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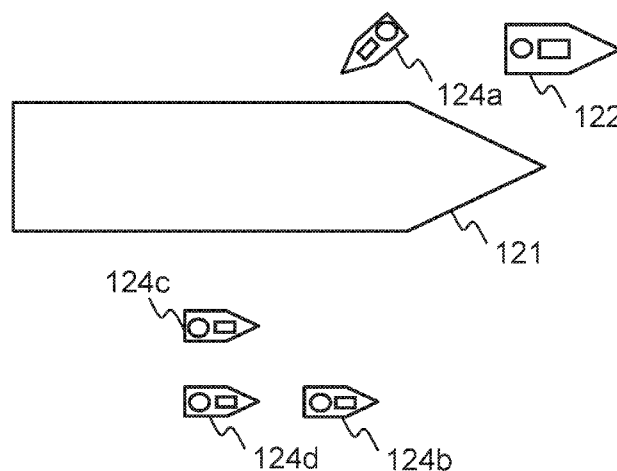


Fig. 2

(57) Abstract: Apparatus and computer-implemented method for automated marine vessel tugging, the method comprising: determining at least following modes: a following mode, wherein a pilot vessel and at least one associated thruster tug are configured to be transferred to a target vessel, and the pilot vessel is configured to control the at least one associated thruster tug during the following mode; a keeping mode, wherein the pilot vessel and the at least one associated thruster tug are configured to be located at working area of the target vessel; a distributing mode, wherein the at least one associated thruster tug is configured to be transferred to an operating position relative to the target vessel, and the pilot vessel is configured to control the associated thruster tug during the distributing mode; and a maneuvering mode, wherein the pilot vessel is configured to control the at least one associated thruster tug based on a dynamic vessel model. The method further comprises controlling transition between the determined modes based on transition control



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**METHOD AND APPARATUS FOR AUTOMATED TUGGING OF MARINE VESSEL****5    TECHNICAL FIELD**

**[0001]**    The present application generally relates to automated vessel tugging method, device and apparatus.

**BACKGROUND**

10    **[0002]**    This section illustrates useful background information without admission of any technique described herein representative of the state of the art.

**[0003]**    The present invention relates to Automated Vessel Tugging System (AVTS) that is to provide automated vessel tugging including unmanned tugging system.

15    **[0004]**    Dynamic positioning (DP) is known. It involves automatic or semi-automatic control of a marine vessel's position and heading by using its own propellers and thrusters with respect to one or more position references. Typically, the intention is to keep the vessel's position fixed within given parameters. Dynamic positioning (DP) is utilized e.g. in offshore drilling operations, for example.

20    **[0005]**    Autopilots are also known. The autopilot (also known as self-steering) is an automatic device or system that guides or maintains a marine vessel's chosen course so that constant 'hands-on' control by a human operator is not necessarily required.

**[0006]**    Automatic radar plotting aid is also known. That can be utilized in calculating a tracked object's course, speed and closest point of approach to detect if  
25    there is a danger of collision with another ship or landmass, for example.

**[0007]**    However, autonomous marine vessel tugging system from controlling of each tug and placing the tugs to operating position as well as controlling them during tug operation in safe and efficient way is still needed.

**[0008]**    Thus, a solution is needed to enable accurate, efficient, and reliable  
30    method for autonomous tugging of marine vessel is needed.

**SUMMARY**

**[0009]** Various aspects of examples of the invention are set out in the claims.

**[0010]** According to a first example aspect of the present invention, there is provided a computer-implemented method for automated marine vessel tugging, the method comprising:

determining at least following modes:

a following mode, wherein a pilot vessel and at least one associated thruster tug are configured to be transferred to a target vessel, and the pilot vessel is configured to control the at least one associated thruster tug during the following mode;

a keeping mode, wherein the pilot vessel and the at least one associated thruster tug are configured to be located at working area of the target vessel;

a distributing mode, wherein the at least one associated thruster tug is configured to be transferred to an operating position relative to the target vessel, and the pilot vessel is configured to control the associated thruster tug during the distributing mode; and

a maneuvering mode, wherein the pilot vessel is configured to control the at least one associated thruster tug based on a dynamic vessel model; and

controlling transition between the determined modes based on transition control information maintained at control apparatus of the pilot vessel.

**[0011]** In an embodiment, the method further comprises generating the dynamic vessel model using target vessel information and thruster tug information.

**[0012]** In an embodiment, the target vessel information comprises at least one of the following:

target vessel dimension information;

target vessel mass information; and

target vessel position information; and

the thruster tug information comprises at least one of the following:

thruster tug position information; and

thruster tug environmental information.

**[0013]** In an embodiment, the thruster tug position information is determined using a Global Navigation Satellite System (GNSS) receiver.

**[0014]** In an embodiment, the method further comprises determining relative position information of at least two associated thruster tugs. The relative position  
5 information may be determined using a position reference sensor comprising an optical assembly, a radar assembly or a differential relative positioning sensor assembly.

**[0015]** In an embodiment, the position reference sensor comprises a pulsed laser device for emitting laser light; a lens arrangement comprising a lenticular lens for  
10 producing a vertically fanned beam of the laser light emitted by the pulsed laser device; and a plurality of photodiode photodetectors for detecting laser light reflected by a retro-reflective target, the level of reflected laser light incident upon each photodetector being individually detectable; the position reference sensor further comprising an actuator for varying the inclination of the optical assembly, the actuator  
15 being automatically controllable based on the level of reflected laser light incident upon each photodetector.

**[0016]** In an embodiment, at least two associated thruster tugs comprise retro-reflective targets.

**[0017]** In an embodiment, the relative position information comprises at least one  
20 of the following: range and bearing information.

**[0018]** In an embodiment, the relative position information is configured to be determined by calibrating at least two associated thruster tugs against the pilot vessel.

**[0019]** In an embodiment, the dynamic vessel model comprises position  
25 information for each associated thruster tug.

**[0020]** In an embodiment, the method further comprises receiving pilot input information; determining thrust vector information based on the pilot input information and the dynamic vessel model; and controlling the at least one associated thruster tug based on the thrust vector information.

**[0021]** In an embodiment, the pilot input information is configured to be provided  
30 by a user operable control device arranged on the pilot vessel.

**[0022]** In an embodiment, the control apparatus of the pilot vessel and/or the control apparatus of the at least one associated thruster tug comprises a Dynamic Positioning (DP) controller.

**[0023]** In an embodiment, the method further comprises:

5       determining a transit control mode associated with route plan data defining transit operation between ports;

          determining an autonomous tugging control mode associated with harbor track data comprising a set of waypoint properties and defining approach zone information and track segments joined at waypoints, wherein the approach zone information  
10       comprises:

          location area information for the approach zone;

          maximum vessel speed for entering the approach zone; and

          maximum heading deviation for entering the approach zone;

          determining target vessel location, speed and heading;

15       comparing the target vessel location, speed and heading to the approach zone information and changing from the transit control mode to the autonomous tugging control mode in response to:

          the target vessel location comprised by the location area information;

          the target vessel speed being lower than the maximum target vessel speed

20       for entering the approach zone; and

          the target vessel heading matching criteria defined by the maximum heading deviation for entering the approach zone.

**[0024]** In an embodiment, the method further comprises determining a dynamic setpoint based on the waypoint properties, wherein the dynamic setpoint comprising  
25       a setpoint position, a setpoint speed and a setpoint heading that change based on the harbor track data.

**[0025]** In an embodiment, the method further comprises determining difference information between the dynamic setpoint and the determined target vessel location using a closed loop controller; determining a force vector based on the difference  
30       information; and controlling thruster commands of the autonomous tugging control mode based on the force vector.

**[0026]** In an embodiment, the method further comprises aligning the target vessel heading to the setpoint heading and the target vessel speed to the setpoint speed, wherein the setpoint heading and the setpoint speed are configurable parameters.

5 **[0027]** In an embodiment, the method further comprises interpolating the setpoint heading and the setpoint speed between waypoints and respective setpoint values based on the target vessel's location on the track segment; and aligning the target vessel heading to the interpolated setpoint heading and the target vessel speed to the interpolated setpoint speed.

10 **[0028]** In an embodiment, interpolating is enabled based on a waypoint property of the waypoint to which the target vessel is heading.

**[0029]** In an embodiment, the method further comprises controlling thruster commands of the at least one associated thruster tug based on the dynamic vessel model by activating full scale three axis position and heading control by allocating full scale thrust to at least one thruster of the at least one associated thruster tug, when  
15 the target vessel speed being less than a lower speed threshold.

**[0030]** In an embodiment, the method further comprises controlling thruster commands of at least one thruster of the at least one associated thruster tug based on the dynamic vessel model by activating partial scale three axis position and heading control by allocating partial scale thrust to the at least one thruster of the at  
20 least one associated thruster tug, when the target vessel speed being between the lower and higher speed threshold.

**[0031]** In an embodiment, the method further comprises maintaining the harbor track data for a port of call and a berthing position within the port, wherein the harbor track data comprises approach corridor data defining bounds on maximum track position deviation allowed during harbor maneuvering; and the approach zone  
25 information.

**[0032]** In an embodiment, the approach zone information further comprises maximum lateral deviation for entering the approach zone, and the method further comprises comparing the target vessel location, speed and heading to the approach  
30 zone information and changing from the transit control mode to the autonomous

tugging control mode in response to the target vessel deviation is less than the maximum lateral deviation for entering the approach zone.

**[0033]** In an embodiment, the method further comprises determining entry leg data in response to changing to the autonomous tugging control mode, wherein the entry leg data is configured to guide the target vessel onto a harbor track defined by the harbor track data.

**[0034]** In an embodiment, in the transit control mode the target vessel is configured to be at least partially in manual control mode.

**[0035]** According to a second example aspect of the present invention, there is provided a marine vessel apparatus for automated tugging, comprising:

- a communication interface for transceiving data;

- at least one processor; and

- at least one memory including computer program code;

- the at least one memory and the computer program code configured to, with the at least one processor, cause the apparatus to:

- determine at least following modes:

- a following mode, wherein a pilot vessel and at least one associated thruster tug are configured to be transferred to a target vessel, and the pilot vessel is configured to control the at least one associated thruster tug during the following mode;

- a keeping mode, wherein the pilot vessel and the at least one associated thruster tug are configured to be located at working area of the target vessel;

- a distributing mode, wherein the at least one associated thruster tug is configured to be transferred to an operating position relative to the target vessel, and the pilot vessel is configured to control the associated thruster tug during the distributing mode; and

- a maneuvering mode, wherein the pilot vessel is configured to control the at least one associated thruster tug based on a dynamic vessel model; and

control transition between the determined modes based on transition control information maintained at control apparatus of the pilot vessel.

**[0036]** In an embodiment, the apparatus further comprises at least one sensor, wherein the at least one sensor is configured to provide position related data or environment related data.

**[0037]** In an embodiment, the at least one sensor comprises at least one of the following:

a position reference sensor;

a global navigation satellite system (GNSS) position sensor;

a docking sensor for providing relative positioning information relative to a berth;

a gyro compass sensor for providing heading information;

a motion reference unit (MRU) sensor for providing pitch and information; and

a wind sensor for providing wind speed and direction information.

**[0038]** In an embodiment, the position reference sensor comprises a pulsed laser device for emitting laser light; a lens arrangement comprising a lenticular lens for producing a vertically fanned beam of the laser light emitted by the pulsed laser device; and a plurality of photodiode photodetectors for detecting laser light reflected by a retro-reflective target, the level of reflected laser light incident upon each photodetector being individually detectable; the position reference sensor further comprising an actuator for varying the inclination of the optical assembly, the actuator being automatically controllable based on the level of reflected laser light incident upon each photodetector.

**[0039]** According to a third example aspect of the present invention, there is provided a computer program embodied on a computer readable medium comprising computer executable program code, which code, when executed by at least one processor of an apparatus, causes the apparatus to:

determine at least following modes:

a following mode, wherein a pilot vessel and at least one associated thruster tug are configured to be transferred to a target vessel, and the pilot vessel is configured to control the at least one associated thruster tug during the following mode;

a keeping mode, wherein the pilot vessel and the at least one associated thruster tug are configured to be located at working area of the target vessel;

a distributing mode, wherein the at least one associated thruster tug is configured to be transferred to an operating position relative to the target vessel, and the pilot vessel is configured to control the associated thruster tug during the distributing mode; and

a maneuvering mode, wherein the pilot vessel is configured to control the at least one associated thruster tug based on a dynamic vessel model; and

control transition between the determined modes based on transition control information maintained at control apparatus of the pilot vessel.

**[0040]** Different non-binding example aspects and embodiments of the present invention have been illustrated in the foregoing. The embodiments in the foregoing are used merely to explain selected aspects or steps that may be utilized in implementations of the present invention. Some embodiments may be presented only with reference to certain example aspects of the invention. It should be appreciated that corresponding embodiments may apply to other example aspects as well.

### **BRIEF DESCRIPTION OF THE DRAWINGS**

**[0041]** For a more complete understanding of example embodiments of the present invention, reference is now made to the following descriptions taken in connection with the accompanying drawings in which:

**[0042]** Fig. 1 shows a schematic picture of a system according to an example embodiment of the invention that shows a following mode;

**[0043]** Fig. 2 shows a schematic picture of a system according to an example embodiment of the invention that shows a distributing mode;

**[0044]** Fig. 3 shows a schematic picture of a system according to an example embodiment of the invention that shows a maneuvering mode;

**[0045]** Fig. 4 shows a schematic picture of an automated or autonomous system according to an example embodiment;

**[0046]** Fig. 5 presents an example block diagram of a control apparatus in which various embodiments of the invention may be applied;

[0047] Fig. 6 presents an example block diagram of a capturing device in which various embodiments of the invention may be applied;

[0048] Fig. 7 presents an example block diagram of a server apparatus in which various embodiments of the invention may be applied;

5 [0049] Fig. 8 presents an example block diagram of a computer apparatus in which various embodiments of the invention may be applied;

[0050] Fig. 9 shows a flow diagram showing operations in accordance with an example embodiment of the invention; and

[0051] Fig. 10 shows a schematic picture of a closed loop controller block  
10 diagram according to an example embodiment of the invention.

#### **DETAILED DESCRIPTION OF THE DRAWINGS**

[0052] In the following description, like numbers denote like elements.

[0053] Embodiments of the invention relate to Automated Vessel Tugging System  
15 (AVTS) that is to provide automated vessel tugging solution including unmanned tugging system for docking or undocking solutions.

[0054] Building blocks such as sensor processing, guidance and control logic, thruster allocation etc. exist for automated tug control. However, different  
20 embodiments disclosed show technical effects on areas of guidance, controls, sensor processing, estimation and thruster allocation, especially when tugging for docking or undocking in automated or autonomous manner.

[0055] An automated tugging system may use unmanned, battery powered, remotely piloted or autonomous tugs for maneuvering of large vessels through harbors to their final berthing location (and vice versa). Such tugs may be called  
25 thruster tugs, for example. As multiple tugs would be used in driving a single vessel, it is considered easier to combine the control of the propulsion units of the thruster tugs using a single dynamic positioning (DP) system. The DP system would provide an operator/user with a single joystick to operate all thruster tugs simultaneously under the command of one master controller.

**[0056]** In its basic form, a pilot station may be provided on the bridge of the larger vessel where the DP controller would be located, with secure radio links used to communicate between the DP controller and each thruster tug.

**[0057]** In an alternative form, an unmanned tugging system may comprise a step of determining the number of one or more tugboats having a remote control function on the basis of the size of a ship to be tugged, a step of setting a tugging path by the tugboats using the position information and tugging position of the ship, a step of moving the tugboats to be adjacent to the ship to be tugged and arranging the tugboats to tug the ship, and a step of moving the ship to the tugging position through the wireless remote control of the tugboats. Problem in this approach is that remote controlling of each tug and placing them to operating position as well as controlling them during tug operation is slightly complex and cumbersome.

**[0058]** Figs. 1-3 present example schematic illustrations on different operational situations of the Automated Vessel Tugging System (AVTS) involving a target vessel 121, a pilot vessel 122 and thruster tugs 124a-d.

**[0059]** Fig. 1 shows a following mode (FOLLOW), wherein the pilot vessel 122 is configured to transport a pilot (pilot may be used in automated mode, but pilot is not necessary in fully autonomous tugging mode) and the thruster tugs 124a-d out to the work area close to the target vessel 121 (not shown in Fig. 1).

**[0060]** Automated Vessel Tugging System (AVTS) involves assembly and transport of thruster tugs 124a-d from their berthing area out to the work area that may require a combination of individual manual, and autonomous, control steps.

**[0061]** In an embodiment, a pilot vessel 122 is configured to be used to transport a pilot and the thruster tugs 124a-d out to the tugging area, after which the thruster tugs 124a-d are distributed around the target vessel 121 under operational control of the pilot vessel apparatus 120.

**[0062]** In automated operation mode, to provide the transportation, the pilot vessel 122 may be installed with a manual remote-control capability for each thruster tug 124a-d, wherein each thruster tug 124a-d may comprise a simple DP controller 220-223, respectively. Using these features the pilot could manually maneuver each thruster tug 124a-d into a "transport" location behind the pilot vessel 122 and then

command the DP controller onboard each thruster tug 124a-d to autonomously maintain a pre-determined separation between itself, the pilot vessel, and adjacent thruster tugs 124a-d (this may be a standard target follow mode in DP systems). The pilot vessel 122 could subsequently be driven out to the work area with the thruster tugs 124a-d automatically following behind (or adjacent, or whatever alternative formation is selected).

**[0063]** In an embodiment, an exemplary solution to provide thruster location information is to provide a mechanism for the thruster tugs 124a-d to calibrate their position relative to each other. An example solution that could be used for determining thruster tug 124a-d position relative to each other is to utilize a position reference sensor (comprised by the DP controllers 220-223 or the control apparatus 120 in Fig. 1) that comprises a pulsed laser device for emitting laser light; a lens arrangement comprising a lenticular lens for producing a vertically fanned beam of the laser light emitted by the pulsed laser device; and a plurality of photodiode photodetectors for detecting laser light reflected by a respective retro-reflective target 210-214, the level of reflected laser light incident upon each photodetector being individually detectable; the position reference sensor further comprising an actuator for varying the inclination of the optical assembly, the actuator being automatically controllable based on the level of reflected laser light incident upon each photodetector.

**[0064]** For example, CyScan (a laser-based position reference system) targets 210-214 could be used, however line of sight between the thruster tugs 124a-d is not guaranteed in each operation mode.

**[0065]** In an embodiment, another exemplary solution to calibrate thruster tug 124a-d position relative to each other is provided. At least one transponder 211-214 (e.g. in each thruster tug) modulates an identifier frequency into a signal from a master transceiver 210 (e.g. in pilot vessel) prior to the reflection of this signal to a series of antenna elements in the master transceiver 210 that based on the frequency of the carrier signal may determine the identity of the signal and based on this the position data is determined.

**[0066]** The modulated signal from the transponder 211-214 solves different issues. The signals are unique for each transponder 211-214 and thus making it possible to distinguish between the different transponders 211-214 used in the system. The signal modulated by the transponders 211-214 relocates the reflected radar signal, making it possible to exclude all conventional radars.

**[0067]** The signal received in the master transceiver 210 may be processed to find the beat frequencies and the Doppler frequencies for each transponder 211-214, and this can be used to calculate the distance and the relative velocity between the master transceiver 210 and each of the transponders 211-214 and enables the relative position definition between the associated thruster tugs 124a-d. The angle between the master transceiver 210 and at least one transponder 211-214 may be calculated by comparing the receiving signal wave front on several receiving antenna elements, for example.

**[0068]** In an embodiment, another exemplary solution to calibrate thruster tug 124a-d position relative to each other is provided. Differential positioning system utilizing GNSS, such as GPS may be used. In such system, simultaneously gathered GPS data from position sensors 210, 211-214 on different vessels can be used to compute distance to target and bearing to target. Relative position between thruster tugs 124a-d and/or between pilot vessel 122 and thruster tugs 124a-d can be determined that is independent of differential correction data. For computation of absolute position, differential corrections may be used.

**[0069]** In an embodiment, Precise Point Positioning (PPP) may be used for position determination of at least one of the pilot vessel 122 and thruster tugs 124a-d. PPP is a positioning technique that removes or models GNSS system errors to provide a high level of position accuracy from a single receiver. A PPP solution depends on GNSS satellite clock and orbit corrections, generated from a network of global reference stations. Once the corrections are calculated, they are delivered to the end user via satellite or over the Internet. These corrections are used by the receiver, such as control units 120, 220-223, resulting in decimeter-level or better positioning with no base station required.

**[0070]** In an embodiment, a keeping mode (STATION KEEPING) is defined, in which mode the pilot vessel 122 and the thruster tug(s) 124a-d are configured to maintain their relative position to the target vessel 121. In this mode the automated vessel tugging system 122, 124a-d is waiting for the tugging operation to start.

5 **[0071]** In the keeping mode (STATION KEEPING), the pilot vessel 122 and the thruster tugs 124a-d may keep their formation as shown in Fig. 1, for example.

**[0072]** In an embodiment, transition between the determined modes may be controlled based on transition control information maintained at control apparatus 120 of the pilot vessel 122.

10 **[0073]** Autonomous tugging may mean a controlled operation where control apparatus 120 is configured to control or command at least one of the associated thruster tug(s) 124a-d (change of modes or determining thrust vector information, for example) without user interaction from the pilot. Automated tugging may mean a controlled operation where control apparatus 120 is configured to control or command  
15 at least one of the associated thruster tug(s) 124a-d with user interaction from the pilot.

**[0074]** In an embodiment, at least one of the associated thruster tugs 124a-d may be configured to operate as a pilot vessel 122 for tugging service, whereas the remaining associated thruster tugs 124a-d are configured to operate as thruster tugs  
20 according to embodiments. Thus, the pilot vessel 122 is not necessarily needed to be otherwise different to the thruster tugs 124a-d but for the allocation of master-slave roles. The associated thruster tug 124a-d arranged to be the master for the tugging service may be labeled as the pilot vessel 122 and the control apparatus 120, such as the DP controller, of the pilot vessel 122 is configured to control the tugging  
25 service as disclosed in various embodiments.

**[0075]** Fig. 2 shows a distributing mode (DISTRIBUTING), wherein the at least one associated thruster tug 124a-d is configured to be transferred to an operating position relative to the target vessel 121, and the pilot vessel 122 is configured to control the associated thruster tug 124a-d during the distributing mode.

[0076] In an embodiment, the distributing mode (DISTRIBUTING) may be configured so that each thruster tug 124a-d is distributed to a pre-defined position around the target vessel 121 for the automated tugging operation.

[0077] In Fig. 2, the thruster tug 124a is being distributed to the pre-defined position around the target vessel 121 for the automated tugging operation while the other thruster tugs 124b-d are maintained in keeping mode (STATION KEEPING) and waiting for their distribution under control of pilot vessel 122.

[0078] Fig. 3 shows a maneuvering mode (MANEUVER) mode, in which mode the control apparatus 120 of the pilot vessel 122 is configured to control the thruster tug(s) 124 for automated tugging operation for the target vessel 121.

[0079] In an embodiment, the pilot vessel 122 is configured to control the at least one associated thruster tug 124a-d based on a dynamic vessel model.

[0080] The dynamic vessel model is generated, wherein the dynamic vessel model comprises data of both the target vessel 121 and the associated thruster tug(s) 124a-d. Based on the dynamic vessel model and possible related input data, the control apparatus 120 is configured to determine thrust vectors for the thruster tug(s) 124a-d. The thruster tug(s) 124a-d are autonomously controlled based on the determined thrust vector information. Each thruster tug 124a-d may receive dynamic thrust vector information from the control apparatus 120 to control operation.

[0081] In an embodiment, the dynamic vessel model is generated using target vessel information and thruster tug information. The target vessel information may comprise at least one of the following: target vessel dimension information; target vessel mass information; and target vessel position information. The thruster tug information may comprise at least one of the following: thruster tug position information; and thruster tug environmental information.

[0082] In an embodiment, when reaching the work site, the thruster tugs 124a-d may be distributed around the target vessel 121 in preparation for moving it. The operation control of the thruster tugs 124a-d may be handed over to a Dynamic Positioning (DP) system installed on the target vessel 121 instead of the control apparatus 120 of the pilot vessel 122. Given the large number of potential target vessels 121 it may be most efficient solution to leave control with the pilot vessel 122.

**[0083]** In an embodiment, distributing thruster tugs 124a-d around the target vessel 121 may be as simple as switching all thruster tugs 124a-d to a station keeping mode (standard DP operation) after arriving at the work site (see Fig. 2), and then taking manual control of each tug and transitioning it to its position relative to the target vessel 121, where it is subsequently connected to the target vessel 121. Thruster tugs 124a-d stationed off from the bow or stern may be set to station keeping while waiting for the maneuvering phase of the operation to begin (see Fig. 3).

**[0084]** In an embodiment, a pilot located at the pilot vessel 122 may maneuver the target vessel 121 using a single joystick and a DP controller (comprised by the control apparatus 120 on board of the pilot vessel 122) may be configured to calculate how to create thrust vectors for each thruster tug 124a-d based on pilot control input (e.g. directions by the joystick) using a dynamic vessel model. For optimal operation, the dynamic vessel model should be accurate, including the dimensions and mass of the target vessel 121 and the location of the thrusters (thruster tugs). Pilot input information is configured to be provided by a user operable control device (e.g. a joystick) arranged on the pilot vessel.

**[0085]** One solution to provide the thruster location information is to provide a mechanism for the thruster tugs 124a-d to calibrate their position relative to each other. An example solution that could be used for determining thruster tug 124a-d position relative to each other is to utilize a position reference sensor that comprises a pulsed laser device for emitting laser light; a lens arrangement comprising a lenticular lens for producing a vertically fanned beam of the laser light emitted by the pulsed laser device; and a plurality of photodiode photodetectors for detecting laser light reflected by a retro-reflective target, the level of reflected laser light incident upon each photodetector being individually detectable; the position reference sensor further comprising an actuator for varying the inclination of the optical assembly, the actuator being automatically controllable based on the level of reflected laser light incident upon each photodetector.

**[0086]** For example, CyScan (a laser-based position reference system) targets could be used, however line of sight between the thruster tugs 124a-d is not guaranteed.

**[0087]** As shown in Fig. 3, there is no line of sight between thruster tug 124c and thruster tug 124d, and not between thruster tug 124b and thruster tug 124a. One solution to this would be to calibrate against the pilot vessel 122, which could be positioned to provide line of sight with both thruster tugs, as shown in Fig. 3. Another solution would be to include global satellite navigation system receiver (GNSS) on each thruster tug 124a-d and use the satellite supplied location data for calibration purposes. Assuming that the approximate location of one tug relative to the target vessel 121 is known, all thruster locations 124a-d could be located in the dynamic vessel model.

**[0088]** A communication interface between the thruster tugs 124a-d and the pilot vessel 122 may be needed to enable accurate operation of the automatic vessel tugging system. A RF data communication link could be used for data communication between at least two thruster tugs 124a-d or between pilot vessel and at least one associated thruster tug 124a-d. One of the issues with this kind of localized communications is that it works best in line of sight scenarios where transmitter and receiver can “see” each other. One of the problems that may exist with the system involving thruster tugs 124a-d and a pilot vessel 122 is the presence of a large steel object that may in some cases block line of sight.

**[0089]** To reduce such problem, some alternative options are available, such as using cellular network or mesh network, for example.

**[0090]** Using local 4G cellular system may depend on the used location. In larger city there is likely to be good coverage of the harbor area by a cellular system with digital data transmission capability. Given that a cellular system relies on the use of multiple distributed antennas, it is possible that dead areas (areas of no coverage) would be limited and cellular communication interface could be used for automated vessel tugging system.

**[0091]** Using digital mesh radio network could provide either a localized setup between at least one thruster tug 124a-d and the pilot vessel 122, or a larger setup to provide coverage over the complete area of possible operation.

**[0092]** In an embodiment, the control of the thruster tugs 124a-d is improved.

5 Since there is a wireless link between the pilot vessel 122 and each associated thruster tug 124a-d the automated vessel tugging system is not just remote "controlling" the thruster tugs 124a-d but more like remote "commanding". Since there is a controller 220-223 (see Fig. 1) on each tug 124a-d, the main pilot vessel control apparatus 120 (see Fig. 1) is configured to instruct to perform and maintain a thrust  
10 vector based on the dynamic vessel model. Thus, automatic tugging system operation, accuracy and reliability is improved.

**[0093]** In an embodiment, the pilot vessel control apparatus 120 is configured to control thruster commands of the at least one associated thruster tug 124a-d based on the dynamic vessel model by activating full scale three axis position and heading  
15 control by allocating full scale thrust to at least one thruster of the at least one associated thruster tug 124a-d, when the target vessel 121 speed is less than a lower speed threshold.

**[0094]** In an embodiment, thruster commands of at least one thruster of the at least one associated thruster tug 124a-d may be disabled when the target vessel 121  
20 speed is greater than a higher speed threshold.

**[0095]** In an embodiment, thruster commands of at least one thruster of the at least one associated thruster tug 124a-d may be controlled based on the dynamic vessel model by activating partial scale three axis position and heading control by allocating partial scale thrust to the at least one thruster of the at least one associated  
25 thruster tug 124a-d, when the target vessel 121 speed is between the lower and higher speed threshold.

**[0096]** In an embodiment, relative position information of at least two associated thruster tugs 124a-d may be determined using a position reference sensor comprising an optical assembly, for example. The relative position information may comprise at  
30 least one of the following: range and bearing of the retro-reflective target. The relative position information may be configured to be determined by calibrating at least two

associated thruster tugs 124a-d against the pilot vessel 122 that comprises a retro-reflective target. Alternatively, the relative position information may be determined using a position reference sensor comprising a radar assembly or a differential relative positioning sensor assembly.

5   **[0097]**   In an embodiment, the dynamic vessel model comprises position information for each associated thruster tug 124a-d. The thruster tug position information of at least one associated thruster tug 124a-d may be determined using a Global Navigation Satellite System (GNSS) receiver, for example.

10   **[0098]**   In an embodiment, the pilot control apparatus 120 receives pilot input information and the control apparatus 120 is configured to determine thrust vector information based on the pilot input information and the dynamic vessel model, and to control the at least one associated thruster tug 124a-d based on the thrust vector information.

15   **[0099]**   Fig. 4 shows a schematic picture of a system 100 according to an example embodiment. A target vessel 121 may be tugged using automated/autonomous vessel tugging system 122, 124 wherein at least one tugging vessel 122 comprising control apparatus 120 comprising means for generating, processing and transceiving automated/autonomous vessel tugging related data.

20   **[00100]**   The apparatus 120 is capable of downloading and locally executing software program code. The software program code may be a client application of a service whose possible server application is running on a server apparatus 130, 131 of the system 100. The apparatus 120 may comprise a capturing device, such a sensor device, for providing vessel related signals and data. The sensor device may comprise an accelerometer, an inclinometer, a gyroscope, a wind sensor, a  
25   positioning sensor, a temperature sensor, a pressure sensor, or a camera, for example. The camera may also be used to provide video data and a microphone may be used for providing audio data, for example. The sensor device may also provide environmental signals and data.

30   **[00101]**   In an embodiment, the automated/autonomous vessel tugging system 122, 124 comprises at least one pilot vessel 122 and at least one thruster tug 124. The automated/autonomous vessel tugging system 122, 124 may be configured to

operate in different dynamic positioning (DP) operating modes called Automated Vessel Tugging System (AVTS) modes in respect of the embodiments disclosed.

**[00102]** Example AVTS modes are discussed earlier when disclosing different embodiments and may comprise modes as follows.

5 **[00103]** A following mode is provided, wherein a pilot vessel and at least one associated thruster tug are configured to be transferred to a target vessel, and the pilot vessel is configured to control the at least one associated thruster tug during the following mode.

**[00104]** A keeping mode is provided, wherein the pilot vessel and the at least one  
10 associated thruster tug are configured to be located at working area of the target vessel.

**[00105]** A distributing mode is provided, wherein the at least one associated thruster tug is configured to be transferred to an operating position relative to the target vessel, and the pilot vessel is configured to control the associated thruster tug  
15 during the distributing mode.

**[00106]** A maneuvering mode is provided, wherein control apparatus of the pilot vessel is configured to control the at least one associated thruster tug based on a dynamic vessel model by transmitting thrust vector information to control apparatus of the at least one associated thruster tug.

20 **[00107]** In an embodiment, an autonomous vessel tugging method comprises determining a transit control mode associated with route plan data defining transit operation between ports, determining an autonomous tugging control mode associated with harbor track data comprising a set of waypoint properties and defining approach zone information and track segments joined at waypoints, wherein  
25 the approach zone information comprises: location area information for the approach zone; maximum vessel speed for entering the approach zone; and maximum heading deviation for entering the approach zone. The method further comprises determining target vessel location, speed and heading, comparing the target vessel location, speed and heading to the approach zone information and changing from the transit  
30 control mode to the autonomous tugging control mode in response to: the target vessel location comprised by the location area information; the target vessel speed

being lower than the maximum target vessel speed for entering the approach zone; and the target vessel heading matching criteria defined by the maximum heading deviation for entering the approach zone.

**[00108]** Between ports, the vessel 121 is able to follow routes using an autonomous, semi-autonomous, remote controlled or manual maneuvering control. However, during docking and undocking, the system 100 may operate in AVTS mode to follow and execute precise maneuvers along a "harbor track" 170.

**[00109]** In an embodiment, the control apparatus 120 may be operated in an operator mode by an operator using, for example, a controller device such as a joystick. Based on the control input received, the control apparatus 120 determines automatically the dynamic thrust vector information for the thruster tug(s) 124 to tug the target vessel 121.

**[00110]** In an embodiment, the control apparatus 120 may be operated in an autonomous mode, wherein the control apparatus 120 operates the AVTS mode to autonomously control the target vessel 121 to follow and execute precise maneuvers along a "harbor track" 170.

**[00111]** The harbor track 170 includes all the necessary information to maneuver the target vessel 121 between the docked position and the high-speed route outside an approach zone 180 of the docking/undocking. If the environment or other constraints so require, the operator or the autonomous control system may choose between different harbor tracks 170. Fig. 4 provides a conceptual illustration of the target vessel 121 following a harbor track 170 to its docked position 171 tugged by the automated (or autonomous) vessel tugging system 122, 124.

**[00112]** The transit operation between ports, and the automated/autonomous tugging/docking/undocking operation, may be performed using separate modes. Alternatively, they may be combined as a single mode.

**[00113]** Automated thruster tug 124 control will involve switching control of the thruster tug 124 propulsion and steering to the AVTS mode and associated control mode controlled by the control apparatus 120. This may be accomplished through the use of a bridge installed switch within the pilot vessel 122, with one position dedicated to "AVTS" control of the associated thruster tugs 124. Use of a switch ensures that

control of thruster tugs 124 can always be restored to some alternative entity, e.g. another pilot vessel or remote-control center.

**[00114]** In an embodiment, the pilot vessel control apparatus 120 is configured to maintain the harbor track 170 data for a port of call and a berthing position within the port, wherein the harbor track data comprises: approach corridor data 190 defining bounds on maximum track position deviation allowed during harbor maneuvering; and the approach zone 180 information. The approach zone 180 information further comprises maximum lateral deviation for entering the approach zone 180, and the AVTS method further comprising: comparing the vessel location, speed and heading to the approach zone information and changing from the transit control mode to the autonomous tugging control mode in response to the vessel deviation is less than the maximum lateral deviation for entering the approach zone 180.

**[00115]** Furthermore, entry leg data may be determined in response to changing to the autonomous tugging control mode, wherein the entry leg data is configured to guide the target marine vessel 121 onto a harbor track 170 defined by the harbor track data. In the transit control mode, the target marine vessel 121 is configured to be at least partially in manual control mode.

**[00116]** Alignment of the target marine vessel 121 may be determined in view of a harbor track 170 using the harbor track data and sail direction determined based on the determined alignment.

**[00117]** In the present description, by target vessel 121 are meant any kinds of waterborne vessels, typically marine vessels. Most typically the target vessel is a ferry, a cargo ship or large cruise vessel, but the present disclosure is also applicable for yachts, for example.

**[00118]** The control apparatus 120 is configured to be connectable to a public network 150, such as Internet, directly via local connection or via a wireless communication network 140 over a wireless connection 122. The wireless connection 122 may comprise a mobile cellular network, a satellite network or a wireless local area network (WLAN), for example. The wireless communication network 140 may be connected to a public data communication network 150, for example the Internet, over a data connection 141. The apparatus 120 may be configured to be connectable

to the public data communication network 150, for example the Internet, directly over a data connection that may comprise a fixed or wireless mobile broadband access. The wireless communication network 140 may be connected to a server apparatus 130 of the system 100, over a data connection. The apparatus 120 may also be  
5 configured to be connectable to a non-public data communication network 150, such as a private Wi-Fi network or a private mesh network, for example. The non-public data communication network 150 in such case is not open to other users and does not have an Internet connection.

**[00119]** In an embodiment, a pilot vessel apparatus 120 may set up local  
10 connections within the pilot vessel 122 with at least one capturing device and a computer device. The capturing device, such as a sensor, may be integrated to the apparatus 120 or the pilot vessel 122, attached to the hull of the pilot vessel 122 and connected to the vessel control system or arranged as separate sensor device and connectable to the network 150 over separate connection.

**[00120]** In an embodiment, the pilot vessel apparatus 120 may set up local  
15 connections within the thruster tug(s) 124 that comprises at least one capturing device and a computer device (e.g. DP controller). The capturing device, such as a sensor, may be integrated to the computer device or to the thruster tug 124, attached to the hull of the thruster tug 124 and connected to the thruster tug 124 control  
20 system or arranged as separate sensor device and connectable to the pilot vessel 122 over separate connection.

**[00121]** The apparatus 120 and its client application may allow the apparatus 120 to log into a vessel data service run on a server 130, for example.

**[00122]** In an embodiment, real-time interaction may be provided between the  
25 apparatus 120 and the server 130 to collaborate for AVTS related data over a network 150. Real-time interaction may also be provided between the apparatus 120 and the remote user device 160 to collaborate for any vessel 121, 122, 124 related data, thruster vector related data, environmental data etc. over a network 150, 161.

**[00123]** A sensor data item is generated by a sensor device of the pilot vessel 122  
30 or at least one thruster tug 124. Sensor data items may also be transmitted to the

server 130. Sensor data items may be processed at the apparatus 120 before transmitting or they may be sent without further processing.

**[00124]** Sensor data may also be stored within the apparatus 120 before transmission over the network 150. Then again, transmitted sensor data may be stored/and or processed at the server apparatus 130 or at the remote user device 160.

**[00125]** The apparatus 120 may be connected to a plurality of different capturing devices and instruments and the apparatus 120 may be configured to select which sensor devices is actively collaborated with.

**[00126]** A user/operator of the apparatus 120 or the remote user device 160 may need to be logged in with user credentials to a chosen service of the network server 130.

**[00127]** In an embodiment, the system 100 comprises a sensor device configured to be comprised by or connectable to the apparatus 120 over a local connection. The local connection may comprise a wired connection or a wireless connection. The wired interface may comprise such as universal serial bus (USB) or National Marine Electronics Association (NMEA) 0183/2000 standard for example. The wireless connection may comprise acoustic connection, Bluetooth™, Radio Frequency Identification (RF-ID) or wireless local area network (WLAN), for example. Near field communication (NFC) may also be used for sensor device identification between the sensor device and the apparatus 120, for example.

**[00128]** In an embodiment, the system 100 may comprise a server apparatus 130, which comprises a storage device 131 for storing service data, service metrics and subscriber information, over data connection 151. The service data may comprise AVTS related data, waypoint properties related data, target vessel related data, target pilot vessel related data, thruster tug related data, thruster vector related data, environmental data, configuration data; account creation data; sensor data; sensor ID's; reference data items, user input data; real-time collaboration data; predefined settings; and attribute data, for example.

[00129] In an embodiment, a proprietary application in the apparatus 120 may be a client application of a service whose server application is running on the server apparatus 130 of the system 100.

[00130] The proprietary application of the apparatus 120 may receive sensor input data and provide the output data. The input data may comprise data captured by the capturing device, such as a sensor device or a camera.

[00131] In an embodiment, configuration information or application download information for any apparatus may be automatically downloaded and configured by the server 130. Thus, the user of the devices may not need to do any initialization or configuration for the service. The system server 130 may also take care of account creation process for the service, such sensor devices, apparatuses and users. Timing of the download may also be configured to be automatic and optimized in view of the vessel travel plan. For example, download may be automatically taking place when the pilot vessel 122 is docked at harbor.

[00132] In an embodiment, the association of the devices can be one-time or stored persistently on any of the devices or the server 130.

[00133] In an embodiment, authentication of a sensor device or apparatus 120 on a system server 130 may utilize hardware or SIM credentials, such as International Mobile Equipment Identity (IMEI) or International Mobile Subscriber Identity (IMSI).

The sensor device or apparatus 120 may transmit authentication information comprising IMEI and/or IMSI, for example, to the system server 130. The system server 130 authenticates the device by comparing the received authentication information to authentication information of registered users / devices / vessels / apparatuses stored at the system server database 131, for example. Such authentication information may be used for pairing the devices and/or apparatuses to generate association between them for a vessel data connection.

[00134] In an embodiment, a service web application may be used for configuration of a system. The service web application may be run on any user device, admin device, or a remote-control device 160, such as a personal computer connected to a public data network, such as Internet 150, for example. The control apparatus 160 may also be connected locally to the apparatus 120 over a local connection 123 and

may utilize the network connections of the apparatus 120 for configuration purposes. The service web application of the control apparatus may provide searching/adding instruments, determining attributes, device setup and configuration, for example. The service web application of the control apparatus 160 may be a general configuration tool for tasks being too complex to be performed on the user interface of the apparatus 120, for example.

**[00135]** In an embodiment, a remote-control apparatus 160 may be authenticated and configuration data sent from the control apparatus 160 to the system server 130, 131, wherein configuration settings may be modified based on the received data. In an embodiment, the modified settings may then be sent to the apparatus 120 over the network 150 and the local connection or the wireless operator. The modified settings may also be sent to external devices correspondingly, through the apparatus 120 or directly over the network 150, for example.

**[00136]** In an embodiment, the sensor device may be wireless or wired.

**[00137]** The system 100 may also comprise a plurality of satellites 110 in orbit about the Earth. The orbit of each satellite 110 is not necessarily synchronous with the orbits of other satellites and, in fact, is likely asynchronous. A global positioning system receiver apparatus such as the ones described in connection with preferred embodiments of the present invention is shown receiving spread spectrum Global Navigation Satellite System global positioning system (GNSS) satellite signals 112 from the various satellites 110.

**[00138]** The remote-control apparatus 160 may be configured to be operated by a remote operator of the vessel 121. The remote-control apparatus 160 may be arranged on a ground station, on the vessel 121 or on another vessel, for example.

**[00139]** In an embodiment, starting automated operations may comprise engaging the AVTS followed by activating the "AVTS" on the Multi-Function Display (MFD), which will transition the control apparatus 120 to the AVTS mode. It is required that the AVTS system associating the pilot vessel 122 and the thruster tug(s) 124 is configured correctly prior to activating "AVTS", else the AVTS will not transition into the AVTS mode.

**[00140]** In an embodiment, the pilot vessel apparatus 120 is configured to determine a dynamic setpoint based on the waypoint properties, wherein the dynamic setpoint comprising a setpoint position, a setpoint speed and a setpoint heading that change based on the harbor track data. Furthermore, difference information may be determined between the dynamic setpoint and the determined vessel location using a closed loop controller, a force vector determined based on the difference information; and thruster commands of the autonomous tugging control mode controlled based on the force vector.

**[00141]** In an embodiment, the target vessel heading may be aligned to the setpoint heading and the target vessel speed to the setpoint speed, wherein the setpoint heading and the setpoint speed are configurable parameters.

**[00142]** Furthermore, the setpoint heading and the setpoint speed between waypoints and respective setpoint values may be interpolated based on the target vessel's 121 location on the track segment, and the target vessel 121 heading aligned to the interpolated setpoint heading and the target vessel 121 speed to the interpolated setpoint speed. Interpolating may be enabled based on a waypoint property of the waypoint to which the target vessel 121 is heading.

**[00143]** The Automated Vessel Tugging System (AVTS) may contain a pre-planned Harbor track 170 for each port of call, and each berthing position 171 within the port, which can be followed from the harbor entry zone 180 to the berth 171 for the purposes of auto-tugging. This track 170 may include an approach corridor 190 which sets bounds on the maximum track position deviation allowed during harbor maneuvering and includes an entry zone 180 that is used when transitioning into the tugging phase involving automated tugging or autonomous tugging. Harbor track 170 data is stored within the pilot vessel apparatus 120 for operation of the AVTS and comprises all necessary data for AVTS, such as data relating to the Harbor track 170, the berthing position 171, the waypoints 181-188, the harbor entry zone 180, and the approach corridor 190, for example.

**[00144]** There are some scenarios that must be considered. One scenario covers the case that the target vessel 121 is transitioning from an autonomous transit to the tugging phase, and a second scenario covers the case that the target vessel 121 is in

manual mode (operator performed a manual transit using the conning) and is transitioning to the (automated or autonomous) tugging phase. For both cases the target vessel 121 must be positioned within the approach zone 180, and must meet required pre-requisite conditions, to be permitted to transition into the tugging phase.

5   **[00145]** The pre-requisite conditions for transition to the tugging phase may comprise, for example:

a. Target vessel speed must be less than the maximum specified by the approach corridor waypoints 181-188

10   b. Heading deviation must be less than the maximum specified by the approach corridor 190 waypoints 181-188

c. Lateral deviation must be less than the approach corridor 190 width

d. Heading and lateral deviations will be checked together. A larger heading deviation can be accepted if the target vessel 121 is steering towards the Harbor track 170 as opposed to steering away from the track 170.

15   **[00146]** Once the target vessel 121 is positioned within the Approach zone 180, and meets the pre-requisite conditions (see above), an "entry leg" may be automatically calculated which is used by the AVTS to autonomously tug the vessel 121 onto the Harbor track 170. At this point the Docking phase has started and the AVTS will proceed to maneuver the target vessel 121 to the dock 171 using the pre-programmed speed and steps specified in the Harbor track 170 data.

20   **[00147]** During the initial approach, the pilot vessel apparatus 120 may use GNSS 110 for positioning. Once the target vessel 121 reaches the proximity of the specified berth 171, the system may automatically start tracking the target vessel's 121 position and heading relative to the berth 171. During the final approach, the pilot vessel apparatus 120 may use relative positioning (docking sensor) to allow greater precision during docking. The transition between absolute and relative positioning may be automatically handled in a bump less fashion by the AVTS.

25   **[00148]** The end of the Docking phase is reached when the target vessel 121 has reached the final waypoint 188, is berthed at position 171 and ready to lower the loading ramp, for example. The behavior at the endpoint 171 of the Harbor track 170 may be configurable in the final waypoint 188 properties from the following options,

for example: Hold Station (this is the same as station keeping), Transition to the Standby state (switch back to manual control), and Transition to the Docked state.

**[00149]** In all cases, except Hold Station, it may be necessary to transition out of the Docking phase (Sail state) prior to triggering any berth activities, such as lowering the loading ramp or gangway (for a cruise ship) or start of unloading operations (for a cargo vessel), as the target vessel 121 position should be secured prior to deploying such actions.

**[00150]** Separately there may be an option for the AVTS to save particular parameters which will be required during a subsequent Undocking phase (this primarily pertains to the "integrals" which form a dynamic component of the closed loop controller).

**[00151]** In an embodiment, to continue with autonomous operation while berthed, the AVTS can be configured to automatically use the thruster tug thrusters to hold the target vessel 121 against the dock 171 using information contained in the final waypoint 188 properties. In this case when the target vessel 121 has completed the Docking phase it will automatically transition to the Docked state and the thrusters will ramp up to push the vessel against the dock.

**[00152]** Undocking is basically the opposite procedure to Docking. For the target vessel 121 to enter the Undocking phase a new destination (and possibly track (associated with track data), if several are available) must be selected, the loading ramp must be up, and the operator must confirm that the target vessel 121 is clear to undock.

**[00153]** During the docking and undocking phases, the system may automatically follow and execute precise maneuvers along the Harbor track 170. The Harbor track 170 data includes all the necessary information to maneuver the target vessel 121 between the docked position 171 and the entry/exit zone 180.

**[00154]** Harbor tracks 170 may comprise straight line segments (legs) joined at waypoints 181-188 with independent predefined turning radii for the purpose of precision maneuvering inside the harbor and close to the berth 171. Due to the precise maneuvering requirements inside the harbor and close to the berth, the harbor track 170 will include a comprehensive set of waypoint properties, which will

not only help to tug the target vessel 121 but also control the behavior of the control system along the track 170. Table below lists some waypoint properties that may be used for the harbor track 170 purposes.

| Waypoint properties                          | Description                                                                                                                       |
|----------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------|
| Lat/Lon                                      | Absolute waypoint position                                                                                                        |
| Radius                                       | Waypoint Turning radius                                                                                                           |
| Corridor width                               | Allowed lateral distance centered over the waypoint in which the vessel can sail                                                  |
| Track setpoint speed                         | Target setpoint speed                                                                                                             |
| Track setpoint acceleration                  | Target setpoint acceleration                                                                                                      |
| Heading setpoint (along track, fixed)        | Target setpoint heading                                                                                                           |
| Heading setpoint ROT                         | Target setpoint Rate of Turn                                                                                                      |
| Advance turn                                 | Distance in meters prior to the waypoint upon which the heading change will be executed                                           |
| Track Direction (ahead, astern)              |                                                                                                                                   |
| COR                                          | Center of rotation –see yaw pivot point                                                                                           |
| Controller mode                              | To set the control strategy based on position along the track                                                                     |
| Controller gains                             | Controller gains in surge, sway, yaw, cross track                                                                                 |
| TAL mode                                     | To set the thruster allocation logic based on position along the track                                                            |
| Cross track alarm threshold                  | Alarm threshold for cross track position error                                                                                    |
| Alongship alarm threshold                    | Alarm threshold for along track position error                                                                                    |
| Heading alarm threshold                      | Alarm threshold for heading error                                                                                                 |
| Auto sensor select                           | To automatically enable sensors based on position along the track                                                                 |
| Max speed threshold (alongship/ athwartship) | Max speed allowed to engage the mode                                                                                              |
| Max Hdg deviation threshold                  | Maximum allowed heading deviation to engage the mode                                                                              |
| Thrust to dock                               | If enabled, and at the last waypoint on the track, the system will command thrust against the dock to keep the vessel in position |
| Freeze integral                              | If enabled, and at the last waypoint on the track, the controller integral will be frozen to prevent                              |

|                     |                                                                                                                                                                                                                                                                  |
|---------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
|                     | integral windup when in the docked position                                                                                                                                                                                                                      |
| Confirm to proceed  | If enabled, a confirmation dialog will be displayed for pre-defined time prior to the waypoint is reached. If not confirmed, the system will stop the vessel at the waypoint. Waypoint with this property set, will have a conspicuous appearance on the display |
| Interpolate speed   | If enabled, the speed setpoint will be interpolated between values of the From and To waypoints. If disabled, the speed setpoint will be set to the value of the From waypoints.                                                                                 |
| Interpolate heading | If enabled, the heading setpoint will be interpolated between the values of the From and To waypoints. If disabled, the speed setpoint will be set to the value of the From waypoints.                                                                           |

**[00155]** When following a Harbor track 170, a plurality of actions and parameters may be needed. Following features are exemplary only and not necessarily all features are needed.

- 5 **[00156]** The default setpoint speed may be pre-programmed into the Harbor track 170 data using a waypoint 181-188. The operator can override (reduce) the setpoint speed control scaled between 0 and 100%, for example.

**[00157]** In an embodiment, the operator can adjust the speed in increments of 0.5 knots, for example. The speed may be increased or decreased as long as it remains  
10 within the defined track limits.

**[00158]** While in AVTM mode, the operator can stop the target vessel 121 on the track at any time by activating a "Current Position" function. This will bring the target vessel 121 to a stop on the track 170 by following a specified deceleration profile. During the deceleration, the "Current Position" function may be indicated on user  
15 interface to indicate that deceleration is in progress. If the operator activates the "Current Position" function a second time while it is already in process, the setpoint will come to an immediate stop. Both actions described above may require operator confirmation to prevent inadvertent action. While the target vessel 121 is stopping, or stopped, a "Continue" function may be enabled. By activating the "Continue" function

it will continue to execute the maneuvering steps defined in the Harbor track 170 data.

**[00159]** While in AVTM mode, the operator can adjust the target vessel's 121 lateral position relative to the track 170, for example, by using "port" and "starboard" offset functions. Each time a function is activated, the lateral offset will be incremented in the direction of the activated function (e.g. touch based button or icon on touch display). The offsets may be numerically and graphically displayed on the user interface of the control apparatus 120. In addition, the offset track line may be displayed relative to the default track. The offset will be limited by the corridor 190 width of the Harbor track 170 at the position of the setpoint. If the operator tries to place the offset outside the corridor 190, a warning may be displayed. If the corridor 190 width is reduced as the target vessel 121 is moving along the track 170, the track offsets will be automatically reduced to keep the target vessel 121 safely inside the corridor 190. An offset reset function will be provided to allow the operator to remove offsets in a single step.

**[00160]** The target vessel 121 may follow the heading of the track 170 with the necessary heading adjustments to maintain zero cross track error.

**[00161]** During low speed tracking, the target vessel 121 may optionally be automatically tugged to its heading for a pre-programmed setpoint heading. This allows the target vessel 121 to perform crabbing maneuvers during the approach when tugged. Heading and speed setpoints are configurable waypoint 181-188 properties. Between waypoints 181-188, the speed and heading setpoints may be interpolated based on the target vessel's 121 location on the track 170. The interpolation option is configurable by a waypoint property of the waypoint 181-188 to which the target vessel 121 is heading.

**[00162]** The yaw pivot point is the point on the target vessel's 121 centerline which appears to be the center of rotation to an on-board observer. The lateral sway velocity at the point is by definition zero. This is important because that means that if the pivot point is used as the control point, sway control force is not needed to be used while turning. The location of a target vessel's 121 yaw pivot point may depend on the target vessel's turn rate and lateral velocity.

**[00163]** In an embodiment, prior to engaging automatic tugging, it is necessary to verify that all necessary thrusters are fully operational. Since thrusters may not have been in use for extended periods of time, a thruster ready indication may not be enough to guarantee the operation of the thruster. For this purpose, an automated thruster check function is used that automatically issues a command and verifies that the thruster of each associated thruster tug 124a-d is following as expected. Successful thruster checks immediately prior to engaging AVTM, can be included as a condition for system readiness.

**[00164]** In an embodiment, a control mode of the control apparatus 120 may be determined from track properties (track data) and vessel speed, for example. Difference information between the dynamic setpoint and the determined thruster tug 124a-d or target vessel 121 location may then be determined using a closed loop controller and a force vector determined based on the difference information. Thruster commands are determined from the control mode and the force vector.

**[00165]** Furthermore, external force information may be determined by the apparatus 120, the force vector may be then combined with the external force information, and the thruster commands determined based on the combination. At least one thruster of a thruster tug 124a-d may be controlled based on the thruster commands. The external force information may comprise e.g. wind information that is detected using a capturing device (e.g. wind sensor), for example.

**[00166]** Fig. 5 presents an example block diagram of a control apparatus 120 in which various embodiments of the invention may be applied. The control apparatus 120 is configured to operate for automated/autonomous tugging.

**[00167]** The general structure of the control apparatus 120 comprises a user interface 540, a communication interface 550, a satellite positioning device (GNSS) 570, a capturing device 560 for capturing current vessel activity data and current environmental data, a processor 510, and a memory 520 coupled to the processor 510. The control apparatus 120 further comprises software 530 stored in the memory 520 and operable to be loaded into and executed in the processor 510. The software 530 may comprise one or more software modules and can be in the form of a

computer program product. The control apparatus 120 may further comprise a user interface controller 580.

**[00168]** The processor 510 may be, e.g., a central processing unit (CPU), a microprocessor, a digital signal processor (DSP), a graphics processing unit, or the like. Fig. 5 shows one processor 510, but the apparatus 120 may comprise a plurality of processors.

**[00169]** The memory 520 may be for example a non-volatile or a volatile memory, such as a read-only memory (ROM), a programmable read-only memory (PROM), erasable programmable read-only memory (EPROM), a random-access memory (RAM), a flash memory, a data disk, an optical storage, a magnetic storage, a smart card, or the like. The apparatus 120 may comprise a plurality of memories. The memory 520 may be constructed as a part of the apparatus 120 or it may be inserted into a slot, port, or the like of the apparatus 120 by a user. The memory 520 may serve the sole purpose of storing data, or it may be constructed as a part of an apparatus serving other purposes, such as processing data. A proprietary automated/autonomous tugging application, track data, thruster tug related data, sensor data, target vessel related data or environmental data may be stored to the memory 520.

**[00170]** In an embodiment, the apparatus 120 is configured to perform a computer-implemented method for automated/autonomous marine vessel tugging, the method comprising determine at least following modes: a following mode, wherein a pilot vessel and at least one associated thruster tug are configured to be transferred to a target vessel, and the pilot vessel is configured to control the at least one associated thruster tug during the following mode; a keeping mode, wherein the pilot vessel and the at least one associated thruster tug are configured to be located at working area of the target vessel; a distributing mode, wherein the at least one associated thruster tug is configured to be transferred to an operating position relative to the target vessel, and the pilot vessel is configured to control the associated thruster tug during the distributing mode; and a maneuvering mode, wherein the pilot vessel is configured to control the at least one associated thruster tug based on a dynamic vessel model. The apparatus 120 is further configured to control transition between

the determined modes based on transition control information maintained at the control apparatus 120.

**[00171]** The user interface controller 580 or the user interface 540 may comprise circuitry for receiving input from a user of the control apparatus 120 (a pilot), e.g., via  
5 a keyboard, graphical user interface shown on the display of the user interfaces 540 of the control apparatus 120, speech recognition circuitry, or an accessory device, such as a headset, and for providing output to the user via, e.g., a graphical user interface or a loudspeaker.

**[00172]** The Global Navigation Satellite System (GNSS, such as GPS) device 570  
10 is configured to provide location information. Such information may comprise, for example, position coordinates, speed, direction of movement; and flute height information.

**[00173]** The communication interface module 550 implements at least part of data transmission. The communication interface module 550 may comprise, e.g., a  
15 wireless or a wired interface module. The wireless interface may comprise such as a WLAN, Bluetooth, infrared (IR), radio frequency identification (RF ID), GSM/GPRS, CDMA, WCDMA, LTE (Long Term Evolution) or 5G radio module. The wired interface may comprise such as universal serial bus (USB) or National Marine Electronics Association (NMEA) 0183/2000 standard for example. The communication interface  
20 module 550 may be integrated into the control apparatus 120, or into an adapter, card or the like that may be inserted into a suitable slot or port of the control apparatus 120. The communication interface module 550 may support one radio interface technology or a plurality of technologies. The control apparatus 120 may comprise a plurality of communication interface modules 550.

**[00174]** A skilled person appreciates that in addition to the elements shown in Fig.  
25 5, the control apparatus 120 may comprise other elements, such as microphones, extra displays, as well as additional circuitry such as input/output (I/O) circuitry, memory chips, application-specific integrated circuits (ASIC), processing circuitry for specific purposes such as source coding/decoding circuitry, channel coding/decoding  
30 circuitry, ciphering/deciphering circuitry, and the like. Additionally, the control

apparatus 120 may comprise a disposable or rechargeable battery (not shown) for powering when external power if external power supply is not available.

**[00175]** In an embodiment, the control apparatus 120 comprises speech recognition means. Using these means, a pre-defined phrase may be recognized  
5 from the speech and translated into control information for the apparatus 120, for example.

**[00176]** The satellite positioning device 570 and the capturing device 560 may be configured to be comprised by the control apparatus 120 or connected as separate devices to the apparatus 120. In case the satellite positioning device 570 and the  
10 capturing device 560 are comprised in the apparatus 120 they may be connected to the apparatus 120 using an internal bus of the apparatus 120. In case the satellite positioning device 570 and the capturing device 560 are external devices connected to the apparatus 120 they may be connected to the apparatus 120 using communication interface 550 of the apparatus 120 or using a connection to the  
15 internal bus.

**[00177]** In an embodiment, the capturing device 560 may comprise a global navigation satellite system (GNSS) position sensor, position reference sensor for pulsed laser device, and a docking sensor. The control apparatus 120 may be configured to select between different sensors depending on the tugging mode  
20 currently active. The capturing device 560 may comprise at least one sensor, wherein the at least one sensor is configured to provide position related data or environment related data. The at least one sensor may comprise at least one of the following: a position reference sensor; a global navigation satellite system (GNSS) position sensor; a docking sensor for providing relative positioning information relative to a  
25 berth; a gyro compass sensor for providing heading information; a motion reference unit (MRU) sensor for providing pitch and information; and a wind sensor for providing wind speed and direction information.

**[00178]** In an embodiment, a Dynamic Positioning (DP) controller 220-223 (see Fig. 1) may comprise similar entities as illustrated for control apparatus 120. Some  
30 entities may be optional for thruster tug 124a-d DP controller, such as user interface controller 580 and user interface 540, for example.

**[00179]** Fig. 6 presents an example block diagram of a capturing device 560 (see Fig. 5), such as a sensor or a sensor device, in which various embodiments of the invention may be applied. The capturing device 560 may comprise various means for activity data detection and environmental data detection, for example. The capturing device 560 may be used for both reference data and current data capturing. The capturing device 560 may be arranged to the at least one associated thruster tug 124a-d, the pilot vessel 122, or the target vessel 121, for example.

**[00180]** In an embodiment, the capturing device 560 may comprise at least one of the following devices:

- 10 - a photodetector for detecting laser light reflected by a retro-reflective target
- an anemometer for providing wind information;
- a wind sensor for providing wind information;
- a sensor for providing flute height information;
- a barometer for measuring air pressure;
- 15 - a temperature sensor for measuring environmental temperature;
- a water depth sensor for measuring depth information;
- a chart plotter for providing position information;
- a sail sensor for providing sail information;
- a speed sensor for providing speed information;
- 20 - a video camera for providing a video signal;
- a gyro compass for providing direction information;
- GNSS device, i.e. absolute position sensor based on satellite navigation (GLONASS, GPS, GALILEO); and
- a motion reference unit (MRU) sensor, i.e. pitch and roll sensor.

25 **[00181]** In an embodiment, the control apparatus 120 or the DP controller 220-223 may include a suite of sensors 560 that will provide position and environment data to support the controller operation. GNSS sensor comprises as absolute position sensor based on satellite navigation (GLONASS, GPS, GALILEO) that provides the current measured position of the vessel 124a-d, 122, 121 on the earth's surface. The GNSS system that may be used, for example, is Fugro OceanStar™ 3 that offers decimeter accuracy for position measurements with a combination of three GNSS receivers.

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Data is also available from individual receivers as a backup position measurement method, though with less available accuracy. Gyro Compass comprises an absolute heading sensor that provides the measured offset of the vessel from true north. The motion reference unit (MRU) sensor comprises a pitch and roll sensor that provides measured offset from the vertical for pitch and roll. The GNSS system may include its own captive motion reference unit (MRU). This may be required to increase accuracy of the GNSS since the GNSS antenna can swing through a large arc during pitch and roll. Mathematical calculation can be used to normalize the measurement to the vertical based on the pitch and roll measurement.

10 **[00182]** The capturing device 560 may also comprise several capturing devices 560, combinations of any above-mentioned devices, and the like. The environmental temperature may comprise air temperature, water temperature or ground surface temperature, for example.

**[00183]** In an embodiment, a wind sensor 560 is configured to determine or measure wind angle and wind speed. The wind sensor 560 may comprise any element of combination of elements operable to sense wind-related information for use by the control apparatus 120. For example, the wind sensor 560 may be operable to sense apparent wind speed, apparent wind angle, true wind speed, true wind angle, wind velocity made good (VMG), combinations thereof, and the like.

20 **[00184]** In an embodiment, a video camera 560 is configured to provide video signal. Based on the video signal the control apparatus 120 may determine at least part of the environmental data or object information around the target vessel 121. For example, flute height may be determined based on the video signal from the video camera 560. The determination may be done by video image processing, pattern recognition, measuring a rocking movement or relative movement of a horizon, for example.

**[00185]** The capturing device 560 may comprise communication interface module implementing at least part of data transmission. The communication interface module may comprise, e.g., a wireless or a wired interface module. The wireless interface may comprise such as a WLAN, Bluetooth, infrared (IR), radio frequency identification (RF ID), GSM/GPRS, CDMA, WCDMA, LTE (Long Term Evolution) or 5G radio

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module. The wired interface may comprise such as universal serial bus (USB) or National Marine Electronics Association (NMEA) 0183/2000 standard for example. The communication interface module may be integrated into the capturing device 560, or into an adapter, card or the like that may be inserted into a suitable slot or port of the capturing device 560. The communication interface module may support one radio interface technology or a plurality of technologies. The capturing device 560 may comprise a plurality of communication interface modules.

**[00186]** Fig. 7 presents an example block diagram of a server apparatus 130 in which various embodiments of the invention may be applied.

10 **[00187]** The general structure of the server apparatus 130 comprises a processor 710, and a memory 720 coupled to the processor 710. The server apparatus 130 further comprises software 730 stored in the memory 720 and operable to be loaded into and executed in the processor 710. The software 730 may comprise one or more software modules and can be in the form of a computer program product.

15 **[00188]** The processor 710 may be, e.g., a central processing unit (CPU), a microprocessor, a digital signal processor (DSP), a graphics processing unit, or the like. Fig. 7 shows one processor 710, but the server apparatus 130 may comprise a plurality of processors.

**[00189]** The memory 720 may be for example a non-volatile or a volatile memory, such as a read-only memory (ROM), a programmable read-only memory (PROM), erasable programmable read-only memory (EPROM), a random-access memory (RAM), a flash memory, a data disk, an optical storage, a magnetic storage, a smart card, or the like. The server apparatus 130 may comprise a plurality of memories. The memory 720 may be constructed as a part of the server apparatus 130 or it may be inserted into a slot, port, or the like of the server apparatus 130 by a user. The memory 720 may serve the sole purpose of storing data, or it may be constructed as a part of an apparatus serving other purposes, such as processing data.

25 **[00190]** The communication interface module 750 implements at least part of radio transmission. The communication interface module 750 may comprise, e.g., a wireless or a wired interface module. The wireless interface may comprise such as a WLAN, Bluetooth, infrared (IR), radio frequency identification (RF ID), GSM/GPRS,

CDMA, WCDMA, LTE (Long Term Evolution) or 5G radio module. The wired interface may comprise such as universal serial bus (USB) or National Marine Electronics Association (NMEA) 0183/2000 standard for example. The communication interface module 750 may be integrated into the server apparatus 130, or into an adapter, card or the like that may be inserted into a suitable slot or port of the server apparatus 130. The communication interface module 750 may support one radio interface technology or a plurality of technologies. Captured automated/autonomous docking related data, track data, vessel activity data associated or environmental data of the control apparatus 120 may be received by the server apparatus 130 using the communication interface 750. Data may be stored for backup or processed and provided to a control apparatus. The data may be utilized for AVTS of another target vessel, for example.

**[00191]** The e-mail server process 760, which receives e-mail messages sent from control apparatuses 120 and computer apparatuses 160 via the network 150. The server 760 may comprise a content analyzer module 761, which checks if the content of the received message meets the criteria that are set for new activity data item of the service. The content analyzer module 761 may for example check whether the e-mail message contains a valid vessel activity data item to be used as reference data item in further automated/autonomous vessel tugging processing, for example. The valid reference data item received by the e-mail server is then sent to an application server 740, which provides application services e.g. relating to the user accounts stored in a user database 770 and content of the content management service. Content provided by the service system 100 is stored in a content database 780.

**[00192]** A skilled person appreciates that in addition to the elements shown in Fig. 7, the server apparatus 130 may comprise other elements, such as microphones, displays, as well as additional circuitry such as input/output (I/O) circuitry, memory chips, application-specific integrated circuits (ASIC), processing circuitry for specific purposes such as source coding/decoding circuitry, channel coding/decoding circuitry, ciphering/deciphering circuitry, and the like.

**[00193]** Fig. 8 presents an example block diagram of a computer apparatus 160 in which various embodiments of the invention may be applied. The computer apparatus

160 may be a user equipment (UE), user device or apparatus, such as a mobile terminal, a smart phone, a laptop computer, a desktop computer or other communication device.

**[00194]** The general structure of the computer apparatus 160 comprises a user interface 840, a communication interface 850, a processor 810, and a memory 820 coupled to the processor 810. The computer apparatus 160 further comprises software 830 stored in the memory 820 and operable to be loaded into and executed in the processor 810. The software 830 may comprise one or more software modules and can be in the form of a computer program product. The computer apparatus 160 may further comprise a user interface controller 860.

**[00195]** The processor 810 may be, e.g., a central processing unit (CPU), a microprocessor, a digital signal processor (DSP), a graphics processing unit, or the like. Fig. 8 shows one processor 810, but the computer apparatus 160 may comprise a plurality of processors. Corresponding elements of the apparatus 160 is discussed in relation to control apparatus 120.

**[00196]** Fig. 9 shows a flow diagram showing operations in accordance with an example embodiment of the invention. In step 900, computer-implemented method for automated marine vessel tugging is started.

**[00197]** In step 910, at least following tugging modes are determined: a following mode, wherein a pilot vessel and at least one associated thruster tug are configured to be transferred to a target vessel, and the pilot vessel is configured to control the at least one associated thruster tug during the following mode; a keeping mode, wherein the pilot vessel and the at least one associated thruster tug are configured to be located at working area of the target vessel; a distributing mode, wherein the at least one associated thruster tug is configured to be transferred to an operating position relative to the target vessel, and the pilot vessel is configured to control the associated thruster tug during the distributing mode; and a maneuvering mode, wherein the pilot vessel is configured to control the at least one associated thruster tug based on a dynamic vessel model.

**[00198]** In step 920, transition between the determined modes is controlled based on transition control information maintained at control apparatus of the pilot vessel.

[00199] The method is ended in step 930.

[00200] In an embodiment, the thruster tugs 124a-d may comprise a plurality of thrusters. The effectiveness of a thruster is curtailed by any forward motion due to the Coandă effect. Most tunnel thrusters are driven by electric motors, but some are  
5 hydraulically powered.

[00201] Fig. 10 shows a schematic picture of a closed loop controller block diagram 1000 according to an example embodiment of the invention.

[00202] A control processor of a pilot vessel control apparatus 120 may comprise a closed loop controller 1010 with interfaces and inputs needed to control the  
10 automated/autonomous vessel tugging. The control apparatus 120 of the pilot vessel may comprise a rack of IO 1020 that is used to interface with thrusters on the thruster tugs 124a-d, position and heading sensor data 1030, position and heading setpoint information 1040 and environmental data 1050, for example.

[00203] The control processor comprises the closed loop controller 1010 that  
15 works in tandem with a sensor processing module 1060 and a Thruster Allocation Logic (TAL) module 1070. In simple terms the closed loop controller 1010 is used to maintain the target vessel over position and heading setpoints based on position and heading setpoint information 1040 that may be pre-programmed and accessible in relation to waypoints of harbor track information. For station keeping the setpoint  
20 would consist of a fixed location and bearing, however for transit and docking operations the setpoint consists of a position and heading that is constantly changing as it is moved along a track between a series of waypoints. As the setpoint is moved, the closed loop controller 1010 will calculate the difference between the setpoint 1040 and actual target vessel position and will use this to calculate thruster tug force  
25 vectors required to close the distance between the two positions. The actual target vessel position is calculated based on position and heading sensor data 1030, processed by the sensor processing module 1060 to provide position estimate that is filtered by a Kalman filter module 1080 to provide the position and heading estimate to be compared with the setpoint 1040. A force vector may be determined by a  
30 proportional–integral–derivative controller (PID controller or three term controller) 1090 that is translated into actual thruster commands (after subtracting environmental

data 1050, such as external forces like wind) by a Thruster Allocation Logic (TAL) 1070, and the IO rack 1020 is then used to communicate these commands to each thruster. The position and heading sensor data 1030 may be received from a plurality of sources, such as from the target vessel position and heading sensor system, from the thruster tug position and heading sensor system, or any combination of them. Any position and heading sensor system data that may be used for determining position and heading information of the target vessel may be used.

**[00204]** Various embodiments have been presented. It should be appreciated that in this document, words comprise, include and contain are each used as open-ended expressions with no intended exclusivity. If desired, the different functions discussed herein may be performed in a different order and/or concurrently with each other. Furthermore, if desired, one or more of the above-described functions may be optional or may be combined. Although various aspects of the invention are set out in the independent claims, other aspects of the invention comprise other combinations of features from the described embodiments and/or the dependent claims with the features of the independent claims, and not solely the combinations explicitly set out in the claims.

**[00205]** Without in any way limiting the scope, interpretation, or application of the claims appearing below, a technical effect of one or more of the example embodiments disclosed herein is improved method and apparatus for automated marine vessel tugging. Another technical effect of one or more of the example embodiments disclosed herein is improved method and apparatus for automated/autonomous marine vessel tugging.

**[00206]** Another technical effect of one or more of the example embodiments disclosed herein is that it enables performing the tugging maneuver automatically in the safest and most efficient way possible. The procedure means that as the target vessel approaches the dock, the pilot vessel control apparatus is programmed with all the relevant variables, such as wind speed, weight, pitch, roll, water depth and current. This data enables it to perform the tugging maneuver automatically in the safest and most efficient way possible. The pilot may control tugging using a control

device, such as joystick. Optionally, while the pilot may have oversight, the steering may be principally handled by software in autonomous mode.

**[00207]** Another technical effect of one or more of the example embodiments disclosed herein is that safety is improved since there is less likelihood of human error; less wear and tear since the thrusters are efficiently utilized; and greater efficiency in tugging which allows more time at berth.

**[00208]** Although various aspects of the invention are set out in the independent claims, other aspects of the invention comprise other combinations of features from the described embodiments and/or the dependent claims with the features of the independent claims, and not solely the combinations explicitly set out in the claims.

**[00209]** It is also noted herein that while the foregoing describes example embodiments of the invention, these descriptions should not be viewed in a limiting sense. Rather, there are several variations and modifications, which may be made without departing from the scope of the present invention as defined in the appended claims.

**CLAIMS**

1. Computer-implemented method for automated marine vessel tugging, the method comprising:

5 determining at least following modes:

a following mode, wherein a pilot vessel and at least one associated thruster tug are configured to be transferred to a target vessel, and the pilot vessel is configured to control the at least one associated thruster tug during the following mode;

10 a keeping mode, wherein the pilot vessel and the at least one associated thruster tug are configured to be located at working area of the target vessel;

a distributing mode, wherein the at least one associated thruster tug is configured to be transferred to an operating position relative to the target vessel, and the pilot vessel is configured to control the associated thruster tug during  
15 the distributing mode; and

a maneuvering mode, wherein control apparatus of the pilot vessel is configured to control the at least one associated thruster tug based on a dynamic vessel model by transmitting thrust vector information to control apparatus of the at least one associated thruster tug; and

20 controlling transition between the determined modes based on transition control information maintained at the control apparatus of the pilot vessel.

2. The method of claim 1, further comprising:

generating the dynamic vessel model using target vessel information and  
25 thruster tug information.

3. The method of claim 2, wherein

the target vessel information comprises at least one of the following:

target vessel dimension information;

30 target vessel mass information;

target vessel position information; and

the thruster tug information comprises at least one of the following:

- thruster tug position information; and
- thruster tug environmental information.

5     4.     The method of claim 3, wherein the thruster tug position information is determined using a Global Navigation Satellite System (GNSS) receiver.

5.     The method of claim 2 or 3, further comprising:  
determining relative position information of at least two associated thruster tugs.

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6.     The method of claim 5, wherein the relative position information is determined using a position reference sensor comprising an optical assembly, a radar assembly or a differential relative positioning sensor assembly.

15     7.     The method of claim 6, wherein the position reference sensor comprises a pulsed laser device for emitting laser light; a lens arrangement comprising a lenticular lens for producing a vertically fanned beam of the laser light emitted by the pulsed laser device; and a plurality of photodiode photodetectors for detecting laser light reflected by a retro-reflective target, the level of reflected laser light incident upon  
20 each photodetector being individually detectable; the position reference sensor further comprising an actuator for varying the inclination of the optical assembly, the actuator being automatically controllable based on the level of reflected laser light incident upon each photodetector.

25     8.     The method of claim 7, wherein at least two associated thruster tugs comprise retro-reflective targets.

9.     The method of any claim 5 to 8, wherein the relative position information comprises at least one of the following: range and bearing information.

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10. The method of any claim 5 to 9, wherein the relative position information is configured to be determined by calibrating at least two associated thruster tugs against the pilot vessel.

5 11. The method of any claim 1 to 10, wherein the dynamic vessel model comprises position information for each associated thruster tug.

12. The method of any claim 1 to 11, further comprising:  
receiving pilot input information;

10 determining thrust vector information based on the pilot input information and the dynamic vessel model; and

controlling the at least one associated thruster tug based on the thrust vector information.

15 13. The method of claim 12, wherein the pilot input information is configured to be provided by a user operable control device arranged on the pilot vessel.

14. The method of any claim 1 to 13, wherein the control apparatus of the pilot vessel comprises a Dynamic Positioning (DP) controller.

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15. The method of any claim 1 to 14, wherein the control apparatus of the at least one associated thruster tug comprises a Dynamic Positioning (DP) controller.

16. The method of any claim 1 to 15, further comprising:

25 determining a transit control mode associated with route plan data defining transit operation between ports;

determining an autonomous tugging control mode associated with harbor track data comprising a set of waypoint properties and defining approach zone information and track segments joined at waypoints, wherein the approach zone information  
30 comprises:

location area information for the approach zone;

maximum vessel speed for entering the approach zone; and  
maximum heading deviation for entering the approach zone;  
determining target vessel location, speed and heading;  
comparing the target vessel location, speed and heading to the approach zone  
5 information and changing from the transit control mode to the autonomous tugging  
control mode in response to:  
the target vessel location comprised by the location area information;  
the target vessel speed being lower than the maximum target vessel speed  
for entering the approach zone; and  
10 the target vessel heading matching criteria defined by the maximum  
heading deviation for entering the approach zone.

17. The method of claim 16, further comprising:

determining a dynamic setpoint based on the waypoint properties, wherein the  
15 dynamic setpoint comprising a setpoint position, a setpoint speed and a setpoint  
heading that change based on the harbor track data.

18. The method of claim 17, further comprising:

determining difference information between the dynamic setpoint and the  
20 determined target vessel location using a closed loop controller;  
determining a force vector based on the difference information; and  
controlling thruster commands of the autonomous tugging control mode based  
on the force vector.

25 19. The method of claim 17 or 18, further comprising:

aligning the target vessel heading to the setpoint heading and the target vessel  
speed to the setpoint speed, wherein the setpoint heading and the setpoint speed are  
configurable parameters.

30 20. The method of any claim 17 to 19, further comprising:

interpolating the setpoint heading and the setpoint speed between waypoints and respective setpoint values based on the target vessel's location on the track segment; and

aligning the target vessel heading to the interpolated setpoint heading and the target vessel speed to the interpolated setpoint speed.

21. The method of claim 20, wherein interpolating is enabled based on a waypoint property of the waypoint to which the target vessel is heading.

22. The method of any claim 18, further comprising:

controlling thruster commands of the at least one associated thruster tug based on the dynamic vessel model by activating full scale three axis position and heading control by allocating full scale thrust to at least one thruster of the at least one associated thruster tug, when the target vessel speed being less than a lower speed threshold.

23. The method of claim 22, further comprising:

controlling thruster commands of at least one thruster of the at least one associated thruster tug based on the dynamic vessel model by activating partial scale three axis position and heading control by allocating partial scale thrust to the at least one thruster of the at least one associated thruster tug, when the target vessel speed being between the lower and higher speed threshold.

24. The method of any claim 16 to 23, further comprising:

maintaining the harbor track data for a port of call and a berthing position within the port, wherein the harbor track data comprises:

approach corridor data defining bounds on maximum track position deviation allowed during harbor maneuvering; and

the approach zone information.

25. The method of claim 16, wherein the approach zone information further comprises maximum lateral deviation for entering the approach zone, and the method further comprising:

5 comparing the target vessel location, speed and heading to the approach zone information and changing from the transit control mode to the autonomous tugging control mode in response to:

the target vessel deviation is less than the maximum lateral deviation for entering the approach zone.

10 26. The method of claim 25, further comprising:

determining entry leg data in response to changing to the autonomous tugging control mode, wherein the entry leg data is configured to guide the target vessel onto a harbor track defined by the harbor track data.

15 27. The method of any claim 16 to 26, wherein in the transit control mode the target vessel is configured to be at least partially in manual control mode.

28. A marine vessel apparatus for automated tugging, comprising:

a communication interface for transceiving data;

20 at least one processor; and

at least one memory including computer program code;

the at least one memory and the computer program code configured to, with the at least one processor, cause the apparatus to:

determine at least following modes:

25 a following mode, wherein a pilot vessel and at least one associated thruster tug are configured to be transferred to a target vessel, and the pilot vessel is configured to control the at least one associated thruster tug during the following mode;

30 a keeping mode, wherein the pilot vessel and the at least one associated thruster tug are configured to be located at working area of the target vessel;

a distributing mode, wherein the at least one associated thruster tug is configured to be transferred to an operating position relative to the target vessel, and the pilot vessel is configured to control the associated thruster tug during the distributing mode; and

5 a maneuvering mode, wherein control apparatus of the pilot vessel is configured to control the at least one associated thruster tug based on a dynamic vessel model by transmitting thrust vector information to control apparatus of the at least one associated thruster tug; and; and

control transition between the determined modes based on transition control  
10 information maintained at the control apparatus of the pilot vessel.

29. The apparatus of claim 28, further comprising at least one sensor, wherein the at least one sensor is configured to provide position related data or environment related data.

15 30. The apparatus of claim 29, wherein the at least one sensor comprises at least one of the following:

a position reference sensor;

a global navigation satellite system (GNSS) position sensor;

20 a docking sensor for providing relative positioning information relative to a berth;

a gyro compass sensor for providing heading information;

a motion reference unit (MRU) sensor for providing pitch and information; and

a wind sensor for providing wind speed and direction information.

25 31. The apparatus of claim 30, wherein the position reference sensor comprises a pulsed laser device for emitting laser light; a lens arrangement comprising a lenticular lens for producing a vertically fanned beam of the laser light emitted by the pulsed laser device; and a plurality of photodiode photodetectors for detecting laser light reflected by a retro-reflective target, the level of reflected laser light incident upon  
30 each photodetector being individually detectable; the position reference sensor further comprising an actuator for varying the inclination of the optical assembly, the

actuator being automatically controllable based on the level of reflected laser light incident upon each photodetector.

32. A computer program embodied on a computer readable medium comprising  
5 computer executable program code, which code, when executed by at least one processor of an apparatus, causes the apparatus to:

determine at least following modes:

10 a following mode, wherein a pilot vessel and at least one associated thruster tug are configured to be transferred to a target vessel, and the pilot vessel is configured to control the at least one associated thruster tug during the following mode;

a keeping mode, wherein the pilot vessel and the at least one associated thruster tug are configured to be located at working area of the target vessel;

15 a distributing mode, wherein the at least one associated thruster tug is configured to be transferred to an operating position relative to the target vessel, and the pilot vessel is configured to control the associated thruster tug during the distributing mode; and

20 a maneuvering mode, wherein control apparatus of the pilot vessel is configured to control the at least one associated thruster tug based on a dynamic vessel model by transmitting thrust vector information to control apparatus of the at least one associated thruster tug; and

control transition between the determined modes based on transition control information maintained at the control apparatus of the pilot vessel.

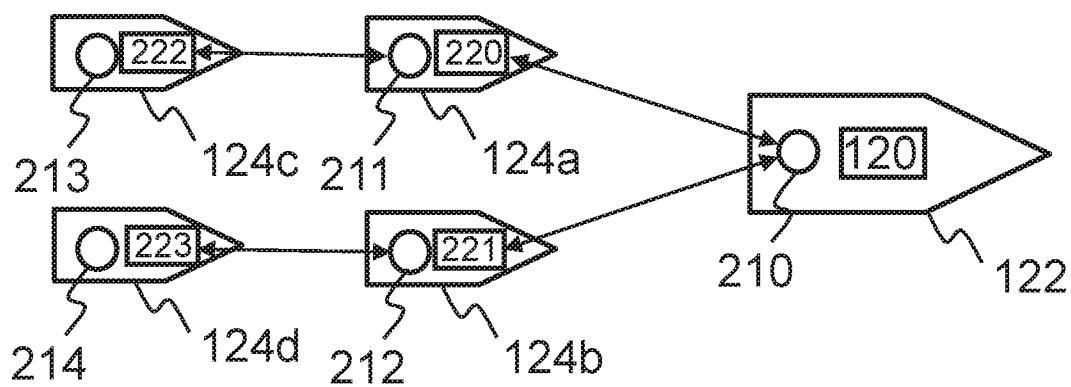


Fig. 1

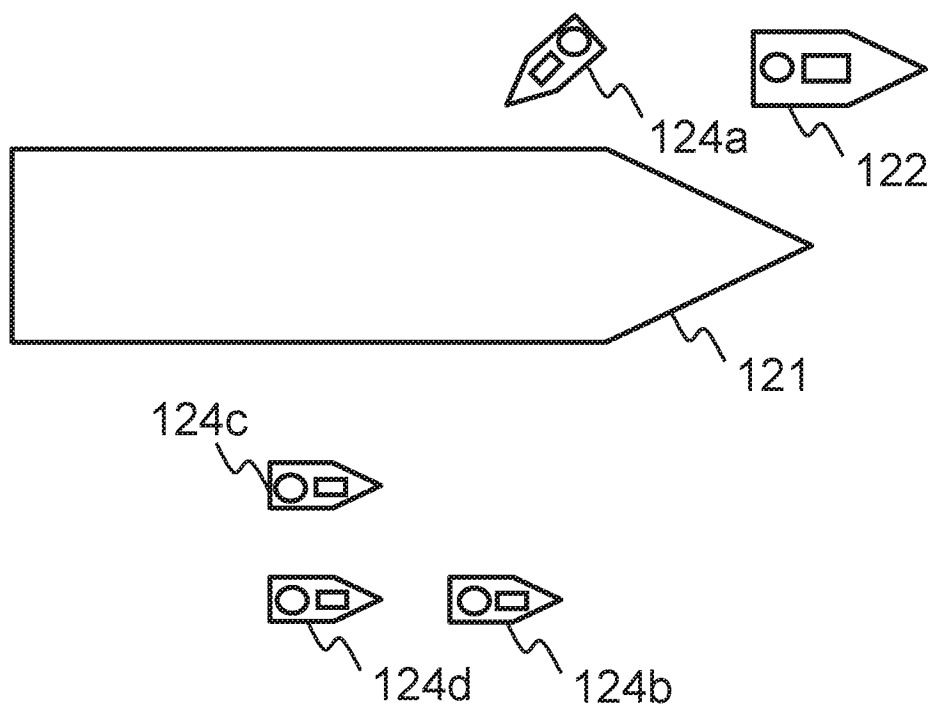


Fig. 2

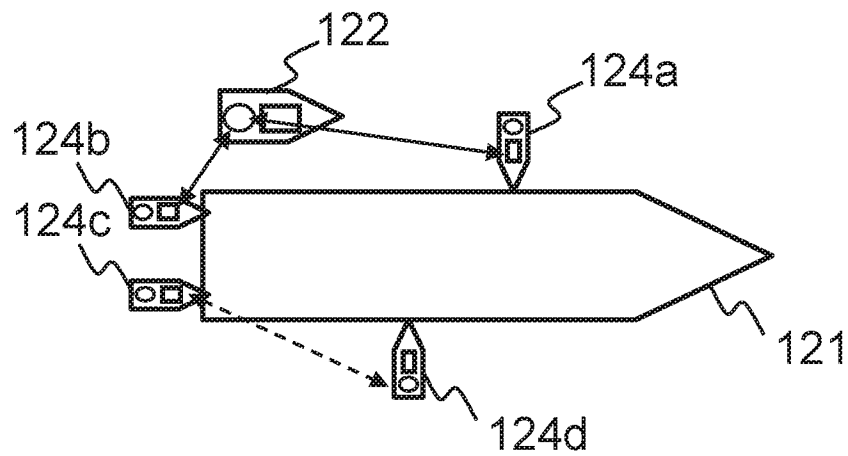


Fig. 3

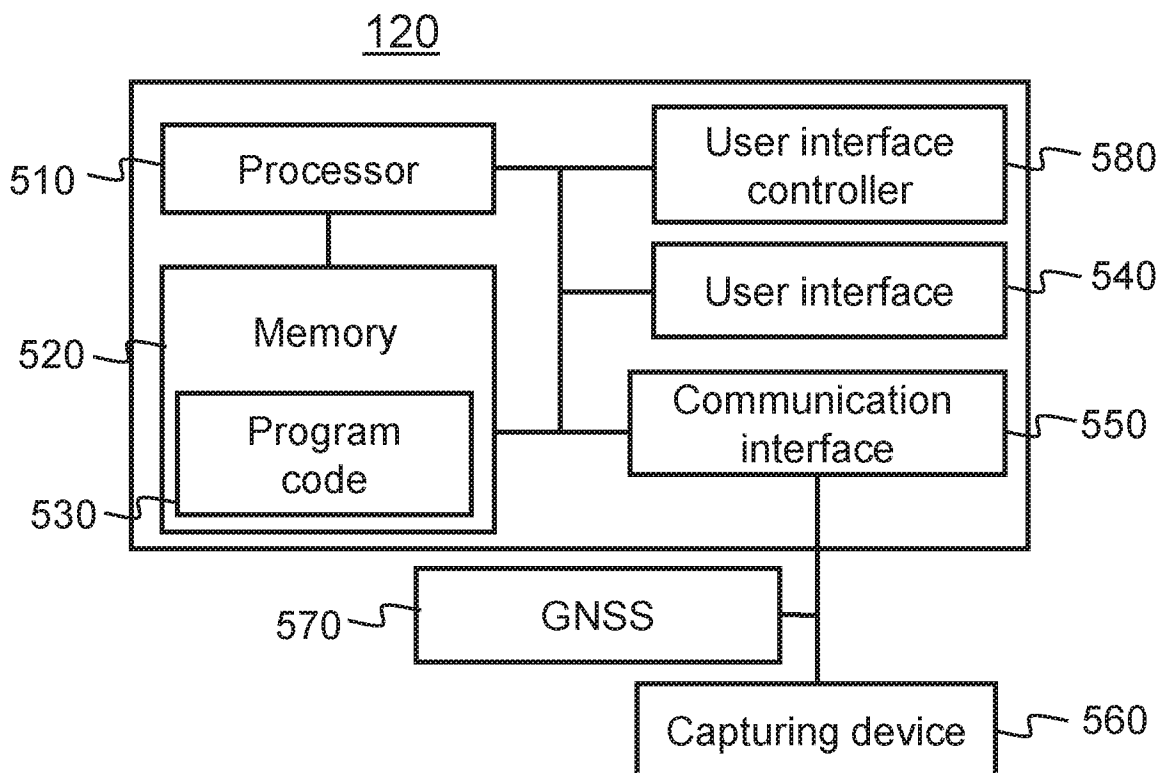


Fig. 5

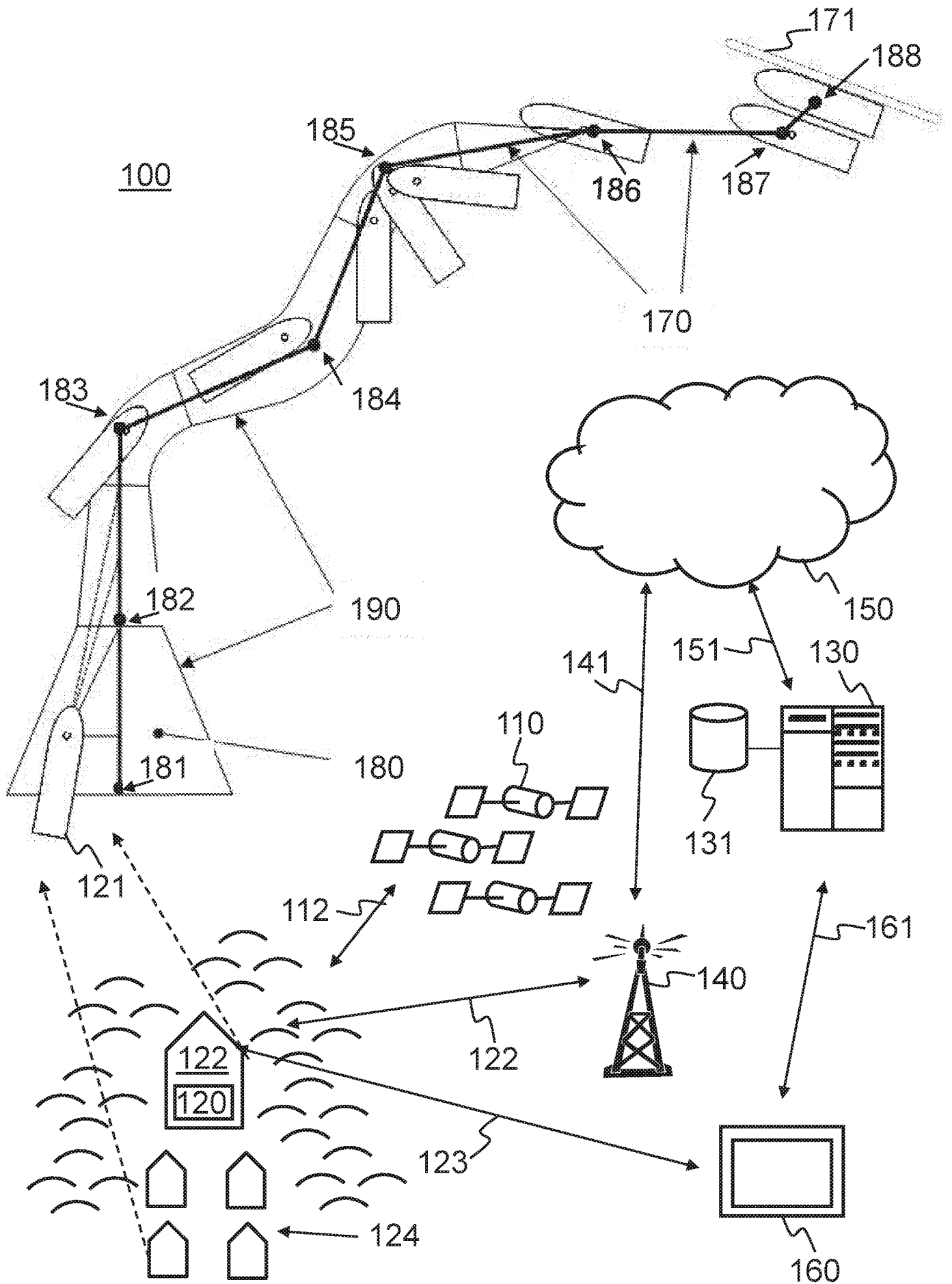


Fig. 4

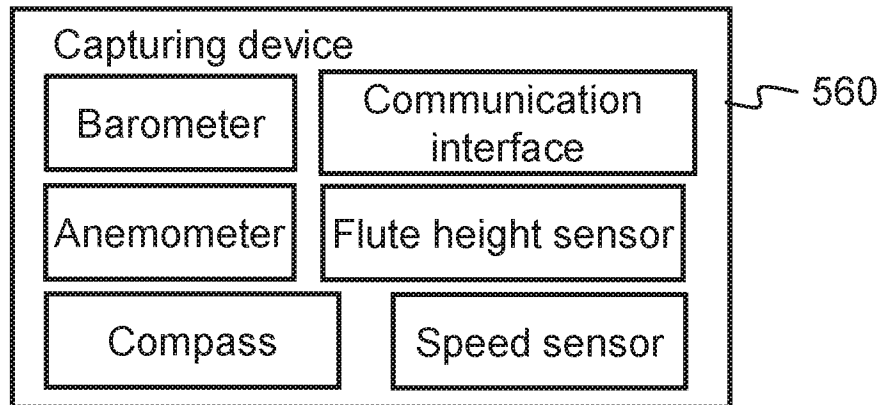


Fig. 6

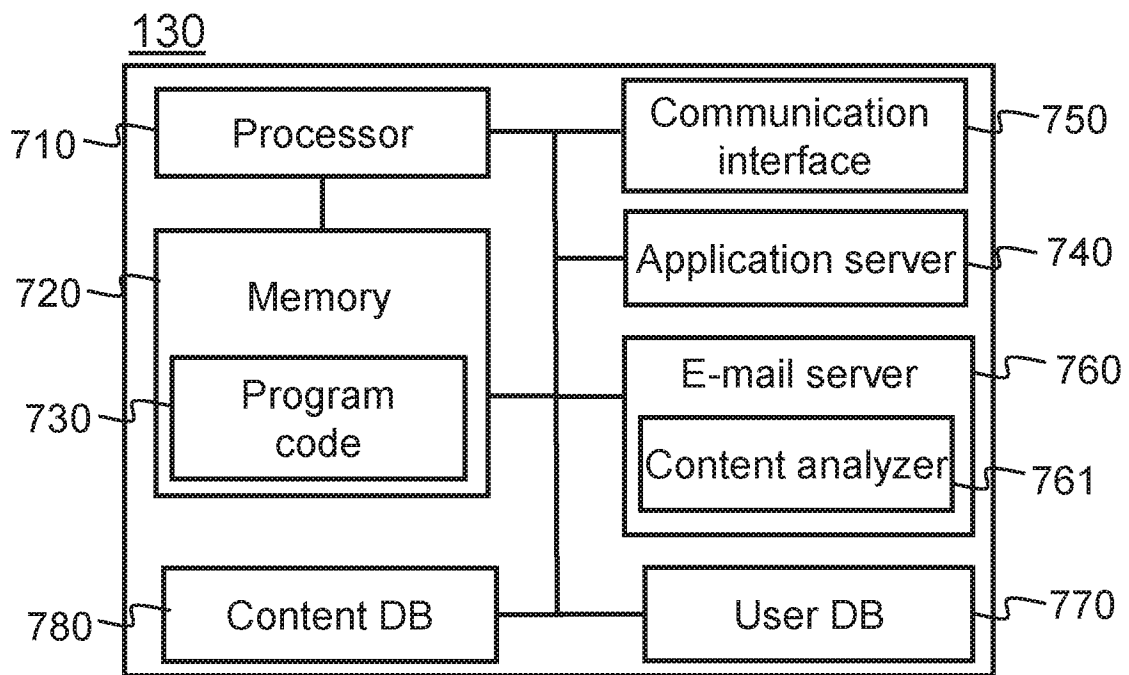


Fig. 7

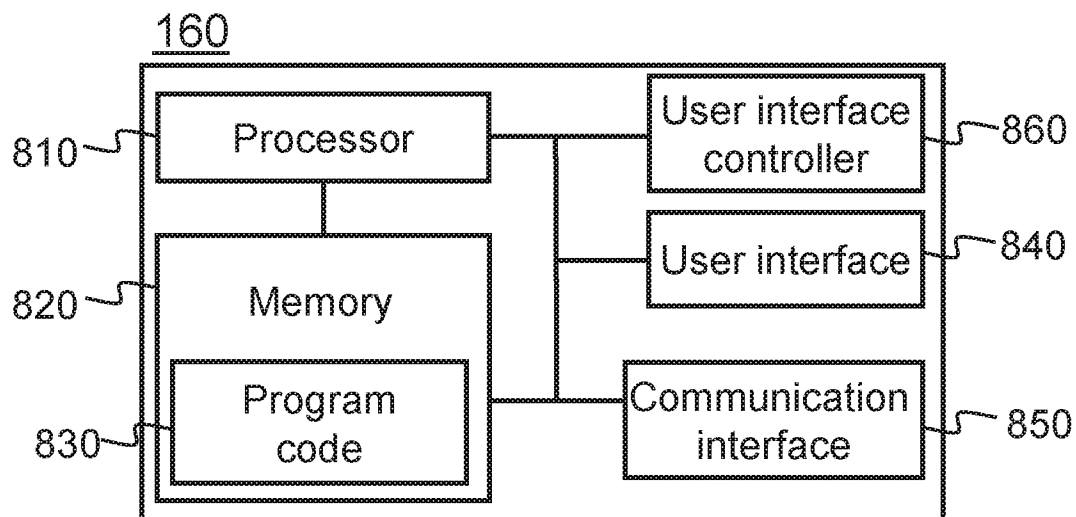


Fig. 8

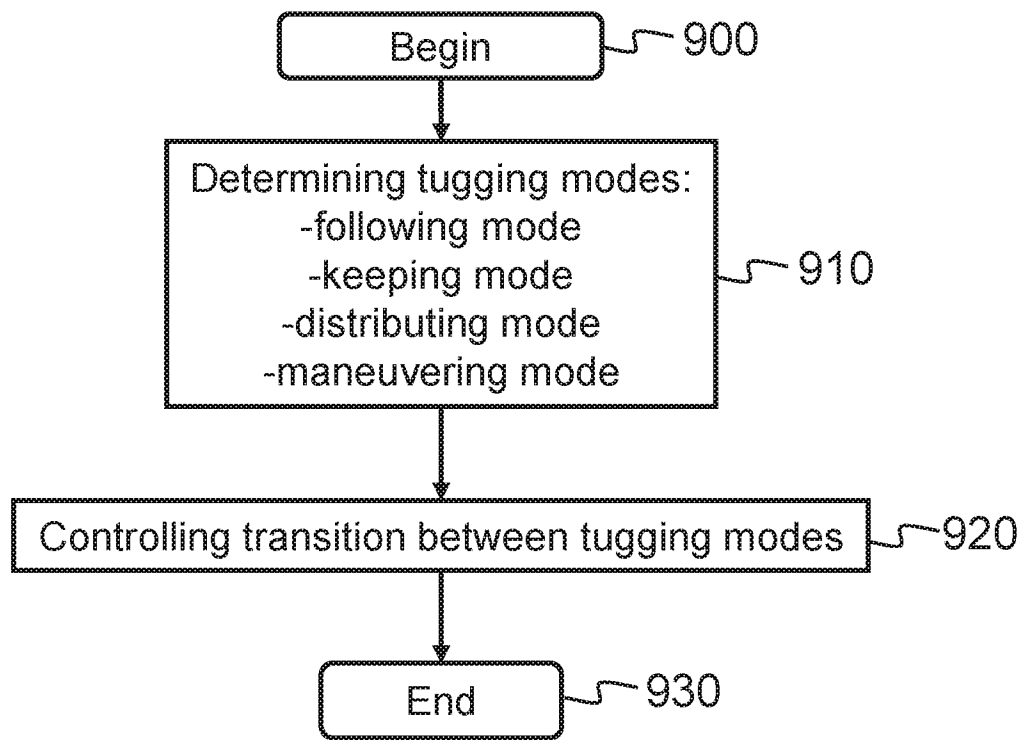


Fig. 9

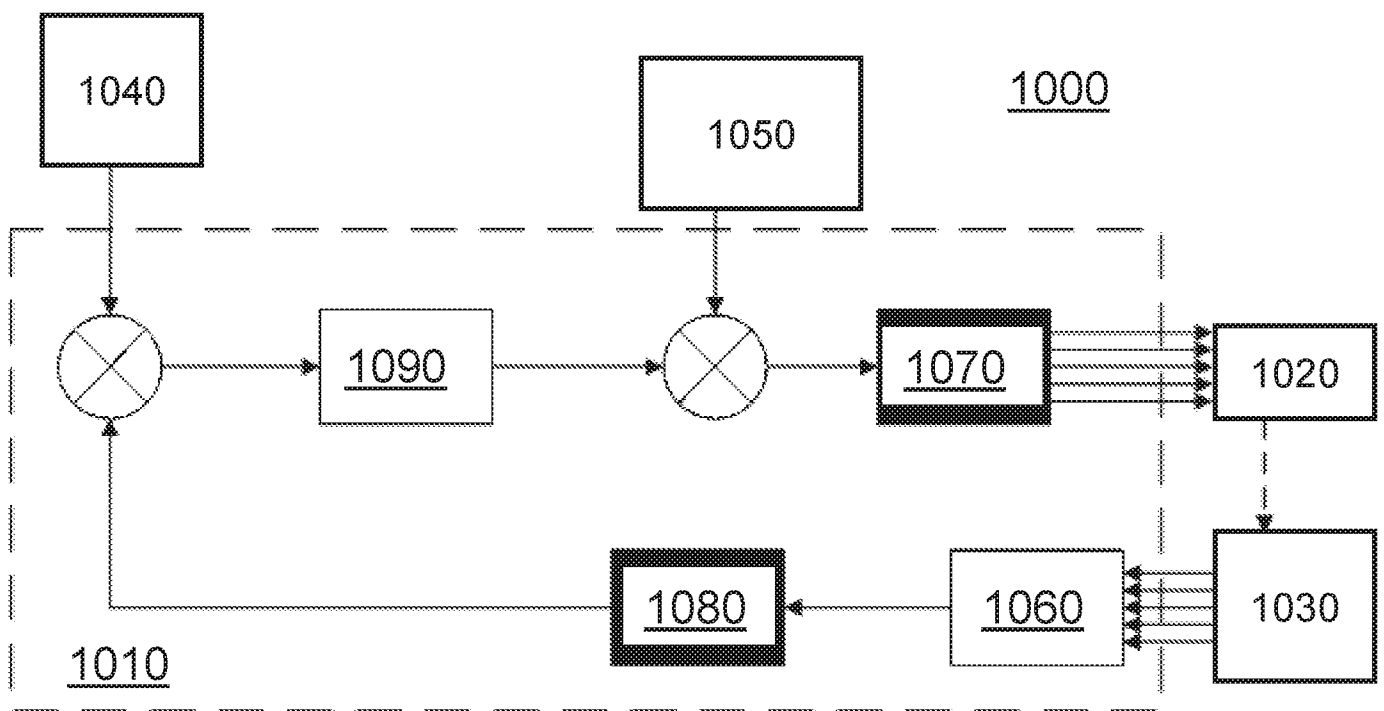


Fig. 10

## INTERNATIONAL SEARCH REPORT

International application No  
PCT/US2019/018391

| <b>A. CLASSIFICATION OF SUBJECT MATTER</b><br>INV. B63B35/00 B63B35/66 G08G3/00 G05D1/02<br>ADD.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |                                                                                                                               |                                                                      |
|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------|
| According to International Patent Classification (IPC) or to both national classification and IPC                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |                                                                                                                               |                                                                      |
| <b>B. FIELDS SEARCHED</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |                                                                                                                               |                                                                      |
| Minimum documentation searched (classification system followed by classification symbols)<br>B63J B63B G08G G05D                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |                                                                                                                               |                                                                      |
| Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       |                                                                                                                               |                                                                      |
| Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)<br>EPO-Internal, WPI Data                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |                                                                                                                               |                                                                      |
| <b>C. DOCUMENTS CONSIDERED TO BE RELEVANT</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       |                                                                                                                               |                                                                      |
| Category*                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           | Citation of document, with indication, where appropriate, of the relevant passages                                            | Relevant to claim No.                                                |
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| <input type="checkbox"/> Further documents are listed in the continuation of Box C. <input checked="" type="checkbox"/> See patent family annex.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |                                                                                                                               |                                                                      |
| * Special categories of cited documents :<br>"A" document defining the general state of the art which is not considered to be of particular relevance<br>"E" earlier application or patent but published on or after the international filing date<br>"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)<br>"O" document referring to an oral disclosure, use, exhibition or other means<br>"P" document published prior to the international filing date but later than the priority date claimed<br>"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention<br>"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone<br>"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art<br>"&" document member of the same patent family |                                                                                                                               |                                                                      |
| Date of the actual completion of the international search<br><br>27 August 2019                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |                                                                                                                               | Date of mailing of the international search report<br><br>04/09/2019 |
| Name and mailing address of the ISA/<br>European Patent Office, P.B. 5818 Patentlaan 2<br>NL - 2280 HV Rijswijk<br>Tel. (+31-70) 340-2040,<br>Fax: (+31-70) 340-3016                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |                                                                                                                               | Authorized officer<br><br>Etienne, Yves                              |

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Information on patent family members

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