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(54) **SYSTEM FOR AUTOMATICALLY MOVING AN ARTICULATED ARM, PARTICULARLY OF A LOADER CRANE, TOWARDS A TARGET POSITION**

(57) A system for automatically moving an articulated arm (101) towards a target position, comprising:
- said articulated arm (101) comprising a plurality of consecutively connected bodies forming an open kinematic chain with an end-effector (105), having a plurality of translative and/or rotative degrees of freedom and a plurality of actuators for moving said bodies;
- a plurality of sensors associated to said bodies, adapted to supply signals indicative of linear or angular positions such to enable to determine the absolute coordinates of the end-effector (105);
- a user interface device configured to command the articulated arm by an operator;
- an emitting probe (5) positioned in the target position, and at least one first (1), one second (2), one third (3) and one fourth detecting probes (4), each positioned in a predetermined different point of the articulated arm, and adapted to communicate with the emitting probe so that each emitting probe-detecting probe pair provide a signal indicative of the relative distance thereof;
- a control unit operatively connected to said actuators, sensors, emitting probe, detecting probes, and user interface device, said control unit being configured to, at each sampling instant of a plurality of subsequent sampling instants:
- estimate, based on the signals from said first, second, third, fourth emitting probes (1, 2, 3, 4) and from said detecting probe (5) the actual absolute position of the emitting probe (5);
- determine the actual absolute position of the end-effector (105) based on the signals from said sensors;
- actuate the actuators so that the end-effector (105) moves towards the estimated actual absolute position of the emitting probe (5).

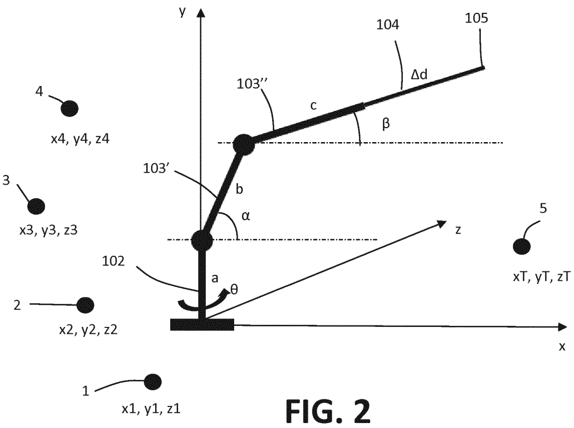

FIG. 2

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Description

Technical field of the invention

[0001] The present invention refers to a system for automatically moving an articulated arm, particularly, of an articulated crane, towards a target position. The term "articulated arm" means a system provided with a plurality of bodies, consecutively connected to each other in order to form an open kinematic chain provided with a plurality of translative and/or rotative degrees of freedom in the space.

Prior art

[0002] Overhead cranes or truss cranes are known to be provided with a plurality of detecting probes and remote control used by the operators for moving the crane itself by an emitting probe, so that the crane, upon a suitable instruction, automatically moves towards the remote control, which represents the target position to be reached.

[0003] The known systems provided for tracking a target position are not completely satisfying when, for example, one or more detecting probes are not capable to communicate with the emitting probe due to boundary conditions.

[0004] A further disadvantage of the known systems is due to the fact that these generally operate correctly if the operator handling the remote control, remains in a stationary position, in other words if he/she does not move during the crane movement.

[0005] Systems according to the prior art are described in documents US 2010/095835 A1, EP 1 327 601 A1, JP S62 96300 A.

Summary of the invention

[0006] Therefore, it is the object of the present invention to make available a system for automatically moving an articulated arm, particularly of an articulated crane, towards a target position, in order to at least partially overcome the cited disadvantages of the prior art.

[0007] This and other objects are obtained by a system for automatically moving an articulated arm towards a target position according to claim 1.

[0008] The dependent claims define possible advantageous embodiments of the invention.

Brief description of the figures

[0009] For gaining a better comprehension of the invention and for better appreciating the advantages thereof, some illustratively non-limiting embodiments of the invention will be described in the following with reference to the attached figures, wherein:

Figure 1 is a side view of an articulated crane;

Figure 2 is a schematic illustration of a system for automatically moving an articulated arm towards a target position according to an embodiment.

Detailed description of the invention

[0010] The present description will refer in a purely exemplifying way to an articulated crane. However, the present invention finds an application for automatically moving articulated arms of other kinds, such as for example robotic arms, or aerial work platforms (PLE).

[0011] Referring to the attached Figure 1, it shows an example of a possible articulated arm, particularly an articulated crane, for example a hydraulic loader crane generally indicated by the reference 101.

[0012] The crane 101 comprises a column 102 rotatable about its own axis, and one or more possibly extendable arms 103', 103". The possibility of extending the arms, if provided, is obtained by a plurality of extensions 104 reciprocally translatingly movable in order to modify the axial length of the respective arm. In the example of Figure 1, only the second arm 103" is extendable by moving the extensions 104. In the following description, the first arm 103', which is devoid of extensions, will be called "main arm", while the second arm 103", provided with extensions 104, will be called "secondary arm". The main arm 103' is rotatable with respect to the column 102, while the secondary arm 103" is rotatable with respect to the main arm 103'.

[0013] The free end 105 of the last extension of the secondary arm 103" is usually known as end-effector. A hook 106 movable for example by a rope winch 107 is provided at the end-effector 105. A PLE on the contrary can be provided with a basket, for example.

[0014] The crane 101 comprises a plurality of actuators for moving the bodies forming the kinematic chain. Figure 1 shows a first hydraulic jack 108, moving the main arm 103' with respect to the column 102, a second hydraulic jack 109 moving the secondary arm 103" with respect to the main arm 103', and an actuator 111 for moving the column 102 with respect to the stationary reference. Obviously, further actuators (not shown in the figures) can be provided, for example of the hydraulic type, for moving the extensions 104. Obviously, even though the cranes are conventionally provided with actuators of the hydraulic type, actuators of a different type (electric or pneumatic, for example) can be possibly provided in the articulated arms.

[0015] The crane 101 comprises a plurality of sensors capable of enabling to determine the absolute coordinates of the end-effector 105, particularly the Cartesian coordinates thereof. For example, if the base of the column 102 is assumed as the origin of the reference Cartesian system, the absolute coordinates of the end-effector 105 can be expressed by three values x, y, z.

[0016] According to a possible embodiment, with reference to the crane 101, the plurality of sensors can include, for example:

1) an angular sensor for measuring the rotation of the column 102 about the axis thereof with respect to a stationary reference;

2) an angular sensor for measuring the rotation of the main arm 103'. This rotation can be absolute, in other words referred to a stationary reference such as the horizontal, or the rotation can be relative, with respect to the column 102;

3) an angular sensor for measuring the rotation of the secondary arm 103". Such rotation can be absolute, in other words referred to a stationary reference, e.g. the horizontal, or can be relative, with respect to the main arm 103';

4) a linear sensor for measuring the translation of the extension 104 with respect to the secondary arm 103".

[0017] For example, the sensors can include linear or angular encoders, magnetostrictive sensors or similar. From the signals of the above cited sensors, it is possible to determine the absolute coordinates of the end-effector 105, by geometrical relationships, as it will be shown in the following.

[0018] The crane 101 comprises a control unit operatively connected to the actuators, for moving them, and to the sensors, for receiving signals indicative of the above cited magnitudes. Moreover, a user interface device 110 connected to the control unit for enabling an operator to manually move the crane and possibly to gain access to other functions, is provided. For example, the user interface device can comprise a remote control, and the control unit can comprise a transmission module for communicating with this latter (a radio transmission module, for example). The operator can visually move the end-effector 105 between following positions by acting for example on a joystick of the remote control.

[0019] With reference to an articulated arm, since the same position of the end-effector 105 can generally correspond to more than one configuration of the crane itself, the movements of the end-effector 105 can be differently performed, in other words by sequentially moving different actuators. Consequently, predefined operative logics are generally provided so that, in order to obtain a certain desired movement of the end-effector, it is possible to select which actuators should be operated for obtaining the same movement. Therefore, the control unit is configured so that, upon an instruction of moving the end-effector towards a certain absolute coordinate, such movement is obtained as a function of a predetermined logic for operating the actuators. For example, an actuating logic can be one adapted to minimize the oil flow rate required for operating the actuators, or to minimize the consumed hydraulic energy. A further logic can be one of the travelled minimum distance of the end-effector for reaching the desired position. A frequently used further criterion, for example, combined with one of the above cited ones, consists of maintaining the actuators far from the stop position. The predetermined operative logics are per se known and therefore will not be particularly described.

[0020] This particularly designed system causes the end-effector 105 to follow a sequence of movements intersecting consecutive points identified by preferably Cartesian absolute coordinates, with respect to the reference system.

[0021] At least one first 1, one second 2, one third 3, and one fourth detecting probes 4 are associated to the crane. Such detecting probes are positioned in different known points of the crane, which can be stationary (the detecting probes can be positioned in the stationary base of the articulated arm, for example) or, as an alternative, can be movable (in other words the detecting probes are fixed to the movable bodies of the articulated arm at known positions, and they move with the movable bodies. Or the detecting probes can be positioned on lateral stabilizing arms of the crane). In the first case, the absolute coordinates invariable with respect to the reference system are known. In the second case, since the movements of the articulated arm are suitably monitored by the above cited sensors, the varying position of the detecting probes can be determined as the articulated arm is gradually moved. According to further variants, it is observed that the detecting probes can be more than four.

[0022] Moreover, an emitting probe 5 capable of communicating with each detecting probe, is provided so that the relative distance between the emitting probe and each detecting probes can be determined. The emitting probe 5 is adapted to be located in the target position.

[0023] The emitting probe 5 and detecting probes 1-4 are preferably of the radio type, still more preferably of the ultra-wideband (UWB) type. Particularly, for example, the emitting probe 5 generates pulses which are sensed by each detecting probe and, based on the time elapsing between the pulse emission and pulse reception, it is possible to determine the relative distance between the emitting probe and the respective detecting probe. It is observed that the measurement that is performed between the emitting probe and detecting probes is of a scalar type, in other words it is only possible to determine a distance, but not a relative position, between the emitting probe and the respective detecting probe. In other words, the information obtained from each pair of emitting probe-detecting probe is that the emitting probe lies on the surface of a sphere having as a center the detecting probe and as a radius the detected distance between the detecting probe and emitting probe. Moreover, it is observed that the terms "emitting" and "detecting" are given only in a conventional way. Therefore, alternatively, the pulse can be emitted by the detecting probes and detected by the emitting probe.

[0024] Advantageously, the emitting probe 5 is positioned on the user interface device 110, in order to calculate the distance among such user interface device and the four detecting probes. The control unit is operatively connected to the detecting probes and emitting probes, for example by a Wi-Fi communication module.

[0025] The control unit is capable of determining the position of the emitting probe 5 and, for this matter, at a plurality of consecutive sampling instants distanced from each other by a sampling time, it is configured to:

- detect the signals from the detecting probes 1-4 and from the emitting probe 5, which are indicative of the relative distance between the respective detecting probe and emitting probe;
- estimate, based on signals from the four emitting probes 1-4 and detecting probe 5, the actual absolute position of the emitting probe;
- determine the actual absolute position of the end-effector 105 based on signals from the sensors;
- operate the actuators so that the end-effector 105 moves towards the estimated actual absolute position of the emitting probe 5. The actuators can be actuated as a function of the predetermined logic, according to what was previously discussed.

[0026] Since the above described steps are iteratively performed, in other words at each sampling instant, the system will be capable to approach the end-effector 105 to the target position, determined by the emitting probe 5, both when this latter is still, and when this latter is moving. Indeed, in the first case, variations in the absolute position of the emitting probe 5 during the following sampling instants are not detected, so that the end-effector 105 will continue to follow its movement until it reaches it. In the second case, at each sampling instant, a new absolute position of the emitting probe will be determined and therefore the control unit updates the movement logic of the actuators for taking into account the variation of the target position.

[0027] Possible modes by which positions relevant for the present invention, in other words the position of the end-effector 105 and the position of the detecting probe 5 are determined, will be more specifically described.

[0028] With reference to Figure 2, it schematically shows an articulated arm 101 provided with a column 102 (simply outlined in the example as perfectly vertical, however it can form a determined inclination angle with the vertical) of a length a, a main arm 103' of a length b and rotatable with respect to the column 102, and a secondary arm 103" rotatable with respect to the main arm 103' and of a length c, wherein the secondary arm 103" further comprises one or more extensions 104 which project of a varying amount Δd with respect to the secondary arm 103". The sensors of the articulated arm comprise a sensor for measuring the angle α between the main arm 103' and horizontal, a sensor for measuring the angle β between the secondary 103" and horizontal, a sensor for measuring the linear projection amount Δd of the extensions 104 with respect to the secondary arm 103". Moreover, a rotation sensor of the column 102, capable of detecting an angle θ with respect to a stationary reference, for example the base of the articulated arm, is provided.

[0029] On the assumption that the origin of the reference Cartesian coordinates x, y, z is at the base of the column 102, then the absolute coordinates of the end-effector 105, which depend on the configuration of the articulated arm, can be calculated by the following relationships, obtainable by measures from the above cited relative angular and linear sensors:

$$x = [b \cdot \cos\alpha + (c + \Delta d) \cdot \cos\beta] \cdot \cos\theta$$

$$y = a + b \cdot \sin\alpha + (c + \Delta d) \cdot \sin\beta$$

$$z = [b \cdot \cos\alpha + (c + \Delta d) \cdot \cos\beta] \cdot \sin\theta$$

[0030] With reference to the detecting probes 1, 2, 3, 4, they will respectively have absolute coordinates with respect to the same reference system x, y, z: x1, y1, z1; x2, y2, z2; x3, y3, z3 and x4, y4, z4. If the detecting probes are in a stationary position, such absolute coordinates are known and do not change over time. On the contrary, if one or more of them are fixed to movable parts of the articulated arm in known positions, the absolute coordinates thereof will vary over time, but are anyway obtainable at each sampling instant by mathematical relationships analogous to the ones given for determining the absolute coordinates of the end-effector 105.

[0031] The emitting probe 5, positioned for example on the remote control, in turn has the coordinates xT, yT, zT which can be fixed or variable.

[0032] According to a possible embodiment, the control unit is configured to estimate, at each sampling instant, the actual absolute position of the emitting probe 5, in other words the target position, as an intersection point of four spheres respectively having as a center the absolute coordinate of the respective detecting probe, and as a radius, the distance between said detecting probe and emitting probe.

[0033] According to a possible embodiment, for the purpose of reducing the computational load for determining the intersection point of four spheres, the control unit is configured to:

- determine the absolute coordinates of the two intersection points of three spheres respectively having, as a center, the absolute coordinate of the first 1, second 2 and third detecting probes 3, and as a radius the distance between the respective detecting probe and the emitting probe 5;
- identify as actual absolute coordinates of the target position, the point between the said two intersection points, which is contained in the volume of a sphere having as a center the absolute coordinate of the fourth detecting probe 4, and as a radius the distance between the fourth detecting probe 4 and emitting

probe 5.

[0034] What said before is based on the fact that all the detecting probes are capable of correctly communicating with the emitting probe. Sometimes, for example, the distance between at least one detecting probe and the emitting probe is not detectable due to intervening obstacles, at a certain sampling instant (which can be the first, or also a sampling instant intermediate during the movement of the end-effector 105). In this case, according to the number of the missing measurements, the control unit can operate in the following way.

[0035] If it is not possible to determine the distance between only one of the detecting probes, for example the first one, and the emitting probe, the control unit is advantageously configured to:

- determine the absolute coordinates of two intersection points of the three spheres respectively having as a center the absolute coordinate of the second, third and fourth detecting probes, and as a radius the distance between the respective detecting probe and emitting probe;
- identify as absolute coordinates of the target position the point, of said two intersection points, nearest to the absolute position of the emitting probe estimated at the previous sampling instant. This approximation assumes that the target position did not move between two consecutive sampling instants or, if it moved, it moved at a reduced speed. This is compatible with the fact that the target position preferably is the same as the position of the user interface device, which moves at the walking speed of an operator.

[0036] More advantageously, if, on the contrary, it is not possible to determine the distances between two of the detecting probes and the emitting probe, the control unit is configured to identify as absolute coordinates of the target position the absolute coordinates of the target position determined at the previous sampling instant. If these previously cited coordinates are not available, for example because the considered sampling instant is the first, preferably the control unit does not perform the automatic movement of the end-effector 105 due to safety reasons.

[0037] Preferably, the control unit moves the actuators so that the end-effector 105 reaches the target position according to a substantially rectilinear trajectory. In the presence of hydraulic actuators, still more preferably, the movement strategy consists of minimizing the oil flow rate to the actuators, required for the motion, or the consumed hydraulic energy.

[0038] Preferably, the control unit moves the actuators so that the end-effector 105 moves according to a ramp speed, in other words so that it gradually accelerates when it starts moving, then moves at an approximately constant speed and finally gradually slows in proximity of the target position.

[0039] According to a possible embodiment, the control unit moves the actuators so that the end-effector 105 moves to a position in proximity of a distance from the target position. In this way, the end-effector is prevented from hitting an operator handling the user interface device, particularly when the operator is still.

[0040] Alternatively or in addition, the user interface device comprises a storing command so that, upon activating it, the target position is held fixed and is not updated after a certain sampling instant even though the emitting probe 5 is moved. In this way, the operator handling the user interface device provided with the emitting probe, is allowed to move from his/her initial position, in which he/she started the automatic movement process, without being reached by the end-effector 105 since this latter will stop moving on its arrival in the stored target position.

[0041] Advantageously, the user interface device comprises a tracking actuation command which must be kept pressed in order to start and hold the above described automatic movement process of the end-effector towards the target position. The process is automatically stopped when such command is released. Also this feature is designed for the safety of the operator.

[0042] It is observed that, in the present description and in the attached claims, the control unit, and also the elements indicated by the term "module", can be implemented by hardware devices (central units, for example), by software or by a combination of hardware and software.

[0043] A person skilled in the art in order to satisfy specific contingent requirements could add many additions, modifications or substitutions of elements with other operatively equivalent ones to the described embodiments, without falling out the scope of the attached claims.

Claims

1. System for automatically moving an articulated arm (101) towards a target position, comprising:

- said articulated arm (101) comprising a plurality of consecutively connected bodies forming an open kinematic chain with an end-effector (105), having a plurality of translative and/or rotative degrees of freedom and a plurality of actuators for moving said bodies;
- a plurality of sensors associated to said bodies, adapted to supply signals representative of linear or angular positions such to enable to determine the absolute coordinates of the end-effector (105);
- a user interface device configured for commanding the articulated arm by an operator;
- an emitting probe (5) positioned in the target position, and at least one first (1), one second

(2), one third (3) and one fourth detecting probes (4), each positioned in a predetermined different point of the articulated arm, and adapted to communicate with the emitting probe so that each emitting probe-detecting probe pair provides a signal indicative of the relative distance thereof;
- a control unit operatively connected to said actuators, sensors, emitting probe, detecting probes, and user interface device, said control unit being configured for, at each sampling instant of a plurality of subsequent sampling instants:

- estimating, based on the signals from said first, second, third, fourth emitting probes (1, 2, 3, 4) and from said detecting probe (5) the actual absolute position of the emitting probe (5);
- determining the actual absolute position of the end-effector (105) based on the signals from said sensors;
- actuating the actuators so that the end-effector (105) moves towards the estimated actual absolute position of the emitting probe (5).

2. System according to claim 1, wherein the control unit is configured for estimating, at each sampling instant, the actual absolute position of the emitting probe (5) as an intersection point of four spheres having as a center the absolute coordinate of the respective detecting probe, and as a radius the distance between said detecting probe and emitting probe.

3. System according to claim 1 or 2, wherein at each sampling instant the control unit is configured for:

- determining the actual absolute coordinates of the two intersection points of three spheres having respectively as a center the absolute coordinate of the first (1), second (2) and third detecting probes (3), and as a radius the distance between the respective detecting probe and the emitting probe (5);
- identifying, as the actual absolute position of the emitting probe (5), the point, between said two intersection points, which is comprised in the volume of the sphere having as a center the absolute coordinate of the fourth detecting probe (4), and as a radius the distance between the fourth detecting probe (4) and the emitting probe (5).

4. System according to any of the preceding claims, wherein the control unit is configured for, in absence of a communication between the first detecting probe (1) and emitting probe (5), at a sampling instant:

- determining the absolute coordinates of two intersection points of three spheres having respectively as a center the absolute coordinate of the second (2), third (3), and fourth detecting probes (4) and as a radius the distance between said detecting probe and the emitting probe (5);
- identifying, as absolute coordinates of the emitting probe (5), the point, between said two intersection points, nearest to the absolute position of the emitting probe (5) estimated at the previous sampling instant.

5. System according to any of the preceding claims, wherein the control unit is configured for, in absence of a communication between two detecting probes and the emitting probe at a sampling instant, identifying as actual absolute coordinates of the emitting probe (5), the absolute coordinates of the emitting probe (5) estimated at the previous sampling instant.

6. System according to any of the preceding claims, wherein said first (1) and/or second (2) and/or third (3) and/or fourth emitting probes (4) are connected to the articulated arm (101) so that the absolute coordinates thereof are constant or are fixedly connected in predetermined positions to the bodies of the articulated arm or to movable parts of the articulated arm.

7. System according to any of the preceding claims, wherein the user interface device (110) is movable and the emitting probe (5) is disposed on the user interface device (110).

8. System according to any of the preceding claims, wherein the control unit is configured for moving the actuators so that the end-effector (105) moves to a position in proximity of and at a distance from the target position.

9. System according to any of the preceding claims, wherein said user interface device comprises a storing command, and the control unit is configured for storing the last target position determined before activating the storing command and for holding it also upon movements of the emitting probe.

10. System according to any of the preceding claims, wherein said user interface device comprises a starting and holding command, the control unit being configured for moving the end-effector (105) towards the target position only until said starting and holding command is active.

11. System according to any of the preceding claims, wherein said absolute coordinates of the end-effector (105) are absolute cartesian coordinates in a 3D space.

12. System according to any of the preceding claims, wherein said articulated arm (101) comprises an articulated crane.

13. System according to the preceding claim, wherein said articulated crane comprises a column (102) rotatable around its axis, a main arm (103’) rotatable around the column (102), a secondary arm (103") rotatable with respect to the main arm (103’) and comprising at least one extension translatingly extendable with respect to the secondary arm itself, and said plurality of sensors comprises an angular sensor for measuring the rotation of the column (102) around its axis, an angular sensor for measuring the absolute rotation of the main arm (103’), an angular sensor for measuring the absolute rotation of the secondary arm (103"), a linear sensor for measuring the translation of the at least one extension (104) with respect to the secondary arm (103").

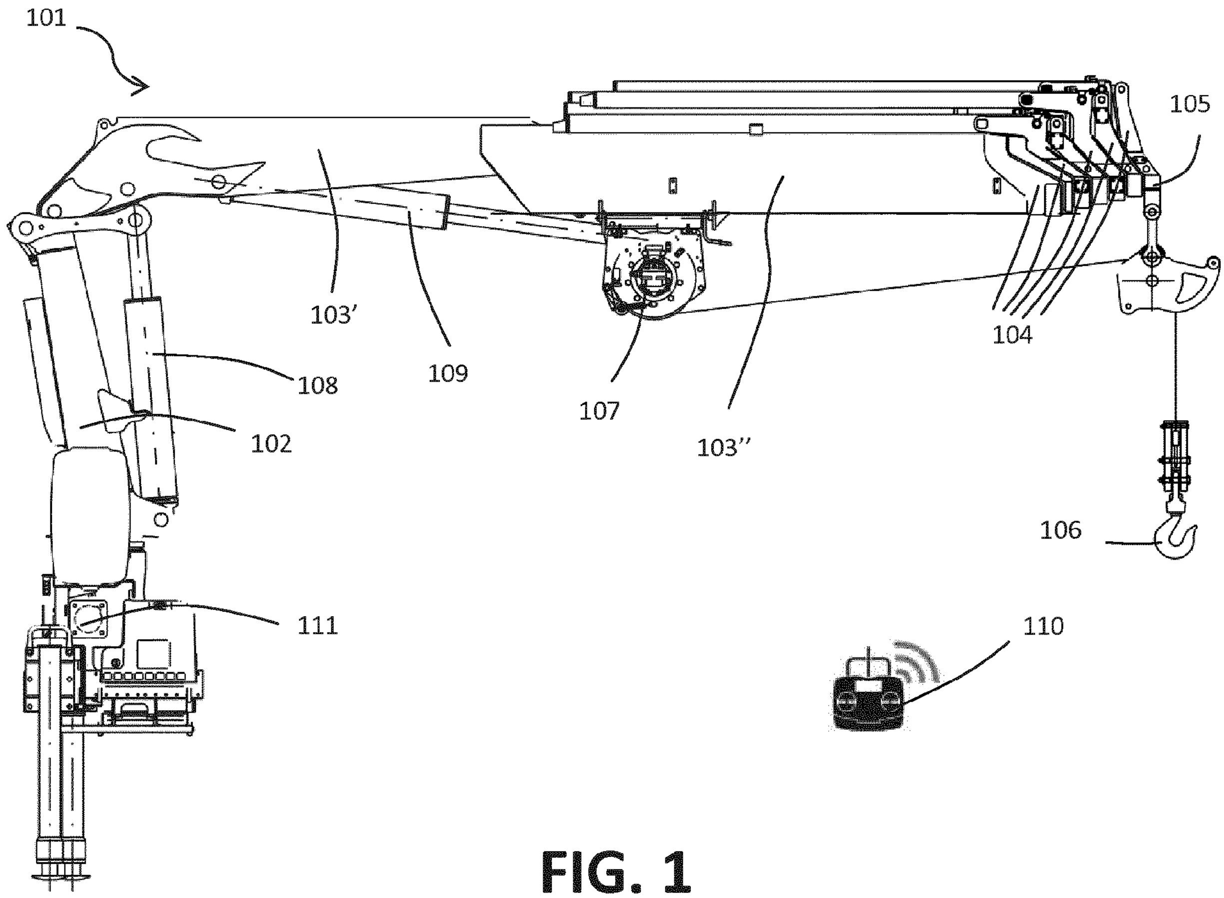
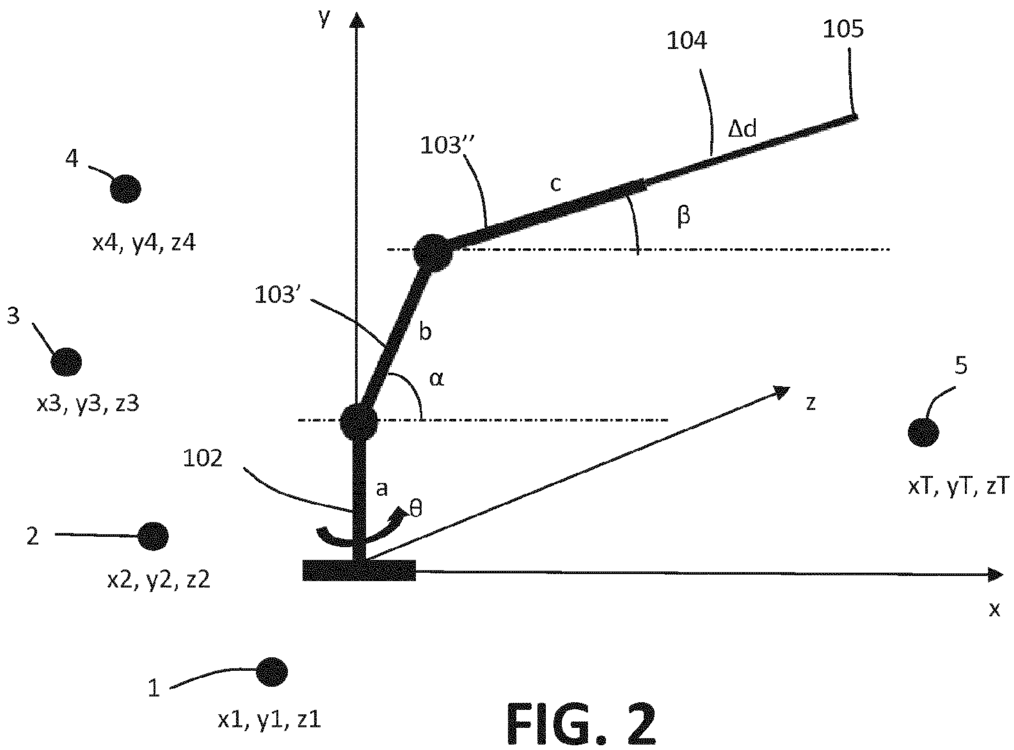

101
105
103'
109
108
104
107
102
103''
106
111
110

FIG. 1


y
104
105
4
103''
Δd
c
β
x4, y4, z4
103'
3
b
α
5
z
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102
xT, yT, zT
a
θ
2
x2, y2, z2
x
1
x1, y1, z1

FIG. 2

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EUROPEAN SEARCH REPORT

Application Number
EP 19 15 3048

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
A	US 2010/095835 A1 (YUAN QINGHUI [US] ET AL) 22 April 2010 (2010-04-22) * paragraph [0004] - paragraph [0005] * * paragraph [0032] * * figures 1, 2, 4 * * see the 4 actuator sensors: 72a, 72b, 72c & 72d * * claims 1, 7 * * 60 is the controller * -----	1-13	INV. B66C13/04 B66C13/18 B66C13/40 B66C13/46
A	EP 1 327 601 A1 (POTAIN SA [FR]) 16 July 2003 (2003-07-16) * paragraph [0001] * * paragraph [0028] * * see the 12 sensors: 36, 37, 38, 39, 40, 41,42,43, 444, 45, 46, 47 * * see the figures, but especially the figures 7 to 11 * * 32 is the controller; 33 is a switch & 34 is manual control device * -----	1	
A	JP S62 96300 A (HITACHI CONSTRUCTION MACHINERY) 2 May 1987 (1987-05-02) * figures 1, 2, 3 * * see especially the four angle detectors: 12, 13, 14 & 15 * * see also the controller: 16 * -----	1	TECHNICAL FIELDS SEARCHED (IPC) B66C E04G B66F B25J G05B G01B G01C

The present search report has been drawn up for all claims

1

Place of search	Date of completion of the search	Examiner
The Hague	21 June 2019	Guthmuller, Jacques

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
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EPO FORM 1503 03.82 (P04C01)

ANNEX TO THE EUROPEAN SEARCH REPORT ON EUROPEAN PATENT APPLICATION NO. EP 19 15 3048

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21-06-2019

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For more details about this annex : see Official Journal of the European Patent Office, No. 12/82

REFERENCES CITED IN THE DESCRIPTION

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- EP 1327601 A1 **[0005]**
- JP S6296300 A **[0005]**