(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) **World Intellectual Property Organization**
International Bureau

(43) **International Publication Date**
30 December 2015 (30.12.2015)

WIPO | PCT

(10) **International Publication Number**
WO 2015/199543 A1

(51) **International Patent Classification**:
B63B 27/30 (2006.01) ***B25J 9/00*** (2006.01)
B63B 27/10 (2006.01)

(21) **International Application Number**:
PCT/NO2014/050110

(22) **International Filing Date**:
23 June 2014 (23.06.2014)

(25) **Filing Language**: English

(26) **Publication Language**: English

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(81) **Designated States** *(unless otherwise indicated, for every kind of national protection available)*: AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IR, IS, JP, KE, KG, KN, KP, KR, KZ, LA, LC, LK, LR, LS, LT, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PA, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SA, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

(84) **Designated States** *(unless otherwise indicated, for every kind of regional protection available)*: ARIPO (BW, GH, GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV,

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(54) Title: POSITIONING SYSTEM WITH DISTAL END MOTION COMPENSATION

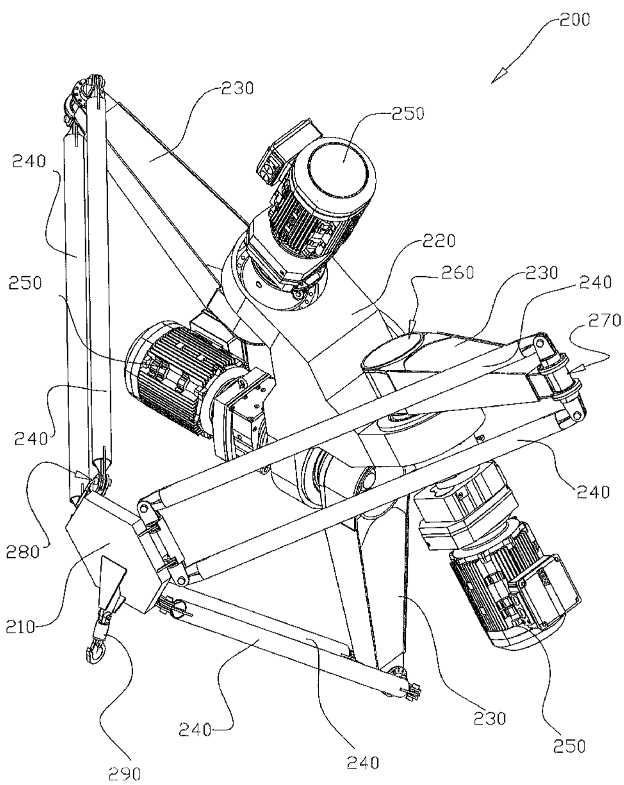

Fig. 2

(57) Abstract: The invention relates to a positioning system (150) having a positioning arm (120, 122, 124) with a distal end (128) for positioning a target (300) relative to a reference point (999), wherein the distal end (128) of the positioning arm (120, 122, 124) and/or the reference point (999) may be subject to undesired motion caused by external factors, such as waves of the sea. The distal end (128) of the positioning arm (120, 122, 124) is provided with an end effector (210) and a motion-compensation actuator (200) coupled between the distal end of the positioning arm (120, 122, 124) and the end effector (210), wherein the motion-compensation actuator (200) is configured for reducing undesired motion of the end effector (210) relative to the reference point (999). The invention further relates to a crane for use on a vessel comprising such positioning system (150), and to a method for positioning a target (300) using such positioning system.

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MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, KM, ML, MR, NE, SN, TD, TG).

Published:

— *with international search report (Art. 21(3))*

POSITIONING SYSTEM WITH DISTAL END MOTION COMPENSATION

The invention relates to a positioning system having a positioning arm with a distal end for positioning a target relative to a reference point, wherein the distal end of the positioning arm and/or the reference point may be subject to undesired motion caused by external factors, such as waves of the sea, such arm being applicable in a wide range of application areas. The invention further relates to motion-compensated cranes, particularly to heave-compensated cranes on vessels. The invention also relates to a method for positioning a target relative to a reference point using a positioning arm with a distal end, wherein the distal end of the positioning arm and or the reference point may be subject to undesired motion caused by external factors, such as waves of the sea.

Motion or heave compensation on cranes on vessels as such is already known for many decades. Hereinafter, a few known offshore heave compensation solutions are discussed.

WO2013/070080A1 discloses a vessel comprising a crane for positioning diver transfer equipment and/or diver equipment overboard the vessel into a body of water. The crane comprises: i) a crane base connected to the vessel; ii) a crane arm with a suspension point that is movably connected to the crane base; iii) control means for controlling the crane arm configuration. The control means are configured for: a) determining a change in position and/or orientation of the crane resulting from vessel motion, b) dynamically adjusting the crane arm configuration to change the position of the suspension point with respect to the crane base so as to at least partially compensate for the change in position and/or orientation of the crane.

WO2009/036456A2 discloses a heave or motion compensation system is employed on the crane to compensate for the heave being experienced by a ship on which the crane is mounted. The heave compensation system includes a motion reference unit mounted on a distal end portion of crane arm to measure the movement (acceleration) thereat. This information is transmitted to a programmable logic control processor to control the operation of a winch carried by the crane thereby to pay out or reel in the load line of the crane. The distal end of the load line is connectable to a load being lowered or lifted by the crane.

US4448396A discloses a heave motion compensation apparatus, which is used to move a load from a supply ship in heavy seas to a platform on an oilrig. A main load line extending down from a point of a crane boom mounted on the oilrig is driven by a pair of hydraulic main hoist drum motors. One of the motors is a variable displacement swash-plate type motor. The motors are driven through a hydrostatic transmission by a pair of variable displacement hydraulic pumps. A signal line running over the boom point is attached to the supply vessel and maintained taut. Sensor and control means reading movement of the signal line with respect to the first platform is used to control the displacement of one of the main hoist pumps to cause an outer end of the main hoist line to move up and down with the supply vessel. The other pump is controlled to raise and lower the outer end of the main load line. The main load line is attached to the load. A signal is generated by the sensor and control means to indicate upward movement of the outer end of the main load line, and this signal is used to generate a signal representative of the rate of change of the speed of the outer load line and the load attached thereto. On demand by the operator, the control means determines when the supply vessel is moving up with respect to the oilrig and the rate of change of velocity is zero. The control means then moves the variable displacement main hoist drum motor and the two variable displacement main hoist pumps to maximum displacement to cause the main load line to pick the load from the supply vessel.

The problem with the above-mentioned known heave compensation systems is that they are all relatively complex, and do not provide for heave-compensating functionality in a satisfactory manner. Moreover, in some of the known systems very large masses have to be moved.

The invention has for its object to remedy or to reduce at least one of the drawbacks of the prior art, or at least provide a useful alternative to prior art.

The object is achieved through features, which are specified in the description below and in the claims that follow.

The invention is defined by the independent patent claims. The dependent claims define advantageous embodiments of the invention.

In a first aspect the invention relates to a positioning system having a positioning arm with a distal end for positioning a target relative to a reference point, wherein the distal end of the positioning arm and/or the reference point may be subject to undesired motion caused by external factors, such as waves of the sea. The distal end of the positioning arm is provided with an end effector and a motion-compensation actuator coupled between the distal end of the positioning arm and the end effector, wherein the motion-compensation actuator is configured for reducing undesired motion of the end effector relative to the reference point.

The effects of the combination of the features of the invention are as follows. By providing a motion compensation actuator on the distal end of a positioning arm (e.g. a boom) of a positioning system (e.g. a crane), the motion compensation on other mechanical parts of the positioning system can be partially or completely dispensed with. Another advantage effect of the invention is that motion compensation may now be carried out for more degrees of freedom (i.e. translations in all directions). This is quite in contrast with the prior art solutions where only the vertical motion is compensated. Furthermore, as only the end effector of the positioning arm is motion-compensated, relative small masses are moved, which is beneficial for the complexity and system power requirement of the system. It must be noted that there are different scenarios possible. Either the distal end of the positioning arm is subject to undesired motion (for instance a crane on a vessel transferring a load to an on-shore location), or the reference point (e.g. the target point where a possible load has to be transferred to) is subject to undesired motion (e.g. a crane located on-shore, which is to take a load from a vessel), or a combination of both (e.g. a crane on a vessel transferring a load to another vessel). Depending on which of the (relative) motions are sensed and used in a control system steering the positioning system, the positioning system according to the invention may be able to compensate (relative) motion in all these circumstances.

In an embodiment of the positioning system of the invention the motion-compensating actuator comprises a robot actuator which constrains at least three degrees-of-freedom of the end effector. Generally, it can be stated that the more degrees-of-freedom are determine by the robot actuator, the more motion-compensation is rendered possible. Expressed differently, the numbers of degrees-of-freedom in which translation or rotation is compensated cannot exceed the number of degrees-of-freedom, which the robot actuator determines.

In an embodiment of the positioning system of the invention the robot actuator at least determines the position of the end effector in three degrees-of-freedom. In the motion compensation of a crane boom tip, for example, it is advantageous to determine the position of the end effector in three degrees-of-freedom. The rotation degrees of freedom are in crane applications less important.

In an embodiment of the positioning system of the invention the motion-compensating actuator is configured for compensating the position variations of the end effector in three degrees-of-freedom. The inventors have realized that when motion-compensation is only done on a distal end of a positioning arm (or boom) of a crane on a ship, it is not needed to compensate for the rotation degrees-of-freedom. Two of the vessels rotation degrees-of-freedom are results in a translation of the distal end (i.e. the suspension point of the load), while the other one (rotation in a plane orthogonal to the last section of the boom) does not even imply a translation at all. Next to this effect it can be understood that any rotations of the end effector are not a problem as such, because such rotations are "cancelled out" in the final guiding tip (or suspension point) on the end effector.

In an embodiment of the positioning system of the invention the motion-compensating actuator comprises a parallel robot. Parallel robots form a very convenient solution for motion-compensation in three position degrees-of-freedom. Moreover, such robots have the advantage that they can be build such that they are fast and precise.

In an embodiment of the positioning system of the invention the parallel robot comprises a delta robot comprising a base that is fixedly coupled to the positioning arm, wherein the delta robot further comprises three rotatable actuator arms, wherein each actuator arm is coupled with a first respective end to the base through a revolute joint, wherein each actuator arm is coupled with a second, opposite, end to a pair of link rods through a first universal or spherical joint, wherein each link rod of each pair of link rods is coupled to the end effector via/through a second universal or spherical joint, such that each pair of link rods forms a parallelogram with the end effector and the respective universal or spherical joints. This embodiment constitutes a specific delta robot construction, which has been proven to be a very efficient motion-compensation actuator in the application of cranes on vessels.

In an embodiment of the positioning system of the invention the respective revolute joints of the actuator arms are positioned around the base and oriented with an offset of 120 degrees relative to each other. This embodiment uses a known delta robot configuration as such, that has been used in 3D positioning systems.

In an embodiment of the positioning system of the invention the respective second spherical joints of the pairs of link rods are positioned around the end effector. This embodiment uses a known delta robot configuration as such, that has been used in 3D positioning systems.

In an embodiment of the positioning system of the invention each actuator arm is driven by a respective drive unit. This embodiment uses a convenient implementation of a motion-compensation system on the distal end of a positioning arm. The drive unit may also comprise multiple drives with a gear-box.

In an embodiment of the positioning system of the invention the positioning system further comprises a motion sensor for directly or indirectly determining a position and/or orientation of the end effector and/or the reference point to obtain a motion sensor output. Motion compensation needs to be done relative to a specific reference point (fixed or variable). It is convenient to determine any motion by means of motion sensor. The motion sensor may be also put on the vessel itself.

In an embodiment of the positioning system of the invention the positioning system comprises a controller for controlling said motion-compensating actuator based upon the motion sensor output. This embodiment uses a convenient implementation of a motion-compensation system on the distal end of a positioning arm.

In a second aspect the invention relates to a crane for use on a vessel, wherein the crane comprises the positioning system of the invention, and wherein the end effector is provided with a suspension point for guiding and lifting a cable with a target. The positioning system of the invention has significant advantages in the application area of cranes on vessels. The solution becomes less complex and expensive. Moreover, the invention opens up cargo transfer functionality (off-shore to on-shore, off-shore to off-shore, and on-shore to off-shore) which has not been possible in the prior art.

In a third aspect the invention relates to a method for positioning a target relative to a reference point using a positioning arm with a distal end, wherein the distal end of the positioning arm and or the reference point may be subject to undesired motion caused by external factors, such as waves of the sea, wherein the method comprises the step of:
- reducing undesired motion of the target using motion compensation at the distal end of the positioning arm. The method of the invention touches the core of the inventors contribution. It is their inventive contribution to invent motion-compensation on a distal end of a position arm.

In an embodiment of the method of the invention the motion compensation is carried out at least for the undesired position variations of the target. The inventors have realized that when motion-compensation is only done on a distal end of a positioning arm (or boom) of a crane on a ship, it is not needed to compensate for the rotation degrees-of-freedom. Two of the vessels rotation degrees-of-freedom are results in a translation of the distal end, while the other one (rotation in a plane orthogonal to the last section of the boom) does not even imply a translation at all. Next to this effect it can be understood that any rotations of the end effector are not a problem as such, because such rotations are "cancelled" in the final suspension point on the end effector.

In an embodiment of the method of the invention the motion compensation is carried out using a motion-compensation actuator provided at the distal end of the positing arm, wherein the motion-compensation actuator preferably comprises a parallel robot, and more preferably a delta robot.

In the following is described an example of a preferred embodiment illustrated in the accompanying drawings, wherein:

Fig. 1 shows a vessel with a crane comprising an embodiment of a positioning system in accordance with the invention;

Fig. 2 shows an enlarged view of the motion-compensation actuator of Fig. 1;

Fig. 3 shows a front view and a top view of the motion-compensation actuator of Fig. 2, and

Fig. 4 illustrates the dynamics of the motion-compensation actuator of Fig. 2.

It should be noted that the above-mentioned embodiments illustrate rather than limit the invention, and that those skilled in the art will be able to design many alternative embodiments without departing from the scope of the appended claims. In the claims, any reference signs placed between parentheses shall not be construed as limiting the claim. Use of the verb "comprise" and its conjugations does not exclude the presence of elements or steps other than those stated in a claim. The article "a" or "an" preceding an element does not exclude the presence of a plurality of such elements. The invention may be implemented by means of hardware comprising several distinct elements, and by means of a suitably programmed computer. In the device claim enumerating several means, several of these means may be embodied by one and the same item of hardware. The mere fact that certain measures are recited in mutually different dependent claims does not indicate that a combination of these measures cannot be used to advantage. Throughout the Figures, similar or corresponding features are indicated by same reference numerals or labels.

Fig. 1 shows a vessel 10 with a crane 100 comprising an embodiment of a positioning system 150 in accordance with the invention. The crane 100 is coupled to the vessel 10 via a crane pedestal 110, which also allows for rotation of the crane 100 relative to the vessel 10. The crane 100 comprises a crane boom 120 (also being referred to as a positioning arm in this description). In the example of Fig. 1 the crane boom 120 comprises two sub-booms, i.e. a primary boom 122 and a secondary boom 124, which are connected via a pivoting joint 123, as is known in the field of cranes. It must be noted that the invention is applicable to cranes having any number of sub-booms, even a single boom. It is known that the distal end of the crane 100 placed on a vessel 10 may be subject to undesired motion caused by the waves of the sea. The gist of the main invention resides in the idea of applying motion-compensation actuator 200 at the distal end 128 of the boom 200, which means that a suspension point at the end of the boom is compensated for at least motion, and therewith also a target or load 300 suspended to the suspension point (see Fig. 2, reference numeral 290). Preferably, the motion compensation is done for three position degrees for freedom.

It must be further noted that the general idea is to compensate motion with regards to a reference point 999 somewhere on earth. In offshore to on-shore cargo transfer applications this reference point 999 is a point on land (or on a typical platform 400 at sea), for example, but the most important is that it is fixed in position coordinates (X, Y, and Z). In off-shore-to-off-shore or vessel-to-vessel cargo transfer, the reference point 999 may also be variable in terms of position coordinates (X, Y, and Z). For example, the reference point 999 may be defined as a fixed point on a target vessel (which may be moving due to waves), i.e. the location where the target or load 300 has to be transferred to. A consequence of this is that it is now possible to compensate for relative motion between two vessels for example, which is very advantageous in vessel-to-vessel cargo transfer.

Many types of actuators may be used as motion compensation actuator, but the invention, as claimed in its broadest sense, is not limited to any specific type. Until now, one specific class of actuators has appeared to be very advantageous, namely the parallel robots, and more specifically the delta robots within the group of parallel robots. Delta robots are fast and accurate positioning systems, and thus be conveniently used in a motion compensation system. A specific implementation of the delta robot that will be discussed hereinafter may only compensate position variations and not the rotational variations. However, the inventors have realized that in crane applications such limitation is very often not a problem.

Fig. 2 shows an enlarged view of the motion-compensation actuator 200 of Fig. 1. Fig. 3 shows a front view and a top view of the motion-compensation actuator of Fig. 2. The motion-compensation actuator 200 constitutes a delta robot, and comprises an end effector 210, which is provided with the earlier-mentioned suspension point 290. The delta robot 200 further comprises a base 220, which is fixed to the distal end 128 of the boom 120 of the crane 100. Under influence of waves the vessel 10 moves, wherein crane 100 moves with the vessel 10, wherein the boom 120 moves with the crane 100, wherein the base 220 moves with the distal end 128 of the boom 120. It is the insight of the inventors that only the movement of the base 220 needs motion-compensation (or heave-compensation). The delta robot 200 comprises three actuator arms 230 that are distributed along the circumference of the base 220 and pivotably connected thereto via a respective revolute joint 260 (only allowing one rotation degree of freedom). Each actuator arm 230 is driven by a respective drive unit 250. Each of the actuator arms 230 is coupled to a pair of link rods 240 via a first universal or spherical joint 270 (allowing two or three rotation degrees of freedom respectively). Each link rod 240 is coupled to the end effector 210 via a second universal or spherical joint 280 (allowing two or three rotation degrees of freedom respectively). Delta robots as such as known to the person skilled in the art and many implementation aspects are therefore not discussed in detail here.

It is important to that that in the invention the distance between the base and the end effector (with the suspension point) changes during the heave- or motion compensation. In case the winch for the crane wire (rope) is provided on the base 220, the system requires measures to properly guide the crane wire from the base 220 to the suspension point 290 on the end effector 210. Furthermore, the winch may need to compensate for the earlier-mentioned variable distance between the base 220 and the end effector.

In an alternative embodiment the suspension point 290 may be equipped with sheaves, a hook, a lowering winch or other apparatuses. In this configuration sheaves are provided such that the crane wire is arranged through a sheave assembly, which is running through actuator arms 230 and link rods 240. In this embodiment the length of the crane rope is not or only minimally affected by compensation of the parallel robot (200).

Motion compensation as such is also considered known to the person skilled in the art and details are therefore not discussed. In order to function as a motion-compensation system the positioning system 150 must also be provided with a controller (not shown) for controlling the motion-compensation actuator 200, wherein such controller requires a motion sensor (not shown) to provide information about the motion to be compensated. The controller may comprise a feedback loop. The motion sensor determines the motion relative to the reference point. Alternatively, in some embodiments, multiple motion sensors (not shown) may be provided each determining a motion of a different part relative to the reference point. Subsequently, a relative motion between said different parts may be determined and used as an input to the controller.

Fig. 4 illustrates the dynamics of the motion-compensation actuator 200 of Fig. 2. Each actuator arm 230 may pivot around the revolute joint 260 such that the respective first universal or spherical joint 270 follows circular path C1 as shown in the figure. Each of the link rods 240 may pivot around the respective first universal or spherical joint 270 such that the respective second universal or spherical joint 280 follows circular path C2 as shown in the figure. As each of the actuator arms 230 is connected to such respective link rod 240 the total reach of the motion-compensation actuator 200 is determined by the sum of the respective radiuses R1, R2 of said circular paths as illustrated in Fig. 4.

Many variations within the scope of the invention are possible. For instance, instead of a three-armed delta robot, a fourth arm may be provided. Such additional arm may be provided to add motion compensation for rotation degrees of freedom, i.e. to determine and compensate the rotation degree-of-freedom of the end effector, for example. Alternatively, such additional arm may be used to create a larger over-determination of the degrees of freedom of the end effector, which may be beneficial for the stiffness and loading of the system. In addition, such variant may be exploited for a larger reach of the system.

Another variant concerns a rotation of the mechanism in that two arms are loaded by compression.

C l a i m s

1. A positioning system (150) having a positioning arm (120, 122, 124) with a distal end (128) for positioning a target (300) relative to a reference point (999), wherein the distal end (128) of the positioning arm (120, 122, 124) and/or the reference point (999) may be subject to undesired motion caused by external factors, such as waves of the sea, c h a r a c t e r i s e d i n that the distal end (128) of the positioning arm (120, 122, 124) is provided with an end effector (210) and a motion-compensation actuator (200) coupled between the distal end of the positioning arm (120, 122, 124) and the end effector (210), wherein the motion-compensation actuator (200) is configured for reducing undesired motion of the end effector (210) relative to the reference point (999).

2. The positioning system (150) as claimed in claim 1, c h a r a c t e r i s e d i n that the motion-compensation actuator (200) comprises a robot actuator which determines at least three degrees-of-freedom of the end effector (210).

3. The positioning system (150) as claimed in claim 2, c h a r a c t e r i s e d i n that the robot actuator (200) at least determines the position of the end effector (210) in three degrees-of-freedom.

4. The positioning system (150) as claimed in claim 1, 2 or 3, c h a r a c t e r i s e d i n that the motion-compensation actuator (200) is configured for compensating the position variations of the end effector (210) in three degrees-of-freedom.

5. The positioning system (150) as claimed in claim 4, c h a r a c t e r i s e d i n that the motion-compensation actuator (200) comprises a parallel robot.

6. The positioning system (150) as claimed in claim 5, c h a r a c t e r i s e d i n that the parallel robot (200) comprises a delta robot comprising a base (220) that is fixedly coupled to the positioning arm (120, 122, 124), wherein the delta robot further comprises three rotatable actuator arms (230), wherein each actuator arm (230) is coupled with a first respective end to the base (220) through a revolute joint (260), wherein each actuator arm (230) is coupled with a second, opposite, end to a pair of link rods (240) through a first universal or spherical joint (270), wherein each link rod (240) of each pair of link rods (240) is coupled to the end effector (210) via/through a second universal or spherical joint (280), such that each pair of link rods (240) forms a parallelogram with the end effector (210) and the respective universal or spherical joints (270, 280).

7. The positioning system (150) as claimed in claim 6, c h a r a c t e r i s e d i n that the respective revolute joints (260) of the actuator arms (230) are positioned around the base (220) and oriented with an offset of 120 degrees relative to each other.

8. The positioning system (150) as claimed in claim 7, c h a r a c t e r i s e d i n that the respective second spherical joints (280) of the pairs of link rods (240) are positioned around the end effector (210).

9. The positioning system (150) as claimed in any one of claims 6 to 8, c h a r a c t e r i s e d i n that each

actuator arm (230) is driven by a respective drive unit(250).

10. The positioning system (150) as claimed in any one of the preceding claims, characterised in that the positioning system (150) further comprises a motion sensor for directly or indirectly determining a position and/or orientation of the end effector (210) and/or the reference point (999) to obtain a motion sensor output.

11. The positioning system (150) as claimed in claim 10, characterised in that the positioning system (150) comprises a controller for controlling said motion-compensation actuator (200) based upon the motion sensor output.

12. A crane (100) for use on a vessel (10), characterised in that the crane (100) comprises the positioning system (150) according to any one of the preceding claims, and wherein the end effector (210) is provided with a suspension point (290) for guiding a cable with a target (300).

13. A method for positioning a target (300) relative to a reference point (999) using a positioning arm (120, 122, 124) with a distal end (128), wherein the distal end (128) of the positioning arm (120, 122, 124) and or the reference point (999) may be subject to undesired motion caused by external factors, such as waves of the sea, characterized in that the method comprises the step of:
- reducing undesired motion of the target (300) using motion compensation at the distal end of the positioning arm (120, 122, 124).

14. The method as claimed in claim 13, c h a r a c t e r i - z e d i n that the motion compensation is carried out at least for the undesired position variations of the target (300).

15. The method of claim 14, c h a r a c t e r i z e d i n that the motion compensation is carried out using a motion-compensation actuator (200) provided at the distal end (128) of the positioning arm (120), wherein the motion-compensation actuator (200) preferably comprises a parallel robot, and more preferably a delta robot.

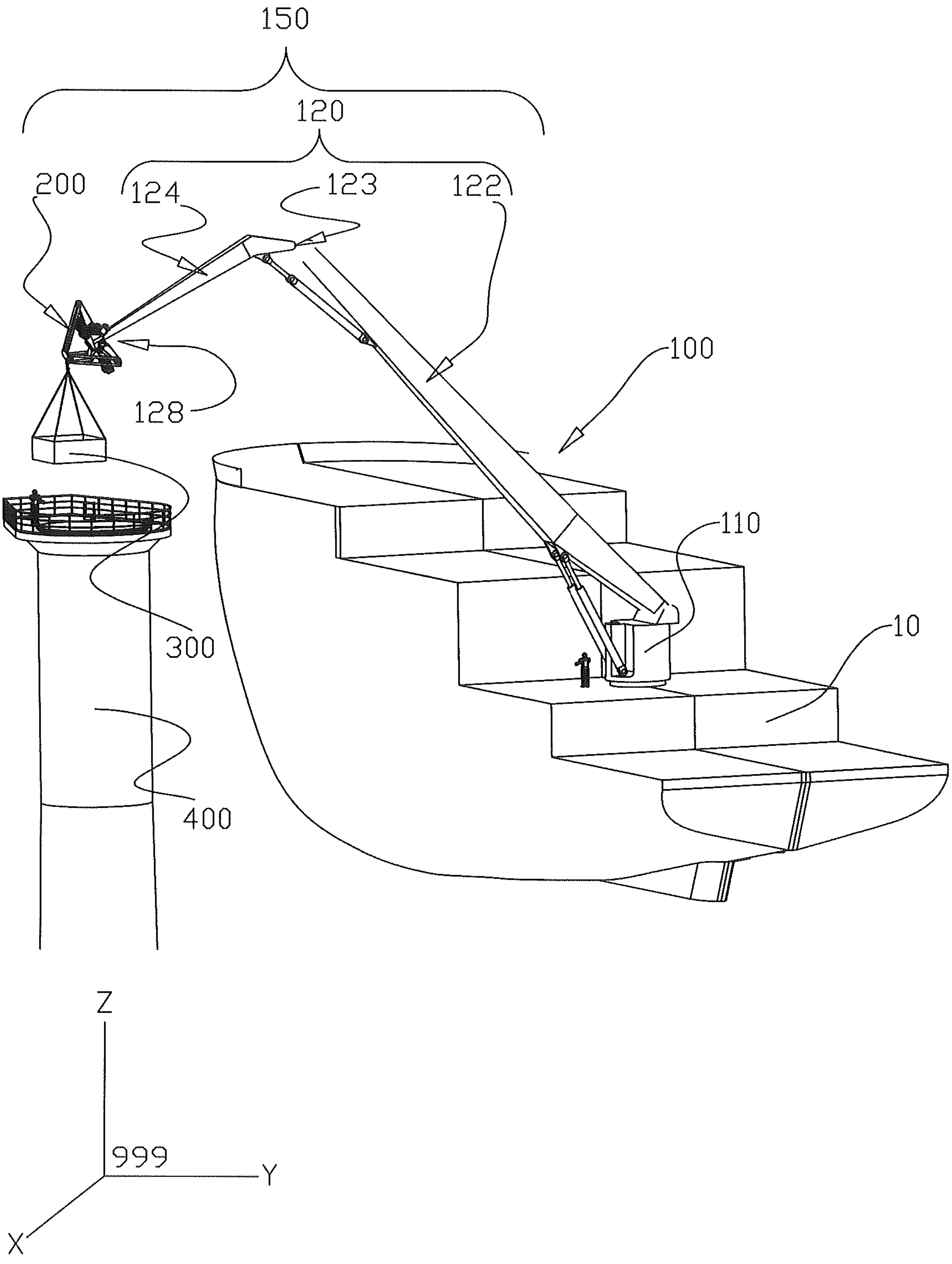

Fig. 1

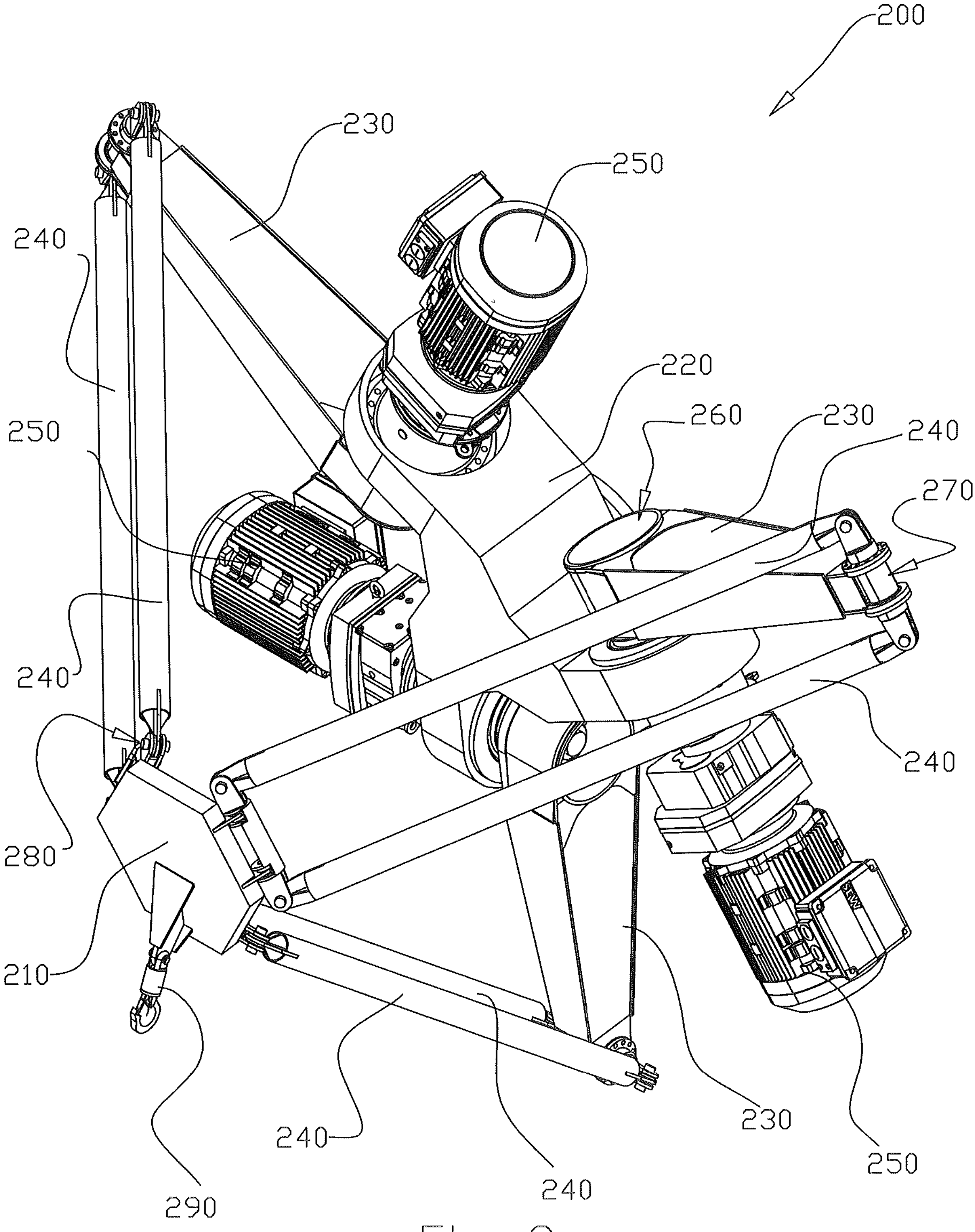
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Fig. 2

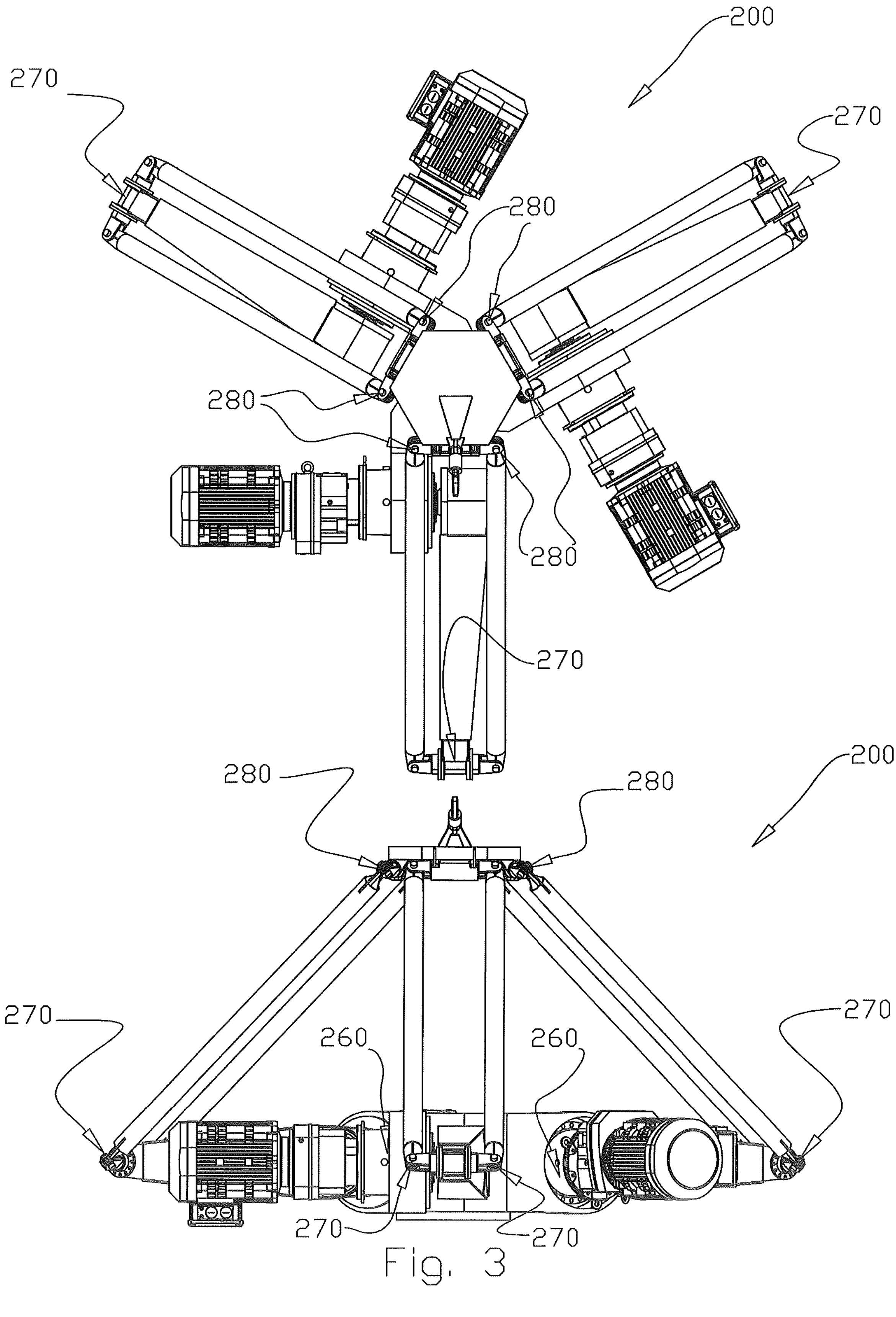
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Fig. 3

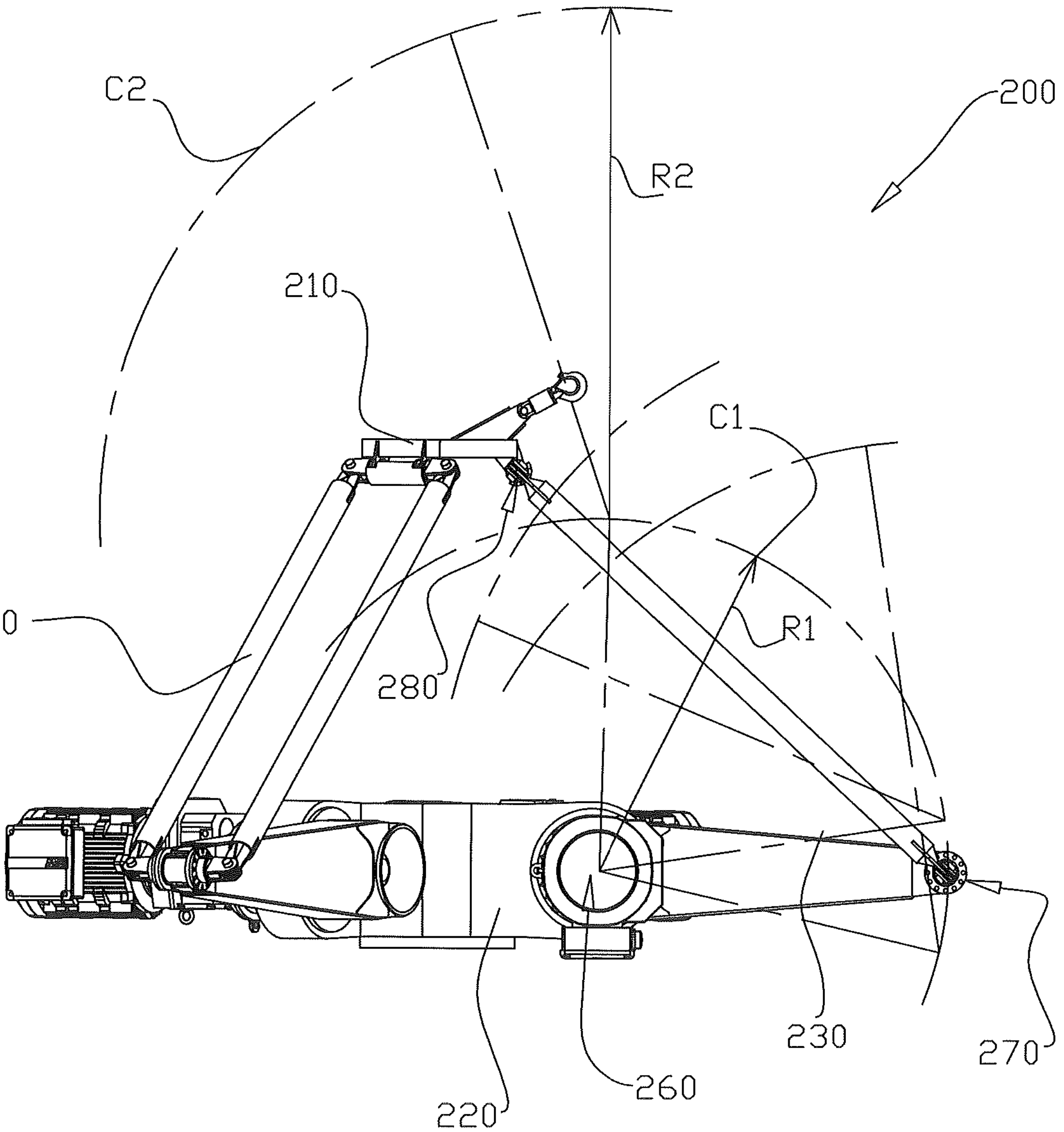

Fig. 4

INTERNATIONAL SEARCH REPORT

International application No.

PCT/NO2014/050110

A. CLASSIFICATION OF SUBJECT MATTER

B63B27/30 (2006.01), B63B27/10 (2006.01), B25J9/00 (2006.01)

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

B63B, B66C

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

DK, NO, SE, FI: Classes as above.

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

EPODOC, WPI, FULLTEXT: German, English, French.

heave, motion, compensate, distal, end, boom, arm, end effector, stewart, platform, parallel, delta, robot, manipulator, maintain, hold, position, control+, mov+

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2012/0282064 A1 (PAYNE, J. A. et al.) 2012.11.08. Claims 1-13, all figures, paragraphs 0009, 0011 and 0029.	1-4, 10-14
Y		5-9, 15
Y	WO 2012/2152559 (BOSCH GMBH et al.) 2012.11.15 Figure 1, 3a, 8, page 6 lines 26-28, page 7 lines 3-5.	5-9, 15

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INTERNATIONAL SEARCH REPORT
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