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(54) LOAD HANDLING SYSTEM FOR A LIFTING ARRANGEMENT

(57) A load handling system (2) for a lifting arrangement (4) for a free-hanging load (6). The load handling system (2) comprises at least two ranging load radio units (8) structured to be arranged at said load (6) at separate positions, at least three ranging fixed radio units (10) structured to be arranged in relation to said lifting arrangement (4) at separate positions, wherein said separate positions are known. Each of said at least three fixed radio units (10) is configured to measure and determine a distance to each of said ranging load radio units (8), and to generate distance signals (12) in dependence thereto. At least one acceleration sensor (14) and at least one angular velocity sensor (18) are provided and structured to be arranged at the load (6), and configured to generate an acceleration signal (16), and an angular velocity signal (20) respectively.

The load handling system comprises a processing unit (22) configured to receive said distance signals (12), said acceleration signal (16) and wireless angular velocity signal (20), and to calculate positions of said at least two ranging load radio units (8) in dependence of distance values of said distance signals (12). The processing unit (22) is configured to apply an estimation algorithm on said calculated positions, acceleration values and angular velocities, in order to determine three rotation angles (24) being defined as angles at which the load is rotated about x-,y-, and z-axis with respect to said lifting arrangement.

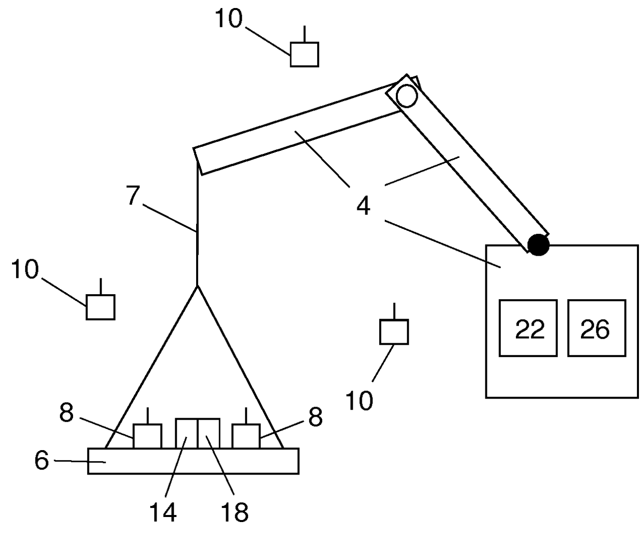

FIG. 2

EP 3 428 110 A1

Description

Technical field

[0001] The present disclosure relates to a load handling system, a lifting arrangement, and a method in relation to the load handling system. In particular the system, arrangement and method aim to achieve an anti-oscillation control of a free-hanging load.

Background

[0002] Articulated, heavy-duty crane systems are well-established in many load handling applications, including construction sites, forestry machines, factories, off-shore, and harbor operations.

[0003] As a distinct feature, many of these systems are under-actuated by nature: only the position/velocity of the crane's tip can be controlled directly to move a load. Therefore, skilled operators have had a key role in controlling each actuator separately via visual feedback. This is, however, prone to human errors and an extensive period of practice is typically required to become familiar with the non-intuitive, open-loop controls.

[0004] Owing to the fact that greater productivity, faster operator training, and increased safety are all simultaneously pursued for within the industry, operator assistance functions, such as automatic load sway damping, put a premium on easy-to-install, cost-effective sensor solutions suitable for providing an appropriate motion feedback. Thereby, to reduce the human element, revealing the state of the load in a continuous manner, any time and under every climatic conditions is of particular interest.

[0005] Investments on cranes are usually associated with the time required for accurate positioning of a payload. Existing anti-oscillation control approaches, broadly speaking, fall into two categories: input shaping and active load sway damping. The first attempts to produce such a trajectory (acceleration profile) for the tip of the crane that oscillations of the system are not produced at all, while the latter is based on estimated load dynamics. However, these solutions are often subject to observability issues and may require special hoisting arrangements, among others.

[0006] Hence, the focus of the present disclosure is active load damping, where much of the existing research has been centered on gantry and boom cranes. Due to the usual cablings, such as the four-cable hoisting arrangement, and the single-axis movement of the typical gantry cranes found, e.g. in harbors, the load's rotation around its vertical axis is usually limited.

Since this allows observing the sway angle of the load in the vertical plane, an optical encoder with a mechanical interface to the hoisting cabling may be deployed for motion feedback of the payload. However, any twisting of the payload can be falsely interpreted as sway motion. Furthermore, in the case of inertial sensors, such as inclinometers and gyroscopes, computer vision and satellite positioning systems are typically utilized to remove the drifting of the inertial estimates.

However, the applicability of these augmenting systems is often limited in dense urban environments, which may lead to observability issues even under static conditions. While a nonlinear model predictive controller may be implemented, the payload's reference trajectory is usually not known beforehand, particularly, under user-supplied motion control mode, which limits the sway damping performance.

[0007] Another recent effort related to one dimensional degree of freedom (1-DOF) nonlinear load sway control, based on minimizing the total energy of the swinging load, has been disclosed for overhead cranes. However, the positioning error was reported to progressively increase over time, which necessitated the use of time-dependent heuristics. Many promising anti-sway controllers are also validated in small-scale mock-ups only and without addressing the complexity of industry-level crane systems.

[0008] Below some background art will be briefly discussed.

[0009] WO-2008/018912 relates to an aircraft load management system that determines the position of an aircraft cargo hook for display to an aircrew, in addition the system also includes anti-sway-algorithms for active load stability inputs. A wireless communication is provided that facilitates communication between a cargo hook system and the load management system. The wireless communication system includes e.g. a passive or active radio frequency emitter tag within or upon the cargo hook and a multiple of sensors located on the aircraft. The three dimensional position and velocity of the cargo hook may then be calculated.

US-2005/0242052 relates to a method and apparatus for gantry crane sway determination and positioning. A grappler assembly is mounted to a frame structure and a position processing unit is configured to determine a location of the grappler assembly. To determine the position of e.g. the grappler, specific sensors may be applied, e.g. inertial sensors such as gyros and accelerometers; radiofrequency location tags; radar altimeters; laser detectors; optical detectors may be placed on the vehicle or the grappler.

US-9352940 relates to a radio frequency identification (RFID) tower crane load locator and sway indicator that includes a plurality of RFID tags at different locations on or around the crane, and at least two RFID readers at different locations on the crane. A RFID tag may be provided at a hook and RFID readers are applied to measure the distance to, and thus, the position of the hook.

[0010] Competing or alternative solutions typically rely either on computer vision, traditional motion sensors, or hoisting arrangements. In some related work, computer vision and satellite positioning systems are utilized to remove the drifting of the inertial estimates. However, the applicability of such augmenting systems is often limited in dense urban environments or prone to changing environmental conditions.

[0011] The object of the present invention is to achieve an improved system, arrangement and method for transferring a load to a desired position in minimum time with maximum accuracy, positioning of the load without overshoot, and limiting the sway angle to a low value for safety restrictions. A more specific object is to achieve an improved system, arrangement and method that are particularly applicable in dense urban environments and not being prone to changing environmental conditions.

Summary

[0012] The above-mentioned object is achieved by the present invention according to the independent claims.

[0013] Preferred embodiments are set forth in the dependent claims.

[0014] Thus, according to a first aspect the present invention relates to a load handling system (2) for a lifting arrangement (4) for a free-hanging load (6). The load handling system (2) comprises at least two ranging load radio units (8) structured to be arranged at said load (6) at separate positions, at least three ranging fixed radio units (10) structured to be arranged at said lifting arrangement (4) at separate positions, wherein said separate positions are known, and wherein each of said at least three fixed radio units (10) is configured to measure and determine a distance to each of said ranging load radio units (8), and to generate distance signals (12) in dependence thereto. In addition is provided at least one acceleration sensor (14) configured to be arranged at said load (6), and configured to measure and determine acceleration values, and to generate an acceleration signal (16) in dependence thereto, and at least one angular velocity sensor (18) configured to be arranged at said load (6), and configured to measure and determine angular velocity values, and to generate an angular velocity signal (20) in dependence thereto. The load handling system further comprises a processing unit (22) configured to receive said distance signals (12), said acceleration signal (16) and wireless angular velocity signal (20), and to calculate positions of said at least two ranging load radio units (8) in dependence of distance values of said distance signals (12). The processing unit (22) is further configured to apply an estimation algorithm on said calculated positions, acceleration values and angular velocities, in order to determine three rotation angles (24) being defined as angles at which the load is rotated about x-,y-, and z-axis with respect to said lifting arrangement.

[0015] The thus defined load handling system is advantageous in that it provides an active damping of oscillation of a load that is founded upon delay less, direct motion feedback from a payload using cost-effective ranging radios and inertial sensing. With the aid of real-time sensor fusion, the swaying angles of the payload can be estimated in real-time for automatic suppression of any oscillation induced by the inertia on the movement of the load. Furthermore, since easy-to-install inertial sensing and ranging radios are used only, no mechanical parts subject to wear or failures are required.

[0016] According to an embodiment, the ranging load radio units (8) and the ranging fixed radio units (10) are ultra-wide band (UWB) ranging radio units.
The UWB radios provide high ranging/positioning accuracy in dynamic no-line-of-sight environments and under the presence multi-path reflections, and are particularly useful for positioning in dense urban environments.
Since the used UWB radios operate on ranges up to a few hundred meters, the pairing renders the payload's orientation estimation robust against common-mode ranging errors (e.g. constant multi-path propagation, obstacles). In a way, this mimics the Earth's magnetic field, but since no magnetic field sensor is required, the oscillation damping is immune to the common (magnetic) anomalies and can be easily deployed to GPS-denied urban environments (e.g. indoors, harbours, etc.).

[0017] In another embodiment the calculated positions, acceleration values and angular velocities to be input to said estimation algorithm to determine the rotation angles at a specific point of time, are all associated to that point of time.

[0018] According to still another embodiment the estimation algorithm includes using sensor fusion, preferably a quaternion-based complementary filter. Using such a filter provides a practical solution for a 3-axis attitude estimation in real-time.

[0019] According to a second aspect the present invention relates to a lifting arrangement (4) comprising a load handling system (2) as defined above. The lifting arrangement comprises a control unit (26) configured to receive the determined three rotation angles (24), and to determine a set of control instructions (28) in dependence of said rotation angles, such that said control instructions are determined to suppress oscillations induced by inertia on movement of the load (6), and to apply said control instructions to control members of said lifting arrangement (2). Thereby an advantageous high overall motion control performance is achieved comprising both low and high speed swaying motions of a free-hanging load.

[0020] According to one embodiment the lifting arrangement comprises a one hoisting cable arrangement, or a gantry or quay-side container crane that comprises a four hoisting cable arrangement. Thus, the herein defined motion control is generally applicable in many various types of lifting arrangements.

[0021] According to a further embodiment the lifting arrangement (4), the set of control instructions (28) is determined by a closed-loop motion control, e.g. a linear quadratic regulator (LQR). Using an LQR sway damping control in combination with internal tip motion control of the lifting arrangement (4) is advantageous as it enables controlling movement of the load to a new position as soon as possible, while concurrently keeping a sway angle at zero, or close to zero.

[0022] According to a third aspect of the present invention a method of a load handling system in a lifting ar-

rangement for a free-hanging load is provided. The load handling system comprises at least three ranging fixed radio units arranged at separate positions in relation to said lifting arrangement, wherein the separate positions are known.
The method comprises:

- arranging at least two ranging load radio units at said load at separate positions,
- arranging at least one acceleration sensor at said load, measuring and determining acceleration values, and generating an acceleration signal in dependence thereto,

- arranging at least one angular velocity sensor at said load, measuring and determining angular velocity values, and generating an angular velocity signal in dependence thereto, and
- measuring and determining, by each of said at least three fixed radio units, a distance to each of said ranging load radio units, and generating distance signals in dependence thereto.

The method further comprises:

- receiving, by a processing unit, said distance signals, said acceleration signal and said angular velocity signal,
- calculating positions of said at least two ranging load radio units in dependence of distance values of said distance signals,
- applying an estimation algorithm on said calculated positions, acceleration values and angular velocities, and
- determining three rotation angles being defined as angles at which the load is rotated about x-,y-, and z-axis with respect to said lifting arrangement.

[0023] According to one embodiment the ranging load radio units and the ranging fixed radio units are ultra-wide band (UWB) ranging radio units. This is advantageous for the reasons stated above in connection with the description of the load handling system.

[0024] According to a further embodiment the estimation algorithm includes using sensor fusion, e.g. a quaternion-based complementary filter. Using such a filter provides a practical solution for a 3-axis attitude estimation in real-time.

[0025] According to still another embodiment the method comprises:

receiving, by a control unit, said determined three rotation angles,
determining a set of control instructions in dependence of said rotation angles, such that said control instructions are determined to suppress oscillations induced by inertia on movement of the load, and
applying said control instructions to control members of said lifting arrangement. Thereby an advantageous high overall motion control performance is achieved comprising both low and high speed swaying motions of a free-hanging load.

[0026] In a further embodiment the method comprises determining the set of control instructions by applying a linear quadratic regulator (LQR), which is advantageous in order to achieve a robust control method for keeping the sway angle close to zero.

[0027] In the following a discussion is presented giving further background and motivation of, and stating advantages to, the system, arrangement and method disclosed herein and which are claimed by the appended claims.

[0028] Load stabilizing control for a freely-hanging load, which was founded on easy-to-install inertial sensor and low-cost UWB ranging radios, was developed and validated experimentally using a hydraulically powered, articulated heavy-duty manipulator.
First, a new unit vector representation was proposed to solve the load's state. The vector representation avoided the algebraic reconstruction of the popular Euler angles and is thereby ideally suited for embedded implementations. Afterward, for delay-less motion feedback of the payload, the sensors were fused by suitably balancing the relative confidence of the inertial and UWB radio measurements using a quaternion-based filter, which provided a practical solution for the longstanding problem for 3-axis attitude estimation in real-time. Then, high overall motion control performance was demonstrated through a suite of experiments comprising both low and high speed swaying motions of the freely-hanging payload. The experiments demonstrated completely drift-free performance for the first time.
It is avoided the problem of extensive system modeling effort, which is often required in the form of observer design, by introducing the radio-aided motion feedback of the payload. This highlights the fact that advanced, user assisting motion control systems may benefit significantly from the adaptation of wireless local ranging/positioning technologies, which can be founded upon relatively low-cost components. Evidently, as acceleration of the tip of the manipulator was the only input to the dynamic model of the swaying load underlying, it is possible to limit the excitation of an under-actuated system by only using low levels of acceleration/deceleration. This was validated by the results on accurate trajectory following, showing increased performance in load positioning, especially under the presence of large oscillatory disturbances. Such disturbances may be caused in practice by wind, collisions, or rapid changes in the user-commanded movement direction when, for example, loading/unloading of the payload is carried out repetitively and fast. The results also clearly point toward the conclusion that high values of the tip acceleration can be used in the user-supplied control mode while maintaining the load at low sway angles. This enables safer point-to-point load positioning and more responsive system in

general.

Note that, owing to the easy-to-install nature of the sensors used and the fact that the load stabilization and the manipulator control dynamics were treated as separate entities, the results are by no means limited to an articulated hydraulic manipulator only. For instance, since the UWB radios are easy to use in urban environments, the results may be considered equally applicable to gantry or quay-side container cranes that often comprise a four hoisting cable arrangement with stringent motion suppression requirements.

Brief description of the drawings

[0029]

Figure 1 is a block diagram schematically illustrating the load handling system and the lifting arrangement according to the present invention.

Figure 2 is a schematic illustration of a lifting arrangement according to the present invention.

Figure 3 is a flow diagram illustrating the method according to the present invention.

Detailed description

[0030] The load handling system, the lifting arrangement, and the method will now be described in detail with references to the appended figures. Throughout the figures the same, or similar, items have the same reference signs. Moreover, the items and the figures are not necessarily to scale, emphasis instead being placed upon illustrating the principles of the invention.

[0031] With references to the schematic block diagram in figure 1 a load handling system 2 is provided suitable for a lifting arrangement 4 for a free-hanging load 6.

The lifting arrangement 4 comprises e.g. a one hoisting cable arrangement, e.g. a crane, or a gantry or quay-side container crane that comprises a four hoisting cable arrangement, or any other type of lifting arrangement for lifting a free-hanging load. In figure 2 a one cable hoisting arrangement is illustrated comprising one hoisting cable 7. The load may be a pallet, a container, a fork to lift the load, etc.

[0032] The load handling system 2 comprises at least two ranging load radio units 8 structured to be arranged at the load 6 at separate positions. The load radio units 8 to be arranged at the load are attached to the load by any type of fastening means (not shown), e.g. some straps, adhesive, etc. that facilitates user-friendly and firm attachment of the radio units to the load.

[0033] The load handling system further comprises at least three ranging fixed radio units 10 structured to be arranged at separate positions in relation to the lifting arrangement 4, such that the separate positions of the fixed radio units are known. The fixed radio units are fixed in relation to each other and in relation to the lifting arrangement and define a reference coordinate system. A higher number of fixed radio unit may be advantageous in order to improve the accuracy, e.g. in the range of 4-8 radio units.

Each of the at least three fixed radio units 10 is configured to measure and determine a distance to each of the ranging load radio units 8 at the load, and to generate distance signals 12 in dependence thereto.

[0034] At least one acceleration sensor 14 is provided, configured to be arranged at the load 6, and configured to measure and determine acceleration values, and to generate an acceleration signal 16 in dependence thereto, which preferably is wireless. The acceleration is measured by using a linear 3-axis acceleration sensor that measures inertial acceleration. Particularly, an inertial MEMS sensor is used featuring a digital 3-axis +/- 5 g accelerometer.

[0035] The load handling system further comprises at least one angular velocity sensor 18, configured to be arranged at the load 6, and configured to measure and determine angular velocity values, and to generate an angular velocity signal 20 in dependence thereto, which preferably is wireless. The angular velocity may be sensed by a 3-axis rate gyro sensor, and specifically a 3-axis +/- 450 °/s angular rate gyroscope.

A sensor applicable for determining the angular velocity works in accordance with the principle of a gyroscope. A gyroscope is a spinning wheel or disc in which the axis of rotation is free to assume any orientation by itself. When rotating, the orientation of this axis is unaffected by tilting or rotation of the mounting, according to the conservation of angular momentum. Because of this, gyroscopes are useful for measuring or maintaining orientation. Gyroscopes based on other operating principles also exist, such as the electronic, microchip-packaged MEMS gyroscopes found in consumer electronics devices, solid-state ring lasers, fibre optic gyroscopes, and the extremely sensitive quantum gyroscope. Herein, MEMS gyroscope has been found particularly useful.

[0036] The load handling system further comprises a processing unit 22 configured to receive the distance signals 12, the wireless acceleration signal 16 and the wireless angular velocity signal 20, and to calculate positions of the at least two ranging load radio units 8 in dependence of distance values of the distance signals 12.

[0037] The processing unit 22 is configured to apply an estimation algorithm on the calculated positions, acceleration values and angular velocities, in order to determine three rotation angles 24 being defined as angles at which the load is rotated about x-, y-, and z-axis with respect to the lifting arrangement.

[0038] According to one embodiment the ranging load radio units 8 and the ranging fixed radio units 10 are ultra-wide band (UWB) ranging radio units. More specifically each radio unit comprises a wireless transceiver module with an integrated antenna, enabling real-time position to a precision of typically some 10 cm for ranges of up to a few hundred meters.

[0039] UWB is a radio technology that can use a very

low energy level for short-range, high-bandwidth communications over a large portion of the radio spectrum. UWB has traditional applications in non-cooperative radar imaging. Most recent applications target sensor data collection, precision locating and tracking applications. Unlike spread spectrum, UWB transmits in a manner that does not interfere with conventional narrowband and carrier wave transmission in the same frequency band. Ultra-wideband is a technology for transmitting information spread over a large bandwidth (>500 MHz); this should, in theory and under the right circumstances, be able to share spectrum with other users.
A significant difference between conventional radio transmissions and UWB is that conventional systems transmit information by varying the power level, frequency, and/or phase of a sinusoidal wave. UWB transmissions transmit information by generating radio energy at specific time intervals and occupying a large bandwidth, thus enabling pulse-position or time modulation. The information can also be modulated on UWB signals (pulses) by encoding the polarity of the pulse, its amplitude and/or by using orthogonal pulses. UWB pulses can be sent sporadically at relatively low pulse rates to support time or position modulation, but can also be sent at rates up to the inverse of the UWB pulse bandwidth. Pulse-UWB systems have been demonstrated at channel pulse rates in excess of 1.3 gigapulses per second using a continuous stream of UWB pulses (Continuous Pulse UWB or C-UWB), supporting forward error correction encoded data rates in excess of 675 Mbit/s.

[0040] An important aspect of UWB technology is the ability for a UWB radio system to determine the "time of flight" of the transmission at various frequencies, that helps overcome multipath propagation. With a cooperative symmetric two-way metering technique, distances can be measured to high resolution and accuracy by compensating for local clock drift and stochastic inaccuracy. Another feature of pulse-based UWB is that the pulses are very short (less than 60 cm for a 500 MHz-wide pulse, less than 23 cm for a 1.3 GHz-bandwidth pulse) - so most signal reflections do not overlap the original pulse, and there is no multipath fading of narrowband signals.

[0041] It has been found that it is advantageous of using the UWB technology herein to determine the distances to the load radio units, as it provides high ranging/positioning accuracy in dynamic no-line-of-sight environments and under the presence multi-path reflections.

[0042] According to another embodiment the calculated positions, acceleration values and angular velocities to be input to the estimation algorithm to determine the rotation angles at a specific point of time, are all associated to that point of time. Preferably, the processing unit 22 is configured to continuously determine the three rotation angles 24 when the lifting arrangement 4 is in a loading procedure state.

[0043] According to an embodiment the estimation algorithm includes using sensor fusion, such as a quaternion-based complementary filter. As an alternative the estimation algorithm may also be implemented by using rotation matrices which may require additional computations. Complementary filters are e.g. discussed in: R. Mahony, T. Hamel, and J.-M. Pflimlin, "Nonlinear complementary filters on the special orthogonal group," IEEE Trans. Automat. Contr., vol. 53, no. 5, pp. 1203 - 1218, Jun. 2008.

[0044] Estimation algorithms refer to techniques that produce estimates of unknown variables in statistical models and often target to be more accurate than those based on a single measurement alone. Herein a low-delay, low-noise estimate of the true rotation of the freely-hanging load can be solved by using an estimation algorithm that combines the load-fixed gyroscope readings with measurements from accelerometers and ranging radios, which typically have low resolutions.

[0045] Quaternions are often preferable for representing three-dimensional rotations in terms of efficiency. For example, compared to the 3-by-3 rotation matrix representation, only four real numbers are required instead of nine. From the well-known Euler angles viewpoint, the quaternion representation also avoids the significant problem of the gimbal lock, which refers to the loss of a degree of freedom when two axis of rotations become parallel.

[0046] From the 3-by-3 rotation matrix representation viewpoint, which is widely applied in the field of inertial sensing, the three-dimensional rotation of a body is often reconstructed by applying constraints in a sequence. That is, the rotational degrees of freedom are resolved algebraically one-by-one using a set of body-fixed inertial sensors. Referring to the nonlinear complementary filter used herein for the motion state estimation of the freely hanging load, the quaternion representation allows propagation of the three-dimensional rotation estimate while using the sensory readings as such (i.e., without applying constraints in a sequence or algebraic manipulation).

[0047] In the domain of sensor fusion, complementary filtering is a general term for describing estimation techniques that provide means to fuse multiple independent measurements from a set of sensors while simultaneously minimizing individual error sources without knowledge of the exact frequency content of error sources. For example, unlike the well-known Kalman filter, the complementary filter does not require a statistical time-domain description of the noise corrupting its input signals.

[0048] Referring to the quaternion-based complementary filter used for the motion state estimation of the freely hanging load in in accordance with one embodiment of the present invention, it is worth noting that the gyroscope bias dynamics can be robustly accommodated to produce smoothed, drift-free rotation estimates of the freely hanging load even if either accelerometer or ranging radio readings were temporarily unavailable. This is based on the fact that the relative contribution of different sensors can be preferentially weighted depending on the relative confidence in the sensor readings. For example, in situations where the ranging radios would be subject to significant multipath propagation or dynamically changing non-line-of sight conditions, it may be wise to reduce the relative weighting of the ranging radio data compared to the accelerometer data. On the other hand, if the accelerometer readings become corrupted by high magnitude perturbations, such as those originating from impacts, it may be wise to reduce the relative weighting of the accelerometer data.

[0049] The present invention also relates to a lifting arrangement 4 comprising a load handling system 2 which has been described above. The lifting arrangement 4 may be a crane comprising one or many extendible booms and provided with a crane tip from which a hoisting cable 7 extends. This variation is illustrated in figure 2. The lifting arrangement may also e.g. be implemented as a four hoisting cable arrangement capable of lifting containers.

[0050] The lifting arrangement 4 comprises a control unit 26 configured to receive the determined three rotation angles 24, and to determine a set of control instructions 28 in dependence of the rotation angles. Particularly, the control instructions are determined to suppress oscillations induced by inertia on movement of the load 6, and to apply the control instructions to control members of the lifting arrangement 2. These control instructions may thus control members in order to perform one or many of extending booms, changing angles between booms, changing hoisting cable length, moving the entire lifting arrangement, rotating the lifting arrangement, etc.

[0051] In one embodiment the set of control instructions 28 is determined by closed-loop motion control, e.g. by applying a linear quadratic regulator (LQR).

[0052] One requirement when transporting heavy hanging loads using a crane typically requires that the sway angle is small at all times. Together with the control objective to move the load to a new position as soon as possible, while concurrently keeping the sway angle at zero, this will lead to the natural choice of regulator being an LQR.
Also other control techniques exist that may be applied, e.g. non-linear control methods.

[0053] With references to the flow diagram shown in figure 3 the present invention also relates to a method of a load handling system in a lifting arrangement for a free-hanging load. The load handling system has been described above and comprises at least three ranging fixed radio units arranged at separate positions in relation to the lifting arrangement, and that the separate positions are known. When describing the method it is, where applicable, referred to the description above of the load handling system and the lifting arrangement.

[0054] The method comprises:

> Arranging at least two ranging load radio units at the load at separate positions.
> Arranging at least one acceleration sensor at the load, measuring and determining acceleration values, and generating an acceleration signal in dependence thereto.
> Arranging at least one angular velocity sensor at the load, measuring and
> determining angular velocity values, and generating an angular velocity signal in dependence thereto.
> Measuring and determining, by each of the at least three fixed radio units, a distance to each of the ranging load radio units, and generating distance signals in dependence thereto.

[0055] According to the invention, the method further comprises:

> Receiving, by a processing unit, the distance signals, the acceleration signal and the wireless angular velocity signal.
> Calculating positions of said at least two ranging load radio units in dependence of distance values of said distance signals.

[0056] Applying an estimation algorithm on the calculated positions, acceleration values and angular velocities. And finally:

> Determining three rotation angles being defined as angles at which the load is rotated about x- ,y-, and z-axis with respect to said lifting arrangement

[0057] The ranging load radio units and the ranging fixed radio units are ultra-wide band (UWB) ranging radio units, according to one embodiment.

[0058] The calculated positions, acceleration values and angular velocities to be input to the estimation algorithm to determine the rotation angles at a specific point of time, are all associated to that point of time.

[0059] In another embodiment the method comprises continuously determining the three rotation angles when the lifting arrangement is in a loading procedure state.

[0060] Advantageously, the estimation algorithm includes using sensor fusion, such as quaternion-based complementary filter.

[0061] According to a further embodiment the method comprises receiving, by a control unit, the determined three rotation angles, and determining a set of control instructions in dependence of said rotation angles, such that said control instructions are determined to suppress oscillations induced by inertia on movement of the load. The control instruction is then applied to control members of the lifting arrangement.

[0062] In still another embodiment the method comprises determining the set of control instructions by applying a linear quadratic regulator (LQR).

[0063] In the following, an example is given where the present invention is applied. Herein it is considered the stabilization of a freely hanging, rotating load that is suspended from a heavy-duty hydraulic manipulator by a single rope. To overcome the aforementioned limitations, the 3-axis attitude of the load is determined using a single

inertial measurement unit, comprising an off-the-shelf 3-axis gyroscope and 3-axis linear accelerometer, and a set of cost-effective UWB ranging radios. In particular, it is devised a robust 3-dimensional localization of the radios with outlier rejection by measuring the transmission and reception time of the UWB pulses. Robust outlier rejection is explicitly implemented according to the well-established statistical principles, though earlier results on machine learning could be equally applied at the cost of a time-consuming measurement campaign.
This renders a cost-efficient, practical solution over the well-known satellite positioning and compass technology, which typically become completely useless inside buildings and suffer from loss of accuracy in complex built environments, such as construction sites or cargo hubs with dynamic line-off sight blockages and magnetic anomalies, where the UWB technology potentially provides high ranging accuracy. A linear quadratic regulator load stabilizing controller is then designed to position the load accurately while minimizing load sway in the radial direction of travel.

[0064] The present invention is not limited to the above-described preferred embodiments. Various alternatives, modifications and equivalents may be used. Therefore, the above embodiments should not be taken as limiting the scope of the invention, which is defined by the appending claims.

Claims

1. A load handling system (2) for a lifting arrangement (4) for a free-hanging load (6), the load handling system (2) comprises

- at least two ranging load radio units (8) structured to be arranged at said load (6) at separate positions,
- at least three ranging fixed radio units (10) structured to be arranged at said lifting arrangement (4) at separate positions, wherein said separate positions are known, and wherein each of said at least three fixed radio units (10) is configured to measure and determine a distance to each of said ranging load radio units (8), and to generate distance signals (12) in dependence thereto,
- at least one acceleration sensor (14) configured to be arranged at said load (6), and configured to measure and determine acceleration values, and to generate an acceleration signal (16) in dependence thereto, and
- at least one angular velocity sensor (18) configured to be arranged at said load (6), and configured to measure and determine angular velocity values, and to generate an angular velocity signal (20) in dependence thereto,

characterized in that said load handling system comprises a processing unit (22) configured to receive said distance signals (12), said acceleration signal (16) and wireless angular velocity signal (20), and to calculate positions of said at least two ranging load radio units (8) in dependence of distance values of said distance signals (12), wherein said processing unit (22) is configured to apply an estimation algorithm on said calculated positions, acceleration values and angular velocities, in order to determine three rotation angles (24) being defined as angles at which the load is rotated about x-,y-, and z-axis with respect to said lifting arrangement.

2. The load handling system (2) according to claim 1, wherein said ranging load radio units (8) and said ranging fixed radio units (10) are ultra-wide band (UWB) ranging radio units.

3. The load handling system (2) according to claim 1 or 2, wherein said calculated positions, acceleration values and angular velocities to be input to said estimation algorithm to determine said rotation angles at a specific point of time, are all associated to that point of time.

4. The load handling system (2) according to any of claims 1-3, wherein said estimation algorithm includes using sensor fusion, preferably a quaternion-based complementary filter.

5. A lifting arrangement (4) comprising a load handling system (2) according to any of claims 1-4, comprising a control unit (26) configured to receive said determined three rotation angles (24), and to determine a set of control instructions (28) in dependence of said rotation angles, such that said control instructions are determined to suppress oscillations induced by inertia on movement of the load (6), and to apply said control instructions to control members of said lifting arrangement (2).

6. The lifting arrangement (4) according to claim 5, comprising a one hoisting cable arrangement, or a gantry or quay-side container crane that comprises a four hoisting cable arrangement..

7. The lifting arrangement (4) according to claim 6, wherein said set of control instructions (28) is determined by closed-loop motion control, preferably a linear quadratic regulator (LQR).

8. A method of a load handling system in a lifting arrangement for a free-hanging load, the load handling system comprises at least three ranging fixed radio units arranged at separate positions in relation to said lifting arrangement, wherein said separate positions are known, the method comprises:

- arranging at least two ranging load radio units at said load at separate positions,
- arranging at least one acceleration sensor at said load, measuring and determining acceleration values, and generating an acceleration signal in dependence thereto,
- arranging at least one angular velocity sensor at said load, measuring and determining angular velocity values, and generating an angular velocity signal in dependence thereto, and
- measuring and determining, by each of said at least three fixed radio units, a distance to each of said ranging load radio units, and generating distance signals in dependence thereto,

characterized in that the method further comprises:

- receiving, by a processing unit, said distance signals, said acceleration signal and said angular velocity signal,
- calculating positions of said at least two ranging load radio units in dependence of distance values of said distance signals,
- applying an estimation algorithm on said calculated positions, acceleration values and angular velocities, and
- determining three rotation angles being defined as angles at which the load is rotated about x-,y-, and z-axis with respect to said lifting arrangement.

9. The method according to claim 8, wherein said ranging load radio units and said ranging fixed radio units are ultra-wide band (UWB) ranging radio units.

10. The method according to claim 8 or 9, wherein said calculated positions, acceleration values and angular velocities to be input to said estimation algorithm to determine said rotation angles at a specific point of time, are all associated to that point of time.

11. The method according to any of claims 8-10, wherein said estimation algorithm includes using sensor fusion, preferably a quaternion-based complementary filter.

12. The method according to any of claims 8-11, comprising:

receiving, by a control unit, said determined three rotation angles,
determining a set of control instructions in dependence of said rotation angles,
such that said control instructions are determined to suppress oscillations induced by inertia on movement of the load, and
applying said control instructions to control members of said lifting arrangement.

13. The method according to claim 12, comprising determining said set of control instructions by applying a linear quadratic regulator (LQR).

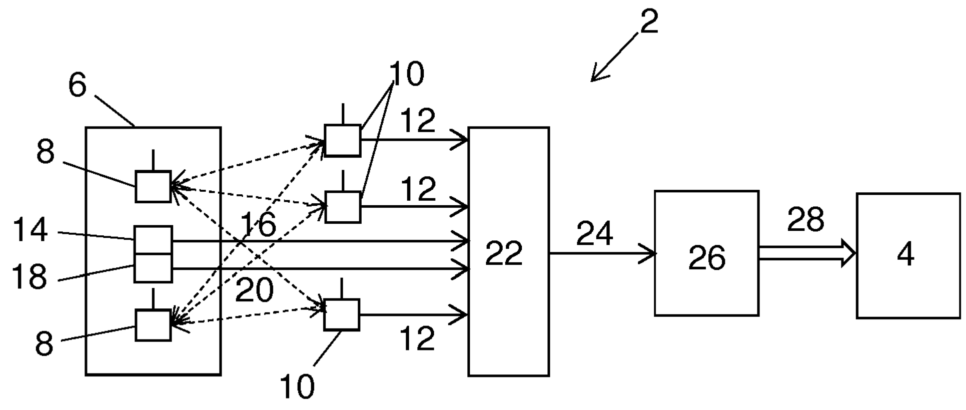
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FIG. 1

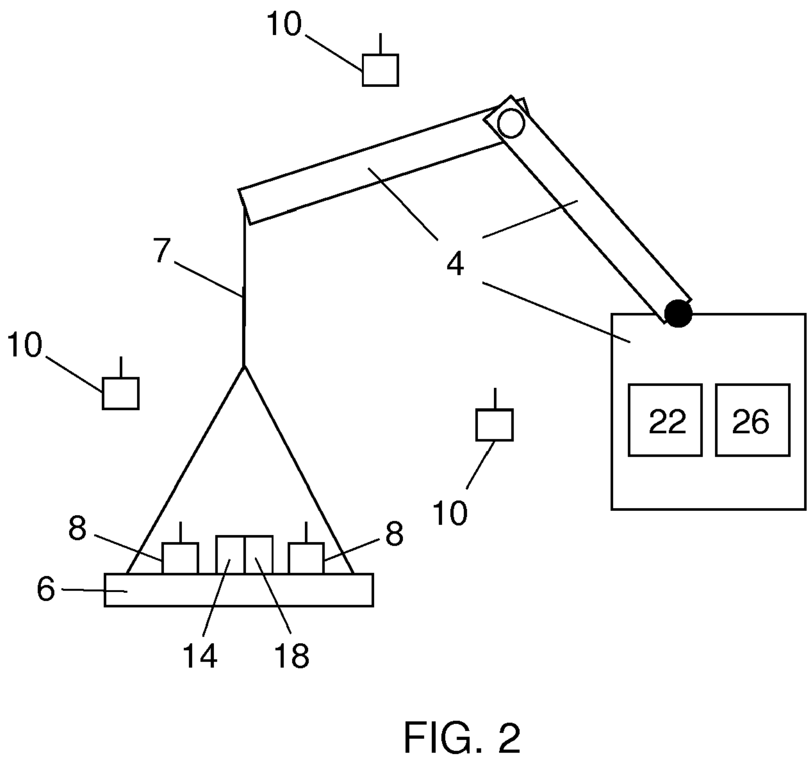
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FIG. 2

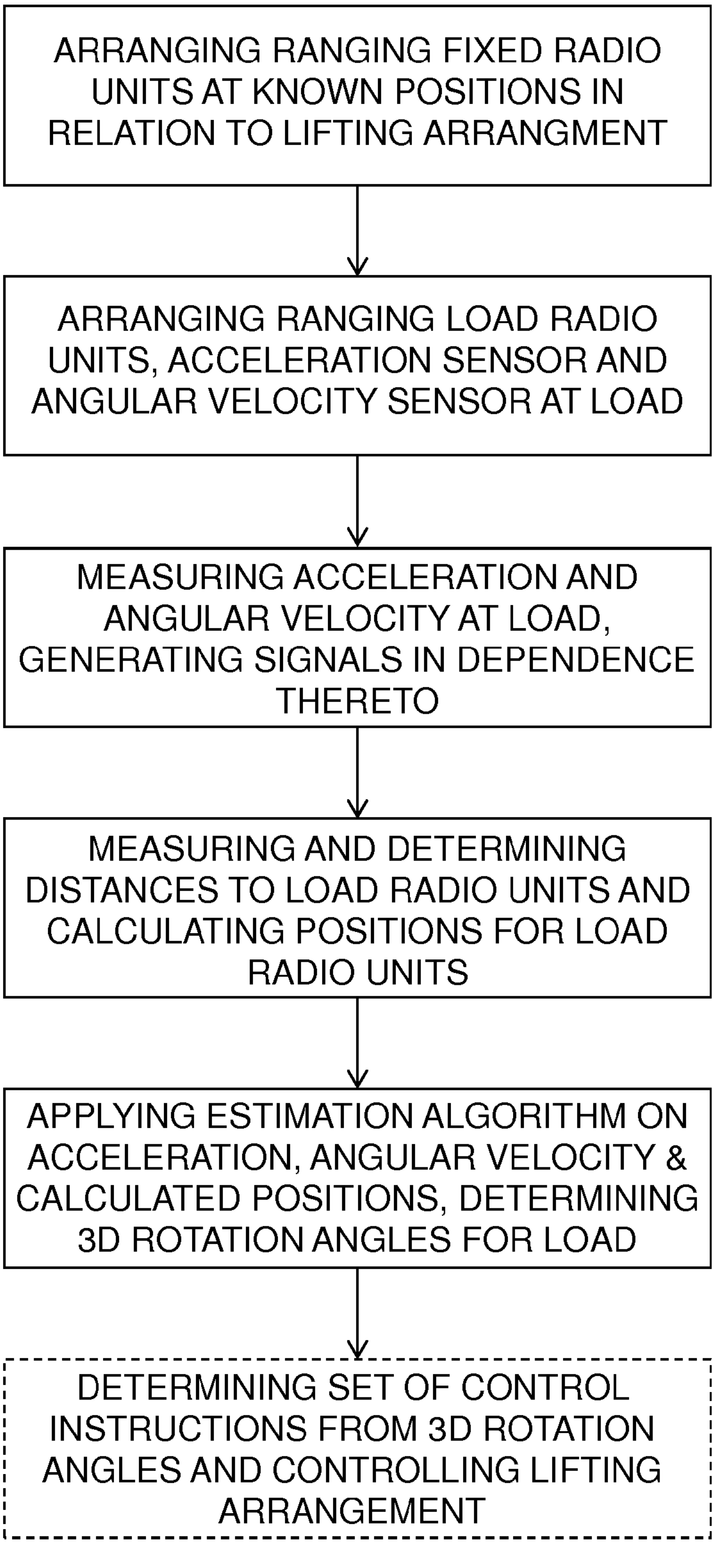
ARRANGING RANGING FIXED RADIO UNITS AT KNOWN POSITIONS IN RELATION TO LIFTING ARRANGMENT
ARRANGING RANGING LOAD RADIO UNITS, ACCELERATION SENSOR AND ANGULAR VELOCITY SENSOR AT LOAD
MEASURING ACCELERATION AND ANGULAR VELOCITY AT LOAD, GENERATING SIGNALS IN DEPENDENCE THERETO
MEASURING AND DETERMINING DISTANCES TO LOAD RADIO UNITS AND CALCULATING POSITIONS FOR LOAD RADIO UNITS
APPLYING ESTIMATION ALGORITHM ON ACCELERATION, ANGULAR VELOCITY & CALCULATED POSITIONS, DETERMINING 3D ROTATION ANGLES FOR LOAD
DETERMINING SET OF CONTROL INSTRUCTIONS FROM 3D ROTATION ANGLES AND CONTROLLING LIFTING ARRANGEMENT

FIG. 3

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EUROPEAN SEARCH REPORT

Application Number
EP 17 18 0558

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,D	US 9 352 940 B1 (CAMERON JOHN F [US] ET AL) 31 May 2016 (2016-05-31) * abstract * * column 3, line 15 - column 5, line 30 * * figures * -----	1,5,8	INV. B66C13/06 B66C13/46
			TECHNICAL FIELDS SEARCHED (IPC)
			B66C

The present search report has been drawn up for all claims

1

Place of search	Date of completion of the search	Examiner
The Hague	17 January 2018	Sheppard, Bruce

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
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ANNEX TO THE EUROPEAN SEARCH REPORT ON EUROPEAN PATENT APPLICATION NO. EP 17 18 0558

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17-01-2018

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

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