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(54) **Method and system for steering a body moving within a fluid**

(57) Described herein is a method for steering a body (10) moving underwater provided with movement control elements (13) independently actuatable for generating rotations of the body (10) about one or more of its axes, the longitudinal axis (x), the transverse axis (y), and the vertical axis (z); the method envisages the step of generating deflections (δ_{UR} , δ_{LR} , δ_{LL} and δ_{UL}) of the four movement control elements (13) according to steering commands (δp , δq , δr) indicating desired rotations about the longitudinal axis (x), transverse axis (y), and vertical

axis (z). The method also envisages, prior to the step of generating, the steps of: verifying that the steering commands (δp , δq , δr) are compatible with structural limitations of the movement control elements (13); and, according to the result of said verification, modifying the steering commands (δp , δq , δr) on the basis of said structural limitations. Also described is a system (11) for steering the body (10) moving underwater, provided with a control unit (15) configured so as to implement the afore-said steering method.

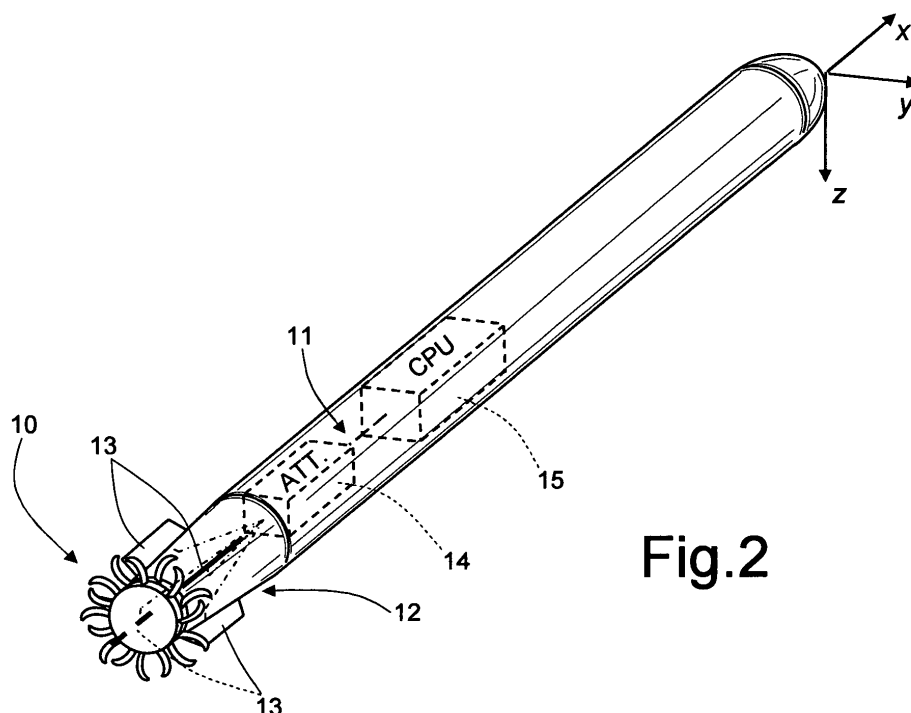


Fig.2

Description

[0001] The present invention relates to a method and a system for steering a body moving, whether self-propelled, guided, or drawn, within a fluid; in particular, the following description will make explicit reference to an underwater vehicle, for example, a torpedo.

[0002] As is known, systems for steering a body (for example, an underwater or air-borne vehicle, or a weapon system, such as a missile or a torpedo) within a fluid (for example, air or water) make use of moving control surfaces carried by the moving body. By imparting commands for appropriate deflections of rudders (which define the aforesaid moving surfaces), rotations of the moving body about its own axes are generated, namely, the longitudinal axis (movement known as "roll"), the transverse axis (movement known as "pitch") and the vertical axis (movement known as "yaw" or "course movement"). In particular, by appropriately combining the commands imparted on the rudders, it is possible to control as desired the movement of the body in the three reference planes: transverse, vertical, and horizontal.

[0003] Figure 1a is a schematic view of a steering system 1, of a known type, for controlling the movement of a body 2, for example, a torpedo having a cylindrical body with substantially circular cross section.

[0004] The steering system 1 comprises four rudders 3, which define a pair of horizontal control surfaces 4a, arranged in the horizontal reference plane xy associated to the body 2 (defined by the longitudinal direction x and the transverse direction y), and a pair of vertical control surfaces 4b arranged in the vertical reference plane xz associated to the body 2 (defined by the longitudinal direction x and the vertical direction z). Via deflections of the horizontal control surfaces 4a, in a first control loop, the pitch movement of the body 2 is controlled, by applying a vertical force F_z ; via deflections of the vertical control surfaces 4b, in a second control loop, the yaw movement of the body 2 is controlled, by applying a horizontal force F_y . Whilst the control of the roll movement of the body 2 (represented by a roll momentum M_x about the longitudinal axis x) is achieved by means of a composition of the deflections of some or all of the horizontal and vertical control surfaces 4a, 4b. In this rudder arrangement, the first and second control loops, acting respectively in the vertical reference plane xz and horizontal reference plane xy, can be considered at least partially free and hence operate according to logics defined specifically for each reference plane.

[0005] Figure 1b shows a different steering system 1, of the type commonly known as "butterfly-rudder system".

[0006] The four rudders 3 are in this case arranged to form a non-zero angle (for example, a 45° angle) with the transverse axis y and vertical axis z, and define control surfaces 5. In particular, the rudders 3 are arranged on mutually opposite sides, and in a position that is symmetrical with respect to the horizontal reference plane xy and vertical reference plane xz. The deflection of any one of the control surfaces 5 acts simultaneously on the horizontal reference plane xy (by means of the horizontal component F_y of the applied force F), the vertical reference plane xz (by means of the vertical component F_z of the applied force F) and the transverse reference plane yz (by means of the resultant roll momentum M_x).

[0007] The advantage of such a configuration of the rudders 3 is that it increases the control surface useful for controlling the movement in each reference plane, and increases the possibility for movement control. This solution is thus potentially effective for steering bodies 2 that are subject to structural limitations as regards control of the movement.

[0008] For example, it is known that torpedoes have control limitations, due to the small dimensions of the moving control surfaces, which are constrained by their necessary placement in the launching tubes (the cross section of the launching tubes limiting the maximum dimension of these surfaces), and moreover due to the wide dynamics of the speed of movement of torpedoes, which can go from low speeds (for example, for reducing the noise when approaching a target) to high speeds (for example, when reaching a target). This wide dynamics of the speed sets limitations on the control of the movement of torpedoes, given that, in a known way, the effectiveness of the moving control surfaces depends, among other elements, upon the speed of the moving body.

[0009] Albeit advantageous for the reasons set forth above, a butterfly-rudder steering system proves to be more complex to implement in so far as it requires the definition of algorithms that take into account the combined effects that the deflection of each of the moving control surfaces has on the three reference planes, in order to determine the commands for the deflections to be imparted on the rudders according to the required movement.

[0010] The aim of the present invention is consequently to provide a method and a system for steering a body in a fluid that will be optimized as regards the management of the moving control surfaces, in particular for bodies subject to structural limitations in the control of the movement.

[0011] According to the present invention, there are consequently provided a steering method and system, as defined in claim 1 and 11, respectively.

[0012] For a better understanding of the invention, embodiments thereof are now described purely by way of non-limiting example and with reference to the attached drawings, wherein:

- Figure 1a is a schematic view of a first configuration, of a known type, of moving control surfaces of a body moving in a fluid;
- Figure 1b is a schematic view of a second configuration, of a known type, of the moving control surfaces;
- Figure 2 is a schematic view of an underwater vehicle, in particular a torpedo, provided with a steering system

according to one aspect of the present invention; and

- Figures 3a-3c illustrate, as a whole, a flowchart regarding an algorithm for optimized distribution of steering commands for the rudders, implemented in the system of Figure 2.

[0013] The present invention stems from the observation, by the Applicant, of the need, in steering systems subject to structural control limitations (for example, due to dimensional limitations of the moving control surfaces and/or to a wide dynamics of the speed of movement), to distribute in an optimized manner, on independent rudders, steering commands imparted simultaneously in the three reference planes.

[0014] In fact, application to the rudders of simultaneous steering commands having an amplitude greater than a maximum controllable deflection (which can even be very small, for example due to the aforesaid dimensional or dynamic limitations), could bring some of them to end-of-travel, especially in a condition of low speed. A simple actuation of the rudders to the end-of-travel value would give rise to a dynamic behaviour of the moving body different from desired one (introducing, for example, over-shooting in height during execution of simultaneous commands in the horizontal and vertical reference planes).

[0015] One aspect of the present invention consequently envisages the definition of an algorithm designed to distribute the commands for steering of the rudders, taking into account the limitations associated to the steering system, so as to obtain the desired behaviour during execution of the required manoeuvres, exploiting in an optimal manner the deflections that can be applied to each rudder.

[0016] Figure 2 shows an underwater vehicle 10, in particular a self-propelled torpedo having control surfaces with small dimensions, provided with a steering system 11 designed to control submarine movement thereof.

[0017] The steering system 11 comprises an arrangement 12 of rudders 13, including four rudders 13 in a "butterfly" arrangement (as described previously as regards Figure 1b), each of which can be controlled individually for generating the rotation of the underwater vehicle 10 about a longitudinal axis x of its own (roll movement), a transverse axis y of its own (pitch movement), or a vertical axis z of its own (yaw movement). In particular, the rudders 13 are generally divided, on the basis of a position thereof with respect to the horizontal and transverse planes of symmetry of the underwater vehicle 10 considered in the direction of its movement, into: an upper-right (UR) rudder, an upper-left (UL) rudder, a lower-left (LL) rudder, and a lower-right (LR) rudder.

[0018] The steering system 11 further comprises: actuator means 14, for example, provided with electric motors, operatively coupled to the rudders 13 for controlling deflection thereof; and a central control unit 15, connected to the actuator means 14 and provided with processing means (for example, microprocessor means), designed to execute appropriate software programs and instructions for controlling desired deflections of the rudders 13 through the actuator means 14. In a per-se known manner, the central control unit 15 receives values of commanded trim (in terms of roll, pitch, yaw) in the three, horizontal, vertical, and transverse, reference planes for the movement of the underwater vehicle 10, from a wire-guide system (not illustrated) that connects the underwater vehicle 10 to a naval support vehicle (not illustrated), or else, in the absence of a wire-guide system (for example, in the process of homing towards a target), generates said values autonomously, according to an attack plan. On the basis of these commanded values and corresponding measurements made by sensors of the underwater vehicle 10, the central control unit 15 generates the commands for the deflections to be imparted on the rudders 13 for each of the three reference planes, which are considered independent. In this way, the simultaneous control in the three reference planes is obtained by summing algebraically for each of the four rudders 13 the deflections assigned for the control in the three reference planes. This is possible where the sum of the controlled deflections does not exceed for any rudder 13 a maximum applicable deflection. An aspect of the present invention consequently consists in configuring the central control unit 15 so as to process and modify the commanded deflections in order to determine, based on an optimized distribution algorithm, the commands for the optimal deflections to be imparted on each of the rudders 13.

[0019] In detail, and with reference to Figures 3a-3c, the distribution algorithm envisages, in an initial block 20, the reception (or autonomous generation) by the central control unit 15 of commanded deflections of roll δp , pitch δq and yaw δr , respectively for the rotation of the underwater vehicle 10 about the longitudinal axis x, the transverse axis y, and the vertical axis z. In particular, the controlled deflections are understood as being positive where they produce clockwise rotations about the respective axes of reference.

[0020] A procedure of optimized distribution of the commanded deflections imparted on the four rudders 13 is then initiated, with the purpose of preventing any saturation that might bring the rudders 13 to an end-of-travel and of respecting a priority criterion of the commands to be executed in the reference planes. In particular, this priority criterion envisages, in the case where a total commanded deflection is greater than a value that would lead the rudders 13 to saturation, the definition of a priority in controlling some reference planes with respect to others, ensuring in any case a minimum deflection for each reference plane.

[0021] In greater detail, in a block 21 subsequent to block 20 a check is made to verify whether the sum of the commanded deflections of pitch δq and yaw δr , considered in absolute value, is less than a maximum deflection $\delta_{\max}$ that can be made by the rudders 13 (without causing end-of-travel saturation), for example, equal to 20° .

[0022] If it is less, the sharing algorithm proceeds as described in what follows with reference to Figure 3b (the continuation of the procedure is represented by block A in Figures 3a and 3b). Otherwise, a procedure is executed for modifying the value of the commanded deflections of pitch δq and yaw δr , in such a way as to bring at the most just one rudder 13 to end-of-travel, at the same time guaranteeing a minimum control band for the rotations about the transverse axis y and the vertical axis z.

[0023] In detail (block 22), a comparison is made between the absolute value of the commanded deflection of yaw δr and a guaranteed minimum value of yaw $\delta r_{\min}$, for example, 5° .

[0024] In the case where the absolute value of the commanded deflection of yaw δr is lower than the guaranteed minimum value of yaw $\delta r_{\min}$ (block 23), the remaining deflection available is assigned to pitch control, modifying the value of the commanded deflection of pitch δq according to the expression

$$\delta q = (\delta_{\max} - |\delta r|) \cdot \text{SIGN}(\delta q)$$

[0025] The procedure then goes to block A.

[0026] In the case where the above absolute value of the commanded deflection of yaw is higher than the guaranteed minimum value of yaw (block 24), a check is made to verify whether the absolute value of the commanded deflection of pitch δq is lower than a guaranteed minimum value of pitch $\delta q_{\min}$, for example, 15° . In particular, the guaranteed minimum values of yaw and pitch $\delta r_{\min}$, $\delta q_{\min}$ are chosen so that their sum is equal to the maximum deflection $\delta_{\max}$

$$\delta q_{\min} + \delta r_{\min} = \delta_{\max}.$$

[0027] In addition, the assignment of a higher value to one of the two guaranteed minimum values of yaw or pitch $\delta r_{\min}$, $\delta q_{\min}$ enables assignment of a priority to the control of the respective movement of yaw or pitch.

[0028] If the absolute value of the commanded deflection of pitch δq is lower than the guaranteed minimum value of pitch $\delta q_{\min}$ (block 25), the remaining deflection available is assigned to yaw control, by modifying the value of the controlled deflection of yaw δr according to the expression

$$\delta r = (\delta_{\max} - |\delta q|) \cdot \text{SIGN}(\delta r)$$

[0029] The procedure then goes to block A.

[0030] Otherwise, i.e., if both the commanded deflection of yaw δr and the commanded deflection of pitch δq are greater than or equal to the respective guaranteed minimum value of yaw or pitch $\delta r_{\min}$, $\delta q_{\min}$, the values of the commanded deflection of yaw δr and of the commanded deflection of pitch δq are modified and set equal to the respective guaranteed minimum value of yaw or pitch $\delta r_{\min}$, $\delta q_{\min}$ (block 26), according to the expressions

$$\delta q = \delta q_{\min} \cdot \text{SIGN}(\delta q) ; \delta r = \delta r_{\min} \cdot \text{SIGN}(\delta r)$$

[0031] The procedure then continues to block A. The choice of the guaranteed minimum value of yaw or pitch $\delta r_{\min}$, $\delta q_{\min}$ enables in this case assignment of a greater deflection to one of the commanded deflections of yaw δr and pitch δq with respect to the other, attributing to them a greater priority of control.

[0032] From block A (see Figure 3b), the optimized distribution algorithm proceeds to block 27, where the residual band available for the control about the longitudinal axis x is determined. In detail, an available residual deflection $\delta \sigma$ for control of the roll, distributed over the four rudders 13, is determined according to the expression

$$\delta \sigma = \delta_{\max} - 0.5 \cdot (|\delta q + \delta r| + |\delta q - \delta r|)$$

[0033] A check is then made (block 28) to verify whether the absolute value of the controlled deflection of roll δp is

lower than the available residual deflection $\delta\sigma$ calculated previously. If it is lower, the distribution algorithm proceeds as described in what follows with reference to Figure 3c (the continuation of the procedure is represented by block B in Figures 3b and 3c).

[0034] Otherwise, if it is not, a check is made to verify (block 29) whether the available residual deflection $\delta\sigma$ is greater than a guaranteed minimum value of roll $\delta p_{\min}$ (which represents a guaranteed minimum control band for the rotation about the longitudinal axis x), for example, 2° .

[0035] If it is (block 30), the controlled deflection of roll δp is modified and set equal to the value of the available residual deflection $\delta\sigma$, according to the expression

$$\delta p = \delta\sigma \cdot \text{SIGN}(\delta p)$$

and the procedure proceeds with block B.

[0036] Otherwise, if it is not, a check is made (block 32) to verify whether the commanded deflection of roll δp is in absolute value greater than the guaranteed minimum value of roll $\delta p_{\min}$.

[0037] In particular, if the absolute value of the commanded deflection of roll δp is greater than the guaranteed minimum value of roll $\delta p_{\min}$, block 33, the commanded deflection of roll δp is set equal to this value, according to the expression

$$\delta p = \delta p_{\min} \cdot \text{SIGN}(\delta p)$$

[0038] If it is not, and also from block 33 the procedure goes to block 34, where the commanded deflections of yaw and pitch δq , δr , previously modified, are reduced in percentage terms according to an appropriate scaling coefficient k_{sc} to take into account the deflection lacking for the required roll control (a check has in fact been made to verify that the available residual deflection $\delta\sigma$ is smaller than the guaranteed minimum value of roll $\delta p_{\min}$). In detail, the scaling coefficient k_{sc} is determined according to the expression

$$k_{sc} = (\delta_{\max} - |\delta p|) / (\delta_{\max} - \delta\sigma)$$

and the commanded deflections of yaw and pitch δq , δr are modified according to the expressions

$$\delta q = k_{sc} \cdot \delta q ; \delta r = k_{sc} \cdot \delta r$$

[0039] The value of the available residual deflection $\delta\sigma$ for control of the roll is also updated, on the basis of the scaled values of the commanded deflections of yaw and pitch δq , δr , once again applying the expression

$$\delta\sigma = \delta_{\max} - 0.5 \cdot (|\delta q + \delta r| + |\delta q - \delta r|)$$

[0040] The procedure then goes to block B.

[0041] From block B (see Figure 3c), the distribution algorithm proceeds with the determination of the total deflections to be applied to the rudders 13, on the basis of the optimized values of the commanded deflections of yaw, pitch and roll δq , δr , δp , as determined previously.

[0042] In detail, block 36, first a check is made on the value of the available residual deflection $\delta\sigma$.

[0043] If the available residual deflection $\delta\sigma$ is zero (condition indicating the fact that no control in roll is made), deflections to be applied to the rudders 13 for roll control are set to zero (block 37). In particular, the distribution algorithm envisages determination of two values of deflection for roll control (in this case both set to zero): a first value of roll control δp_{UR-LL} to be applied to the upper-right (UR) rudder and lower-left (LL) rudder (which produce momenta of rotation in the same direction about the longitudinal axis x), and a second value of roll control δp_{LR-UL} to be applied to the lower-

right (LR) rudder and upper-left (UL) rudder (which produce momenta of rotation in the opposite direction about the longitudinal axis x).

[0044] Otherwise, block 38, the first and second values of roll control δp_{UR-LL} , δp_{LR-UL} required for generating the desired roll deflection are determined according to the expressions

$$\delta p_{UR-LL} = (\delta_{\max} - |\delta q - \delta r|) \cdot \delta p / \delta \sigma$$

$$\delta p_{LR-UL} = (\delta_{\max} - |\delta q + \delta r|) \cdot \delta p / \delta \sigma$$

[0045] Next, in block 40, from which access is gained both at output from block 37 and at output from block 38, the distribution algorithm ends with determination of the total deflections to be applied to the rudders 13, according to the expressions

$$\delta_{UR} = \delta q - \delta r + \delta p_{UR-LL}$$

$$\delta_{LR} = \delta q + \delta r + \delta p_{LR-UL}$$

$$\delta_{LL} = -\delta q + \delta r + \delta p_{UR-LL}$$

$$\delta_{UL} = -\delta q - \delta r + \delta p_{LR-UL}$$

where δ_{UR} , δ_{LR} , δ_{LL} and δ_{UL} are, respectively, the total deflections to be applied to the upper-right rudder, lower-right rudder, lower-left rudder and upper-left rudder (considered positive if they generate clockwise rotations about the longitudinal axis, evaluated in the direction of movement of the underwater vehicle 10).

[0046] The advantages that the steering method and system described enable are clear from the foregoing discussion.

[0047] They enable a reduction in the time of execution of the manoeuvres (compatibly with the dynamic capabilities of the rudders 13), safeguarding a priority of execution assigned to the control of the movement in the various reference planes and guaranteeing minimum control bands for the movements of yaw, pitch, and roll. In particular, the deflections applied to at least three of the four rudders 13 are less than the maximum deflection $\delta_{\max}$ so as to prevent any end-of-travel saturation of the same rudders, and consequent undesirable behaviour of the moving body. The distribution algorithm envisages the use of the available degree of freedom (given the presence of three steering commands applied to four rudders), to distribute the steering commands in an optimized manner.

[0048] As previously highlighted, the algorithm proposed is particularly effective for control moving bodies having structural limitations of control (for example, due to dimensional and/or dynamic limitations of the moving control surfaces).

[0049] Finally, it is clear that modifications and variations may be made to what is described and illustrated herein, without departing from the scope of the present invention, as defined by the annexed claims.

[0050] In particular, the algorithm described can be modified for ensuring the guaranteed minimum value of yaw $\delta r_{\min}$ or pitch $\delta q_{\min}$ even in the case where it is subsequently necessary to perform a scaling of the commands for ensuring the roll control; for example, the operation of scaling (block 34) could regard only the controlled deflection of yaw δr , guaranteeing a value of the controlled deflection of pitch δq that is not less than the respective guaranteed minimum value of pitch $\delta q_{\min}$.

[0051] In addition, the optimal distribution of the deflection for roll control on the opposite pairs of rudders is applicable in principle also to the configuration of rudders illustrated in Figure 1a (which presents pairs of horizontal and vertical rudders).

[0052] The steering system 10 could envisage an arrangement of the rudders 13 different from the butterfly one described and illustrated so far, in which the rudders 13 are in any case independent and capable of generating rotations in the three reference planes.

[0053] The order of the comparisons made between the commanded deflections of yaw δr and pitch δq and the respective guaranteed minimum values of yaw $\delta r_{\min}$ and pitch $\delta q_{\min}$ (blocks 22 and 24) could be reversed.

[0054] In addition, the guaranteed minimum values of yaw $\delta r_{\min}$ and pitch $\delta q_{\min}$ might not be constant and determined beforehand, but be variable and redefinable during execution of the control operations (for example, by the central control unit 15 or via commands received from the wire-guide system) so as to vary in real time the assignment of priority to the commands in the various reference planes.

[0055] Finally, it is clear that the steering system and method described can be advantageously implemented for controlling the movement of different underwater vehicles (for example, submarines, countermeasures of a motor-driven type, underwater drawn vehicles, etc.) presenting structural limitations of control (for example, caused by the small dimensions of the control surfaces or by the low operative speed).

Claims

1. A method for steering a body (10) moving underwater provided with movement control elements (13) independently actuatable for generating rotations of said body (10) about one or more of its axes, the longitudinal axis (x), the transverse axis (y), and the vertical axis (z), said method comprising the step of generating deflections (δ_{UR} , δ_{LR} , δ_{LL} and δ_{UL}) of said movement control elements (13) according to steering commands (δp , δq , δr) indicative of desired rotations about said longitudinal axis (x), transverse axis (y), and vertical axis (z),
characterized by comprising, prior to said step of generating:

- verifying that said steering commands (δp , δq , δr) are compatible with structural limitations of said movement control elements (13); and

- according to the result of said verification, modifying said steering commands (δp , δq , δr) on the basis of said structural limitations.

2. The method according to claim 1, wherein said structural limitations include a maximum end-of-travel deflection ($\delta_{\max}$) of said movement control elements (13); and said step of modifying comprises modifying said steering commands (δp , δq , δr) so that one or more of said deflections (δ_{UR} , δ_{LR} , δ_{LL} and δ_{UL}) are less than said maximum deflection ($\delta_{\max}$).

3. The method according to claim 1 or 2, wherein said step of modifying comprises guaranteeing a desired minimum band of rotation ($\delta p_{\min}$, $\delta q_{\min}$, $\delta r_{\min}$) about one or more of said longitudinal axis (x), said transverse axis (y), and said vertical axis (z).

4. The method according to claim 3, wherein said step of guaranteeing comprises guaranteeing respective desired minimum bands of rotation ($\delta p_{\min}$, $\delta q_{\min}$, $\delta r_{\min}$) about each of said longitudinal axis (x), said transverse axis (y), and said vertical axis (z); further comprising the step of modifying, during control of said movement, the value of said desired minimum bands of rotation ($\delta p_{\min}$, $\delta q_{\min}$, $\delta r_{\min}$) according to a priority of control of the movement about said longitudinal axis (x), said transverse axis (y), and said vertical axis (z).

5. The method according to any one of claims 2-4, wherein said steering commands (δp , δq , δr) include a roll steering command (δp), a pitch steering command (δq), and a yaw steering command (δr); said step of verifying comprises verifying that the sum of deflection contributions due to said pitch (δq) and yaw (δr) steering commands is lower than said maximum deflection ($\delta_{\max}$); and said step of modifying comprises, if said sum exceeds said maximum deflection ($\delta_{\max}$), the step of limiting said pitch (δq) and yaw (δr) steering commands.

6. The method according to claim 5, wherein said step of limiting comprises: if the sum of the absolute values of said pitch (δq) and yaw (δr) steering commands is not less than said maximum deflection ($\delta_{\max}$), and also said pitch (δq) and yaw (δr) steering commands are, in absolute value, not less than a respective desired minimum band of rotation ($\delta q_{\min}$, $\delta r_{\min}$) about a respective one of said transverse axis (y) and said vertical axis (z), the step of limiting said pitch (δq) and yaw (δr) steering commands to the value of said respective desired minimum band of rotation ($\delta q_{\min}$, $\delta r_{\min}$); and, if a first one of said pitch (δq) and yaw (δr) steering commands is, in absolute value, less than the respective desired minimum band of rotation ($\delta q_{\min}$, $\delta r_{\min}$), the step of setting the second of said pitch (δq) and yaw (δr) steering commands equal to said maximum deflection ($\delta_{\max}$) reduced by the absolute value of the first one of said pitch (δq) and yaw (δr) steering commands.

7. The method according to claim 5 or 6, wherein said step of modifying further comprises determining a residual band

of rotation ($\delta\sigma$) for control of the rotation about said longitudinal axis (x), as a function of said maximum deflection ($\delta_{\max}$) and of said pitch (δq) and yaw (δr) steering commands, possibly limited.

- 5 8. The method according to claim 7, wherein said step of modifying further comprises: if said residual band of rotation ($\delta\sigma$) is not higher than said roll steering command (δp) and than a desired minimum band of rotation ($\delta p_{\min}$) about said longitudinal axis (x), the step of limiting said pitch (δq) and yaw (δr) steering commands on the basis of a scaling coefficient (k_{sc}), which is a function of said residual band of rotation ($\delta\sigma$) and of said roll steering command (δp) .
- 10 9. The method according to any one of the preceding claims, wherein said movement control elements include four rudders (13) arranged in butterfly fashion, and said step of generating deflections comprises determining deflections (δ_{UR} , δ_{LR} , δ_{LL} and δ_{UL}) of said rudders (13) according to the steering commands (δp , δq , δr), possibly modified by said step of modifying.
- 15 10. The method according to any one of the preceding claims, wherein said structural limitations correspond to dimensional limitations of moving control surfaces of said movement control elements (13).
- 20 11. A system (11) for steering a body (10) moving underwater, comprising movement control elements (13) actuatable independently for generating rotations of said body (2) about one or more of its axes, the longitudinal axis (x), the transverse axis (y), and the vertical axis (z), **characterized by** comprising a control unit (15) configured so as to implement the steering method according to any one of the preceding claims.
- 25 12. The system according to claim 11, wherein said movement control elements (13) are four in number.
- 30 13. The system according to claim 11 or 12, wherein said control unit (15) comprises a processing unit provided with a software module including instructions such as to implement said steering method.
- 35 14. The system according to any one of claims 11-13, further comprising actuator means (14), which are operatively coupled to said movement control elements (13) and which can be actuated by said control unit (15) for generating said deflections (δ_{UR} , δ_{LR} , δ_{LL} and δ_{UL}) of said movement control elements (13).
- 40 15. A computer program product, comprising software instructions capable of implementing, when run in a control unit (15) of the steering system (10) according to any one of claims 11-14, the steering method according to any one of claims 1-10.
- 45 16. An underwater vehicle (10), **characterized by** comprising a steering system (11) according to any one of claims 11-14.
- 50 17. The underwater vehicle according to claim 16, of a self-propelled, guided, or drawn type, chosen in the group comprising: a torpedo, a submarine, and an underwater countermeasure.
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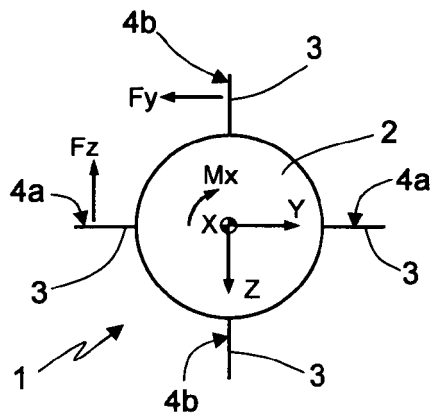


Fig.1a

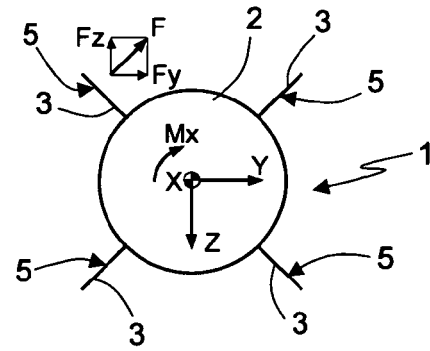


Fig.1b

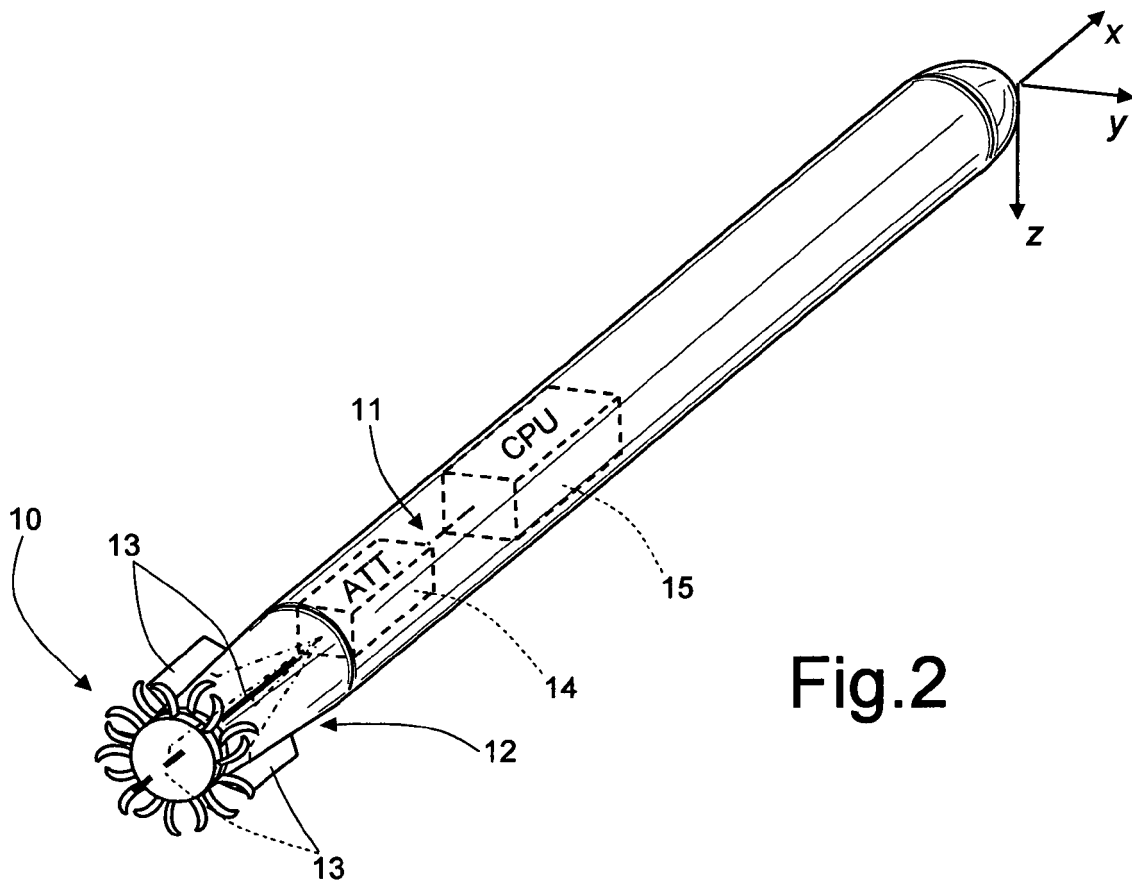


Fig.2

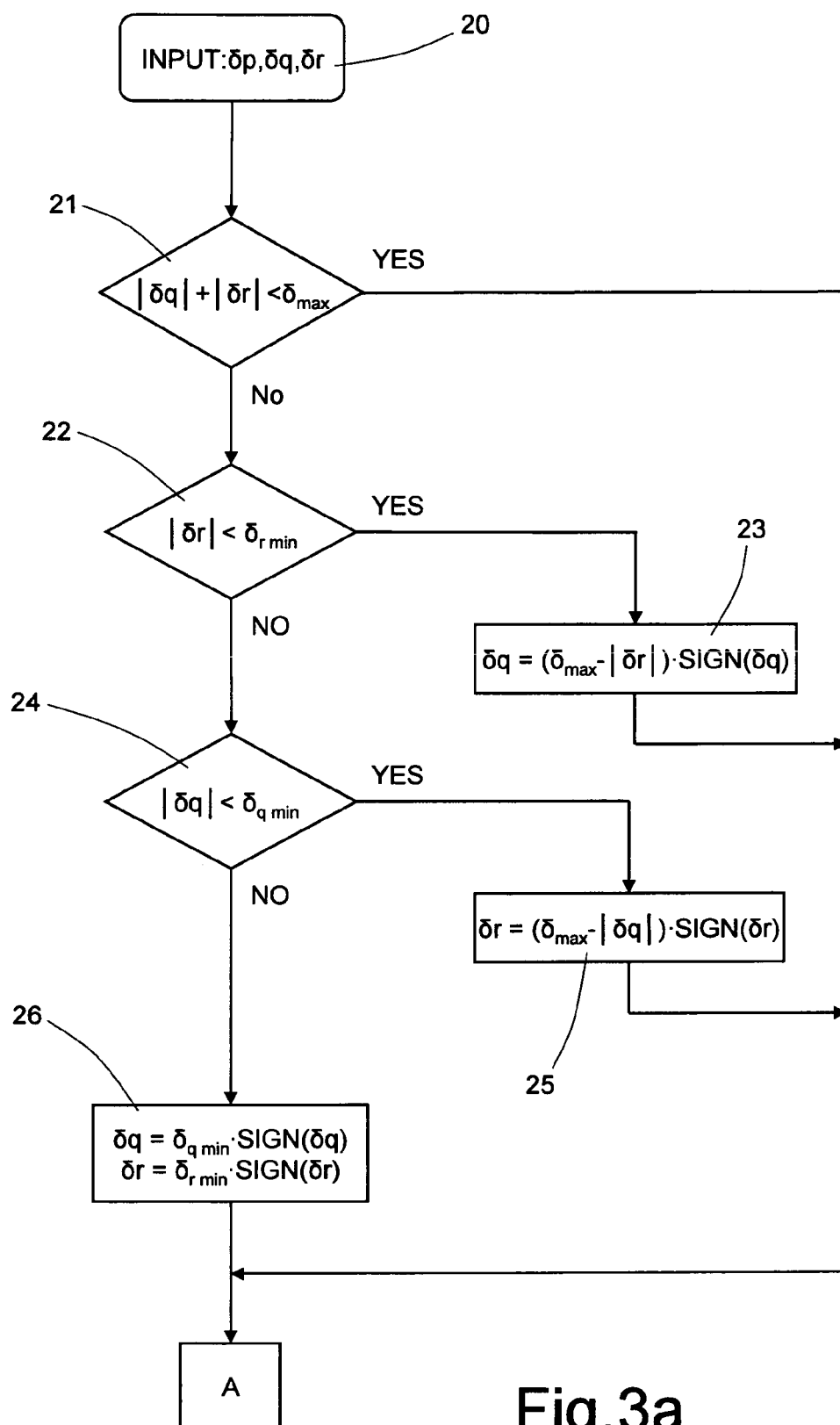


Fig.3a

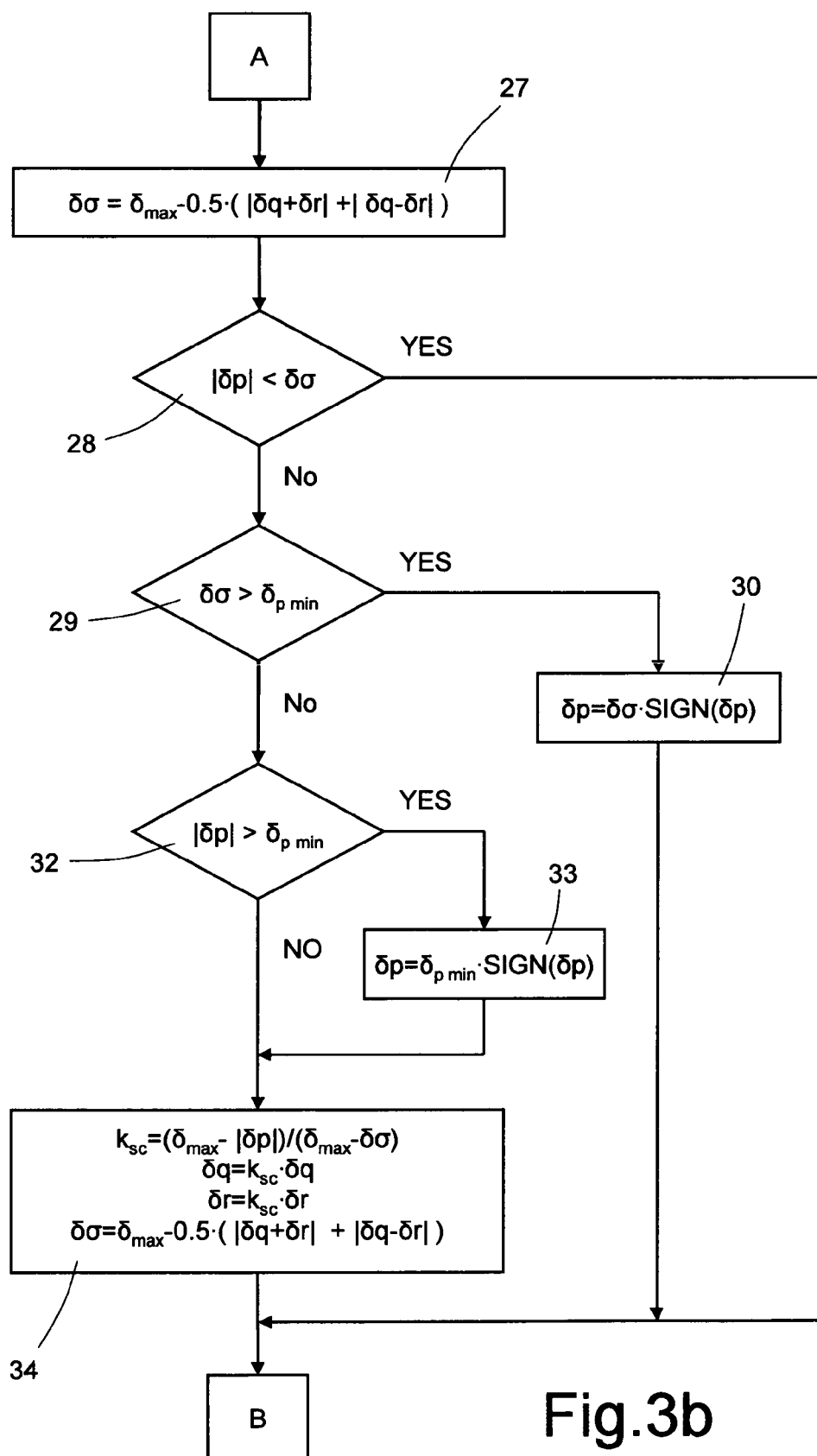


Fig.3b

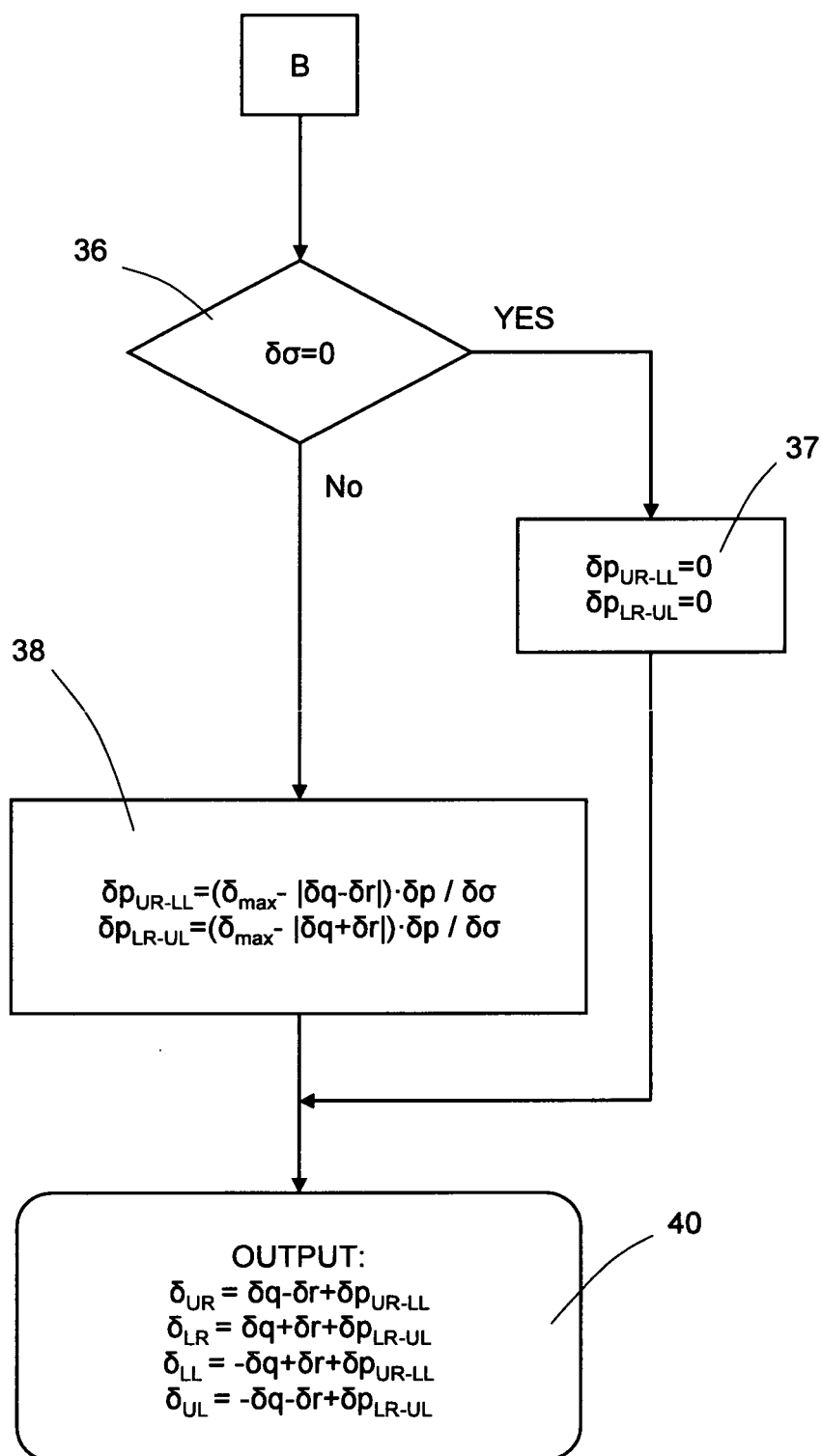


Fig.3c



EUROPEAN SEARCH REPORT

Application Number
EP 08 42 5219

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Place of search The Hague		Date of completion of the search 6 October 2008	Examiner Beaufumé, Cédric
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