166 is a step 174 in which a local section of the object 110 is surveyed and a step 176 in which a region of the surface 112 of the bottom of the body of water is also surveyed in the surroundings of the section of the object 110. The combining of the measurement data in step 164 can alternatively or additionally be integrated in step 166, in step 168 and/or in step 170.

[0108] By means of the navigation means 6, the position, the direction and the speed of the underwater vehicle 2 is determined in a step 178. By means of the determined position, the position of the local section of the object 110 is determined in a step 180. The measurement data provided and optionally combined are used to this end and/or the position of the object determined by the step 166 is used to this end. In a step 182, the optionally combined and/or further processed measurement data are assigned to the position of the local

section and/or the position of the underwater vehicle 2. For example, the same respective time signal is assigned to all measurement data determined at a specific time and/or all data obtained from the measurement data as well as data provided by the navigation means 6, and/or the positions of the underwater vehicle and/or the position of the local section, so that by means of the time signal, it is possible to correlate data relative to one another, for example during a subsequent evaluation.

[0109] In a step 184, the relative position of the localized section is determined relative to the local surface 112 of the bottom of the body of water and using this determined position in a step 186 it is established whether the respective section of the object 110 rests on the bottom 114 of the body of water, is buried in the bottom 114 of the body of water or exposed.

[0110] Steps 160 to 182 take place repeatedly during a mission. Optionally, steps 184 and 186 also take place when the mission is being carried out. Otherwise, steps 184 and 186 can also take place after a mission, during an evaluation and/or follow up after the mission.

[0111] The method is not only suitable for detecting marine cables or pipelines. For example, mines can also be advantageously detected by means of the invention. In particular, the combining of the data in step 164 makes it possible to differentiate mines very reliably from other objects, as for example in the case of an object which has the appearance of a mine with a metal casing but is not identified as an object comprising metal, by means of the magnetic sensors 38 and/or by means of the magnetometer it is able to be excluded that the object is such a mine.

[0112] FIG. 8 shows the method sequence of a method 187 according to various exemplary embodiments of the invention. The method 187 starts with a step 188. Subsequently in a step 190 a mission is prepared, the prepared mission carried out in a step 192 and in a step 194, the carried out mission is followed up. The method is thereby terminated according to a step 196.

[0113] FIG. 9, FIG. 10 and FIG. 11 show the method steps 190, 192 and 194 of the exemplary embodiment according to FIG. 8 subdivided into detailed steps.

[0114] FIG. 9 shows the preparation of the mission according to step 190. Initially the mission is planned in a step 198. For example, with prior knowledge about the position of the object 110 at the bottom 114 of the body of water, the submerged position 146 is established. In a step 200, according to the planned mission, control data are subsequently generated, the control data being suitable for navigating the underwater vehicle 2 by means of the navigation means 6 to the submerged position 136 and, after carrying out its task again, to a retrieval position from which it can be retrieved and/or in which it can be supplied with power.

[0115] According to a step 202 the control data are transmitted to the underwater vehicle 2, for example by means of a portable mass storage device, via radio or via a network connection. Finally, the underwater vehicle 2 in a step 204 is let into the water. From there it can be navigated automatically but alternatively also assisted by information which it receives via a cable, when the underwater vehicle is configured and correspondingly used as an ROV.

[0116] FIG. 10 shows steps when carrying out the mission according to step 192. In particular, the underwater vehicle 2 submerges according to a step 206 on its submersion trajectory 136 to the submerged position 146. Subsequently, in step

156, the object is localized, in step 158 the object is simultaneously examined and in a step 212 the object path is simultaneously followed and/or the object path tracked. Finally, the underwater vehicle 2 in a step 214 travels towards the retrieval position and/or surfaces.

[0117] FIG. 11 shows the step 194 with three sub-steps, namely with a step 216, in which the underwater vehicle 2 which has reached the retrieval position, is retrieved, with a step 218 in which the collected measurement data and/or data are read and with a step 220 in which the read measurement data are evaluated. The read measurement data to be evaluated can in this case be the measurement data provided in step 162 and/or contain the measurement data and/or pre-prepared and/or corrected measurement data or can be data obtained from measurement data, in particular in combination with further measurement data. Also the location information relative to the underwater vehicle 2 and/or relative to the localized sections of the object 110 are contained in this data.

[0118] FIG. 12 shows the step 206 according to FIG. 10 and/or the submersion to the submerged position in a particular embodiment in detail.

[0119] In a step 222 initially by means of the Global Positioning System (GPS), before submersion, the current position of the underwater vehicle 2 is determined from the received satellite signals. Also, a communication via radio between the underwater vehicle 2 and the support vessel 132 is still possible at this point. Moreover, the underwater vehicle 2 can communicate by means of satellite signals with the support vessel 132 or with a further mobile or fixed device, for example on land.

[0120] In a step 224, the submersion of the underwater vehicle 2 is initiated. Subsequently, the underwater vehicle 2 is navigated according to a step 226 via travel time measurements of waterborne sound signals between the underwater vehicle 2 and the support vessel 132 and assisted by the further navigation means, for example by the magnetic compass 74, the aneroid barometer 76 or the acceleration sensor 88. Alternatively in step 226, the navigation is initiated by means of other navigation means which are suitable for navigation in water.

[0121] The underwater vehicle 2 now attempts to reach its operating depth 140. This is illustrated by a query 228, according to which it is queried whether the operating depth 140 has been reached. Only when the operating depth 140 has been reached in a step 230 is the submersion terminated. Navigation to the submerged position 146 which is at the operating depth 140, follows according to a step 232.

[0122] The navigation to the submerged position 146 is continued according to a query 234 as to whether the submerged position 146 has been reached, until the submerged position 146 is reached. Subsequently the navigation is stopped by means of the travel time measurements to the support vessel 132 in a step 236. However, the position can also be determined later on by such travel time measurements to the support vessel 132. Subsequently, in a step 238 the sensor carriers 26 and 28 are pivoted out and thus the sensors fastened thereto made ready for use. In combination with the movement of the underwater vehicle 2, with a suitable combination of measurement data obtained by means of the sensors on the sensor carriers 26, 28, the observation surface is spanned according to a step 240. Thus, for example, it is possible to locate the object 110 by means of the side scan

sonar device 46 and/or examine the bottom 114 of the body of water three-dimensionally by means of the 3D underground sonar 220.

[0123] FIG. 13 shows the steps 208, 210 and 212 and/or the localization and examination of the object 110 as well as the tracking of the object path in a specific embodiment in detail.

[0124] In a step 242, the underwater vehicle 2 carries out a search routine. In this case, according to a specific pattern, the surroundings are searched for the object 110. This takes place according to a query 244 as to whether the object 110 has been located, until a section of the object 110 has been detected and localized. In this case, the local object path is already detected so that in the event that the query 244 is positive, in a step 246, the travel trajectory 150 to the start position 152 is calculated such that the start position is located above the object 110 and the direction of the start-up trajectory 150 in this start position 152 coincides with the direction of the local object path below the start position 152. In a step 248, this start-up trajectory 150 is finally traversed by the underwater vehicle 2.

[0125] Subsequently, in a step 146 the localizing of local sections of the object 110 is initiated, in a step 252 the simultaneous examining of local sections of the object 110 is initiated and in a step 254 the tracking of the local object path is initiated. Thus the underwater vehicle 2 travels over the object 110, tracking the object path, surveys the object 110 at the same time and examines the object 110, for example visually by means of the camera 48.

[0126] This is interrupted if it is established according to a query 256 that the contact with the object 110 has locally been lost and/or that local sections of the object 110 could not be detected. Accordingly, in this case in a step 258, the localization of the local sections of the object 110 is interrupted and/or, incorporated in the following search routine 242, continued. At the same time as step 258, in a step 260 the examination of the local sections of the object 110 is interrupted and in a step 262 the tracking of the local object path is interrupted.

[0127] During the localization and examination of the local sections of the object 110 and during the tracking of the local object path and/or when the query 256 is negative, it is determined in a query 264 as to whether the target position has been reached. If it is established that the target position has been reached, similar to the steps 258, 260 and 262, in a step 266, the localization of the local sections of the object 110 is terminated, in a step 268, the examination of the local sections of the object 110 is terminated and in a step 270, the following of the local object path is terminated. Subsequently, the procedure is continued with step 214 according to FIG. 10.

[0128] If, however, according to step 264, the target position has not yet been reached, in a query 272 it is determined whether the charged state of an energy supply source and/or an accumulator of the underwater vehicle 2 is below a specific value. This specific value can be such that a maneuvering of the underwater vehicle 2 by a separate drive is still possible to the designated retrieval position and/or for the surfacing of the underwater vehicle 2 but only a limited safety reserve of stored electrical energy is present in the energy storage device of the underwater vehicle 2. If the charged state falls below the defined value, the procedure is continued with steps 266, 268 and 270 so that the underwater vehicle subsequently travels towards its retrieval position and/or surfaces. In any case, queries 256, 264 and 272 are performed repeatedly, until one of the queries is able to be positively answered.

[0129] All of the features cited in the above description and in the claims, are able to be used both individually and in any combination with one another. The disclosure of the invention is, therefore, not limited to the described and/or claimed combinations of features. On the contrary, all combinations of features should be considered as disclosed.

1-15. (canceled)

16. An unmanned autonomous underwater vehicle for localizing and examining an object arranged at a bottom of a body of water, such as a pipeline or a marine cable, said vehicle comprising:

- an object localization means for localizing the object;
- an object examination means for examining the object, and
- a sonar device having a 3D underground sonar for collecting measurement data,

wherein, utilizing the measurement data, the sonar device and the object localization means are designed for three-dimensional acoustic localization of local sections of the object that are arranged both above and below the surface of the bottom of the body of water while the underwater vehicle is simultaneously moving along the local sections, thereby examining at least one of the local sections and adjacent local sections of the object utilizing the object examination means.

17. The vehicle according to claim 16, further comprising:

- an object path identification means for identifying the local object path of the object by means of the localized local sections irrespective of whether the local sections are at least one of resting on the surface of the bottom of the body of water, are buried under the bottom of the body of water, and are partially exposed within the bottom of the body of water; and
- an object path tracking means for adapting a trajectory of the underwater vehicle utilizing the identified local object path such that a lateral offset of the trajectory relative to the identified local object path is kept at least one of below a specific threshold value and substantially constant when a deviation from the lateral offset is below the specific threshold value.

18. The vehicle according to claim 17 further comprising a multi-sensor system that in combination with the 3D underground sonar is structured and operable to collect the measurement data and at least one of localize the object and examine the object, the multi-sensor system comprising at least one of:

- at least one camera,
- a side scan sonar device,
- a multibeam sonar device,
- a front scan sonar device, and
- at least one magnetic sensor of a magnetic field detection device.

19. The vehicle according to claim 18, wherein the multi-sensor system is further structured and operable to:

- collect measurement data that are suitable for surveying a local surface of the bottom of the body of water below the underwater vehicle,
- identify the position of the detected local sections of the object relative to the local surface of the bottom of the body of water, and
- classify, utilizing the identified position, whether the local sections are sections of the object that at least one of rest on the surface of the bottom of the body of water, are buried under the bottom of the body of water, are par-

tially exposed within the bottom of the body of water, and are underwashed within the bottom of the body of water.

20. The vehicle according to claim 19 further comprising a navigation means for providing navigation data for independent navigation of the underwater vehicle to determine the respective position of the respectively localized section of the object and for assigning at least one of the navigation data and the measurement data to the respective position, the navigation means comprising at least one of:

- a pitch sensor for determining the rotational movement of the underwater vehicle about its transverse axis;
- a roll sensor for determining the rotational movement of the underwater vehicle about its longitudinal axis;
- a magnetic compass for determining the direction and orientation of the underwater vehicle relative to field lines of the earth's magnetic field;
- an echo sounder for determining a water depth below the underwater vehicle;
- an aneroid barometer for determining a water pressure at a depth of the underwater vehicle below the water surface, wherein the determined water pressure is used to determine the depth of the underwater vehicle below the water surface;
- a device of an "ultra short baseline" underwater navigation system for determining the position using travel time measurements of underwater sound signals to a plurality of other devices in the water;
- a waterborne sound speed sensor for determining a sound speed in the water;
- a transponder device for transmitting signals in response to reception of signals;
- a responder device for transmitting signals in response to the reception of signals;
- an ultrasonic doppler profile flowmeter for determining a water flow relative to the underwater vehicle;
- at least one acceleration sensor for determining an acceleration of the underwater vehicle in an inertial reference system;
- a measuring probe for determining a salt content and a temperature of the surrounding water and for determining a depth of the measuring probe below the water surface;
- a receiver device for receiving satellite signals of a satellite-assisted navigation system, and for determining the position of the underwater vehicle by means of the satellite signals; and
- a turbidity sensor for determining a turbidity of the surrounding water.

21. The vehicle according to claim 20, wherein the receiver device for receiving satellite signals of a satellite-assisted navigation system comprises a global positioning system (GPS).

22. The vehicle according to claim 20, wherein the 3D underground sensor comprises a plurality of waterborne sound transducers arranged in series, as a physical aperture and an artificial aperture for spanning an observation surface permitting the three-dimensional localization of the object by means of repeatedly determined measurement data of the waterborne sound transducers, wherein the underwater vehicle has at least one sensor carrier that is pivotable relative to the longitudinal axis of the underwater vehicle, to which the waterborne sound transducers are fastened at least in their majority, in each case at a plurality of different intervals

relative to a point of reference on the longitudinal axis, wherein the waterborne sound transducers that determine the measurement data are arranged symmetrically relative to the longitudinal axis of the underwater vehicle, such that a center of a scanning region that is able to be scanned by means of the measurement data has a lateral offset to the longitudinal axis of the underwater vehicle.

**23.** The vehicle of claim **22**, wherein the waterborne sound transducers are fastened to the at least one sensor carrier a plurality of different intervals relative to a point of reference on the pivot axis of the respective sensor carrier.

**24.** The vehicle of claim **22**, wherein the center of the scanning region that is able to be scanned by means of the measurement data has a lateral offset of at least one half of a metre to the longitudinal axis of the underwater vehicle.

**25.** The vehicle according to claim **22** further comprising a control device comprising:

- a means for manoeuvring the underwater vehicle to an operating depth defined by a submerged position;
- a means for manoeuvring the underwater vehicle to the submerged position after reaching the operating depth;
- a means for carrying out a search routine after reaching the submerged position, wherein available prior knowledge about the position of the object is taken into consideration by the search routine;
- a means for calculating and traversing a start-up trajectory to a start position defined as a function of the determined position of the object; and
- a means for following the trajectory located above a determined object path.

**26.** A system comprising:

an autonomous underwater vehicle comprising:

- an object localization means for localizing the object;
- an object examination means for examining the object, and

a sonar device having a 3D underground sonar for collecting measurement data,

wherein, utilizing the measurement data, the sonar device and the object localization means are designed for three-dimensional acoustic localization of local sections of the object that are arranged both above and below the surface of the bottom of the body of water while the underwater vehicle is simultaneously moving along the local sections, thereby examining at least one of the local sections and adjacent local sections of the object utilizing the object examination means;

a mission planning device for producing control data for controlling the mission;

a control data transmission device for transmitting the control data from the mission planning device to the underwater vehicle;

a measurement data reading device for reading measurement data stored during the mission; and

a measurement data evaluation device for at least one of: classifying sections of the object as sections which at least one of rest on the surface of the bottom of the body of water, are buried under the bottom of the body of water, are partially exposed within the bottom of the body of water, and

determining a condition of the object.

**27.** A method for localizing and examining an object arranged at the bottom of a body of water, by means of an unmanned underwater vehicle, that comprises an object

localization means that localize the object and that has an object examination means that examine the object, said method comprising:

collecting measurement data utilizing a sonar device with 3D underground sonar of the vehicle

localizing, utilizing the object localization means, local sections of the object by utilizing the measurement data in a three-dimensional acoustic manner, while the underwater vehicle is simultaneously moving along the local sections of the object and simultaneously the object examination means examines at least one of the local sections and adjacent local sections of the object, irrespective of whether the local sections are at least one of resting on the surface of the bottom of the body of water, are buried under the bottom of the body of water, and are partially exposed within the bottom of the body of water.

**28.** The method according to claim **27**, further comprising identifying, utilizing an object path identification means, the local object path of the object utilizing the localized sections irrespective of whether the local sections are at least one of resting on the surface of the bottom of the body of water, are buried under the bottom of the body of water, and are partially exposed within the bottom of the body of water; and

adapting the trajectory of the underwater vehicle, utilizing an object path tracking means, utilizing the identified object path such that a lateral offset of the trajectory relative to the identified local object path is kept at least one of below a specific threshold value and substantially constant when a deviation from the lateral offset is below the specific threshold value.

**29.** The method according to claim **28**, wherein the vehicle further comprises a multi-sensor system for, in combination with the 3D underground sonar, collecting the measurement data, the multi-sensor system comprising a plurality of sensors comprising:

- at least one camera,
- a side scan sonar device,
- a multibeam sonar device,
- a front scan sonar device, and
- at least one magnetic sensor of a magnetic field detection device,

wherein the method further comprises:

combining the measurement data of at least two of the 3D underground sonar and the multi-sensor system sensors; and

at least one of localizing and examining the object utilizing the combined measurement data.

**30.** The method according to claim **29** further comprising surveying, utilizing the collected measurement data, a local surface of the bottom of the body of water below the underwater vehicle;

identifying a position of the localized sections of the object relative to the local surface of the bottom of the body of water and

classifying, utilizing the identified position, whether the local sections are sections of the object that at least one of rest on the surface of the bottom of the body of water, are buried under the bottom of the body of water, are partially exposed within the bottom of the body of water, and are underwashed within the bottom of the body of water.

**31.** The method according to claim **30** further comprising:  
 automatically navigating the underwater vehicle utilizing navigation data provided by a navigation means;  
 determining a respective position of the respectively localized section of the object; and  
 assigning at least one of the navigation data and the measurement data to the respective position of the localized section, wherein, for providing the navigation data, the navigation means comprises at least one of:

- a pitch sensor for determining the rotational movement of the underwater vehicle about its transverse axis;
- a roll sensor for determining the rotational movement of the underwater vehicle about its longitudinal axis;
- a magnetic compass for determining the direction and orientation of the underwater vehicle relative to field lines of the earth's magnetic field;
- an echo sounder for determining a water depth below the underwater vehicle;
- an aneroid barometer for determining a water pressure at a depth of the underwater vehicle below the water surface, wherein the determined water pressure is used to determine the depth of the underwater vehicle below the water surface;
- a device of an "ultra short baseline" underwater navigation system for determining the position using travel time measurements of underwater sound signals to a plurality of other devices in the water;
- a waterborne sound speed sensor for determining a sound speed in the water;
- a transponder device for transmitting signals in response to reception of signals;
- a responder device for transmitting signals in response to the reception of signals;
- an ultrasonic doppler profile flowmeter for determining a water flow relative to the underwater vehicle;
- at least one acceleration sensor for determining an acceleration of the underwater vehicle in an inertial reference system;
- a measuring probe for determining a salt content and a temperature of the surrounding water and for determining a depth of the measuring probe below the water surface;
- a receiver device for receiving satellite signals of a satellite-assisted navigation system, and for determining the position of the underwater vehicle by means of the satellite signals; and
- a turbidity sensor for determining a turbidity of the surrounding water.

**32.** The method according to claim **31**, further comprising three-dimensionally localizing the object utilizing the 3D underground sonar, wherein the underwater vehicle pivots at least one sensor carrier relative to the longitudinal axis of the underwater vehicle and subsequently a plurality of waterborne sound transducers arranged in particular in series, at a plurality of different intervals in

each case relative to a pivot axis of the respective sensor carrier, arranged at least in their majority on the sensor carrier, repeatedly determine measurement data and by means of an artificial aperture span an observation surface permitting the three-dimensional localization of the object, wherein the sensor carrier pivots such that for determining the measurement data the waterborne sound transducers have been arranged asymmetrically relative to the longitudinal axis of the underwater vehicle and the waterborne sound transducers subsequently scan a scanning region, the centre thereof having a lateral offset, preferably of at least one metre, to the longitudinal axis of the underwater vehicle.

**33.** The method according to claim **32** further comprising planning a mission utilizing a mission planning device, prior knowledge about the position of the object, and producing control data suitable for carrying out the mission and transmitting the control data to the underwater vehicle, subsequently the underwater vehicle independently navigating in the water carries out a submersion manoeuvre, wherein

the underwater vehicle manoeuvres to an operating depth defined by a submerged position, and at the same time repeatedly determines the position of the underwater vehicle, and additionally a surface vessel repeatedly determines the position of the underwater vehicle and transmits said position to the underwater vehicle, and

after reaching the operating depth the underwater vehicle performs a "navigation alignment navigation manoeuvre" to reach the submerged position,

subsequently the underwater vehicle performs a search routine, wherein the underwater vehicle takes into consideration the prior knowledge and after locating the object calculates and traverses a start-up trajectory to a start position, and

subsequently the underwater vehicle determines the local object path, follows the object path on its trajectory thereabove, simultaneously examines the object and simultaneously stores detected measurement data in a memory device and subsequently the measurement data stored in the memory device are read and evaluated, wherein at least one of:

classification takes place as to whether of the object are sections at least one of rest on the surface of the bottom of the body of water, are buried under the bottom of the body of water, are partially exposed within the bottom of the body of water, and are underwashed within the bottom of the body of water, and the condition of the object is determined.

**34.** The method of claim **33**, wherein the position of the underwater vehicle is determined utilizing an "ultra short baseline" system.

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