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(54) **AUTONOMOUS LOADING OPERATIONS OF A MINING MACHINE**

(57) According to an example aspect of the present invention, there is provided a method, comprising: receiving, during a first action of an automatic adaptive loading procedure by a work machine equipped with a boom and a bucket connected to the boom, driveline information of at least one driveline component of the work machine, defining a set of control parameters on the basis of the received driveline information, and controlling position of the boom, position of the bucket, and speed of the work machine on the basis of the defined set of control parameters during a second action of the automatic adaptive loading procedure.

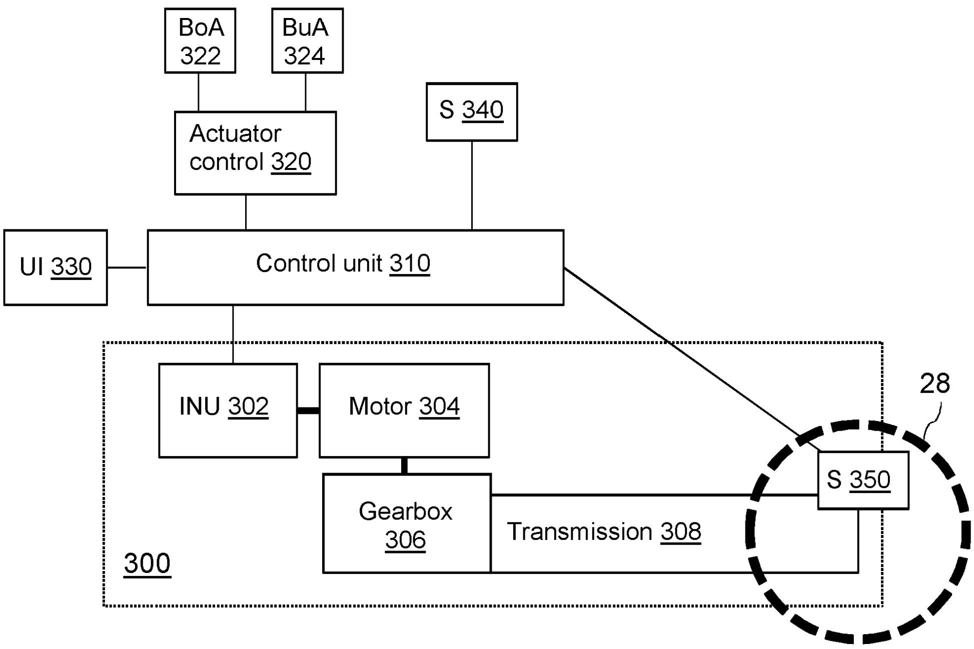

Fig. 3

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Description

FIELD

[0001] The present invention relates to loading work machines, and in particular to controlling autonomous loading operations by such vehicles.

BACKGROUND

[0002] Mining or construction excavation worksites, such as hard rock or soft rock mines, may comprise areas for automated operation of mobile work machines, which may also be referred to as mine vehicles. Such work machine may be an unmanned, e.g. remotely controlled from a control room, or a manned mine vehicle, i.e. operated by an operator in a cabin of the mobile vehicle. Work machines may be configured to perform at least some of tasks autonomously. An automated work machine operating in an automatic mode may operate independently without external control but may be taken under external control at certain operation areas or conditions, such as during states of emergencies.

[0003] Loading equipment may be used to load and transport excavated material, such as ore, rocks or sand from one place to another, for example after excavation from an underground mine loading position to out of the mine or to a conveyor transport equipment or a sport reserved for unloading the material. Due to the dynamic and unpredictable nature of bucket-rock interactions, it is very challenging to develop automated bucket filling that would work efficiently at various conditions. A loading controller needs to manage not only the motion of excavation arms, such as boom and bucket positions, but also penetration rate based on motion of loading equipment platform. For example, the forces that act on a bucket as it is actuated to penetrate a rock pile may vary significantly depending on the properties of rock media in the pile, pile geometry, and distribution of particle sizes and geometry.

[0004] Patent publication EP3207187 discloses a method for controlling automated bucket loading. A bucket control profile is selected from a set of bucket control profiles, the profiles comprising indications for positions of the boom of the work machine as a function of a distance travelled by the work machine with reference to a reference location. There is a need to further improve automatic bucket loading adapting to varying loading conditions.

SUMMARY

[0005] The invention is defined by the features of the independent claims. Some specific embodiments are defined in the dependent claims.

[0006] According to a first aspect, there is provided an apparatus, being configured to or comprising means configured for performing at least: receiving, during a first action of an automatic adaptive loading procedure by a work machine equipped with a boom and a bucket connected to the boom, driveline information of at least one driveline component of the work machine, defining a set of control parameters on the basis of the received driveline information, and controlling position of the boom, position of the bucket, and speed of the work machine on the basis of the defined set of control parameters during a second action of the automatic adaptive loading procedure. The means may comprise at least one processor, and at least one memory including computer program code, the at least one memory and the computer program code being configured to, with the at least one processor, cause the performance of the apparatus.

[0007] According to a second aspect, there is provided a method for controlling autonomous loading operations, comprising: receiving, during a first action of an automatic adaptive loading procedure by a work machine equipped with a boom and a bucket connected to the boom, driveline information of at least one driveline component of the work machine, defining a set of control parameters on the basis of the received driveline information, and controlling position of the boom, position of the bucket, and speed of the work machine on the basis of the defined set of control parameters during a second action of the automatic adaptive loading procedure.

[0008] According to a third aspect, there is provided an apparatus comprising at least one processing core, at least one memory including computer program code, the at least one memory and the computer program code being configured to, with the at least one processing core, cause the apparatus at least to perform the method or an embodiment of the method.

[0009] According to a fourth aspect, there is provided a computer program, a computer program product or (a non-tangible) computer-readable medium comprising computer program code for, when executed in a data processing apparatus, to cause the apparatus to perform the method or an embodiment thereof.

[0010] According to an embodiment of any of the aspects, a termination condition of the automatic adaptive loading procedure is determined in response to receiving a signal from a bucket limit switch.

[0011] According to an embodiment of any of the aspects, the driveline of the work machine comprises an electric motor driven by an inverter unit, and the apparatus is configured to transmit control signals in accordance with the defined set of control parameters to the inverter unit to control driveline rotational speed and/or torque. In another embodiment, the driveline of the work machine comprises a combustion engine controlled on the basis of the defined set of control parameters.

[0012] According to an embodiment of any of the aspects, the set of control parameters defines temporal relationship between at least some of plurality of control parameters in the set, and the at least some of the plurality of control parameters are applied for controlling the position of the boom, position of the bucket, and/or the speed of the work machine in accordance with the temporal relationship.

[0013] According to an embodiment of any of the aspects, a parameter in the set is applied for a predefined period of time identified by the set.

[0014] According to an embodiment of any of the aspects, the timing of at least some of the control parameters of the set in relation to one or more other parameters of the set is defined by the set.

BRIEF DESCRIPTION OF THE DRAWINGS

[0015]

FIGURE 1 illustrates an example of a work machine equipped with a bucket;

FIGURE 2 illustrates a method according to at least some embodiments;

FIGURE 3 illustrates an arrangement for controlling automatic loading of a work machine;

FIGURE 4 illustrates adaptive automatic bucket filling method according to some embodiments; and

FIGURE 5 illustrates an example apparatus capable of supporting at least some embodiments.

EMBODIMENTS

[0016] The presently disclosed embodiments are applicable, in particular, to various work machines used in mining industry, construction sites etc., suitable for loading, transporting and unloading excavated material or other bulk material. Particular examples of such work machines include loading equipment or loaders comprising a bucket attached to a boom. The excavated material may, for example, be rocks excavated in a surface or underground operating area. In this context, the term "rock" is to be understood broadly to cover also a boulder, rock material, crust and other relatively hard material.

[0017] Figure 1 shows an example of a work machine 10 comprising a (mobile) carrier 12, one or more booms 14 and a bucket 16 attached in a pivotable or otherwise movable manner to the one or more booms 14. For example, the bucket 16 may be coupled to two booms 14. The attachment may comprise at least one pivot 22, and the bucket 16 may be turned with respect to the pivot(s). The work machine 10 may be an articulated vehicle comprising two sections connected by a joint 32. The work machine may be a load and haul (LHD) device, or a device mainly intended for loading.

[0018] The work machine 10 further comprises a first actuator 18 for moving the boom 14 upwards and downwards, and a second actuator 20 for turning the bucket 16 in respect to the pivot 22. The actuators 18, 20 may be hydraulically and/or electrically operable actuators, or operable by some other source of energy. It should also be noted that Figure 1 is simplified and e.g. the first actuator 18 and/or the second actuator 20 may in practise comprise more than one actuator. For example, a lever arm arrangement may be applied for connecting a cylinder to the bucket 16.

[0019] The work machine 10 typically comprises a system of pumps 24 for generating hydraulic pressure for operating various parts of the machine, such as lifting the boom 14, turning the bucket, 16 etc. The work machine 10 may comprise one or more other sources of energy, such as an accumulator, a hydrogen container, a fuel tank, etc.

[0020] The work machine 10 may comprise a motor 26, which may be driven by the hydraulic pump (system) 24 or it may be e.g. a combustion engine or an electric motor. Power from the motor 26 may be provided by a crank shaft (not shown) to front and/or rear wheels 28 either directly or via a gear box (not shown).

[0021] The work machine 10 comprises at least one control unit 30, which may comprise one or more processors and memory, configured to control at least some functions and/or actuators of the work machine. In some embodiments, the control unit 30 is configured to control at least autonomous loading control related operations, and there may be one or more other control units in the work machine for controlling other operations. It is to be appreciated that the control unit 30 may be configured to perform at least some of the below illustrated features, or a plurality of control units or controllers may be applied to perform these features. There may be further operations modules or functions performed by the control unit(s), e.g. an automatic bucket loading module, at least one positioning unit/module, autonomous driving control module, and/or an obstacle detection module.

[0022] The work machine 10 may be an automated work machine, which in their autonomous operating mode may operate/drive independently without requiring continuous user control but which may be taken under external control during states of emergencies, for example.

[0023] The work machine 10 may comprise a wireless data transfer unit 34, by which the control unit 30 may establish a data transmission connection to another (second) control system 40 external to the work machine 10 by utilising a wireless connection provided by a base station or access node 42. The data transfer unit 34 may thus be connected to a communications system of the worksite, such as a wireless access system comprising a wireless local area network (WLAN) and/or a cellular communications network (e.g. a 4G, 5G or another generation cellular network).

[0024] The system 40 may comprise or be connected to a further network(s) and/or data processing system(s), such a worksite management system, a cloud service, a data analytics device/system, an intermediate communications network, such as the internet, etc. The system may comprise or be connected to further device(s) or control unit(s), such as a handheld user unit, a vehicle unit, a worksite management device/system, a remote control and/or monitoring device/system, data analytics device/system, sensor system/device, etc.

[0025] For example, a server of the system 40 may be configured to manage at least some operations at the worksite, such as provide a UI for an operator to remotely monitor and, when needed, control automatic operation operations of the work machines and/or assign work tasks for a fleet of vehicles and update and/or monitor task performance and status. Thus, the work machine 10 may be unmanned, the user interface may be remote from the work machine, and the work machine may be remotely monitored or controlled by an operator in proximity to the work machine (e.g. in the tunnel), or in control room at the worksite or even long distance away from the worksite via communications network(s). However, it is to be noted that the below described features may be applied also in manually-operated machines to assist bucket filling.

[0026] The work machine 10 may comprise a positioning system or unit. At surface-operated work machines, it may be possible to use satellite-based navigation, such as the GPS system, for determining the location and orientation of the mining vehicle with sufficient accuracy. At underground-operating work machines, instead of satellite based positioning information, positioning based on dead-reckoning and/or scanning tunnel surfaces may be used.

[0027] The work machine 10 may comprise one or more scanning units, or scanners 36, configured to perform scanning of the environment of the work machine. In an embodiment, the scanner 36 may be a 2D or 3D scanner configured to monitor tunnel walls. The control unit 30 may compare operational scanned tunnel profile data to reference profile data stored in an environment model and position the work machine on the basis of finding a match in the environment model to position the work machine and/or correct positioning by dead-reckoning. In some embodiments, the scanning results are applied to detect position and orientation of the work machine and one or more further elements thereof, such as the scanner 36 or the bucket 16.

[0028] A driving plan, or a route plan, may define a route to be driven by the work machine 10 and may be used as an input for automatic control of the work machine. The plan may define a start point, an end point, and a set of route points for the automatic drive. The driving plan may comprise information of loading area or point and may comprise data for controlling loading of the bucket 16. Automatic loading may be initiated in response to the work machine entering a position or route point of loading area in the driving plane. The driving plan may be sent via a wired or wireless connection to, or otherwise loaded to the work machine, to a memory of the work machine for access by the control unit 30.

[0029] During bucket loading the work machine 10 is driven near a stack or pile 50 of excavated material such as ore, rocks or sand. The bucket 16 and also the boom 14 may be lowered down, such that the bucket is on the surface of the ground or near it. The work machine may be driven forward so that the bucket contacts the pile. Bucket loading comprises many stages and actions and it is a difficult task especially for an operator with less experience. If the work machine stops due to too high resistance of the stack of material, the bucket may be lifted upwards, which may enable driving the work machine 10 a bit further, etc.

[0030] The bucket loading procedure by the work machine 10 may be automated, i.e. the machine may autonomously perform a sequence of appropriate movements controlled by the controller unit 30 to fill the bucket 16 and complete the loading by positioning the bucket at a position appropriate for leaving the pile 50 and hauling the load to an unloading location.

[0031] There is a need to improve existing automatic bucket filling solutions which do not always work very well in changing rock pile conditions, e.g. where rock dimensions vary considerably. This results only partially filled buckets.

[0032] There is now provided an adaptive automatic bucket loading system based on adaptive control parameter set adjustment based on driveline information, enabling to further improve bucket filling efficiency in varying conditions.

[0033] Figure 2 illustrates a method according to some embodiments. The method may be performed by a work machine and a controlling apparatus thereof, such as the work machine 10, and by the control unit 30 thereof.

[0034] The method for controlling autonomous loading may comprise receiving 200, during a first action of an automatic adaptive loading procedure by a work machine equipped with a boom and a bucket connected to the boom driveline information of at least one driveline component. A set of control parameters is defined 210 on the basis of the received driveline information (for controlling boom position, bucket position, and speed of the work machine). Position of the boom, position of the bucket, and speed of the work machine is controlled 220 on the basis of the defined set of control parameters during a second action of the automatic adaptive loading procedure.

[0035] The driveline information refers generally to information indicative of status or parameter of a driveline component or system. Driveline components of a work machine typically comprise a motor, a gearbox, and a transmission mechanism. The driveline information may be received from a driveline component or a control system or unit thereof. For example, driveline information may be received from an inverter unit or another type of (drive control) unit driving or controlling a motor. The driveline information may be generated on the basis of signals from the driveline component(s). In some embodiments, the driveline information is indicative of driveline rotational speed and/or torque status. It is also to be noted that the speed of the work machine controlled in block

220 is to be understood broadly to speed control in the work machine, such as instructing a motor controller with information affecting ground speed or motor speed.

[0036] When sets of control parameters are preconfigured in a memory of the work machine 10, such as memory accessible by the control unit 30, the set of control parameters may be selected in block 210 among stored sets of control parameters based on the received driveline information. The work machine may also be configured to dynamically generate some or all of the values in the parameter set, based on preconfigured control logic.

[0037] The first action and the second action may be considered as consecutive stages of the adaptive bucket loading procedure. An action and associated control parameter set may be selected and entered to react to detected trigger condition based on the driveline information.

[0038] Temporal relationship between at least some of the plurality of control parameters in the set may be defined, and these parameters may be applied in block 220 according to the temporal relationship. Such temporal relationship information, such as timing information for parameters in the set, may be stored as part of the parameter set. The set of control parameters may be a sequence of control parameters. Timing of at least some of parameters may be defined in the set. The timing may be defined in relation to one or more other parameters of the set or another reference, such as start of block 220.

[0039] A control parameter in the set may define a target value for a controlled entity, and control action is initiated in block 220 to approach the target value. The set of parameters may comprise a plurality of subsequent values for a given parameters. For example, there may be a plurality of different speed values to be applied in the set. Different values may have different durations, i.e. time periods during which they are applied. There may be another criterion than time elapsed or time threshold for changing the value, some further examples being illustrated below.

[0040] Figure 3 illustrates an arrangement and elements of the work machine, such as the work machine 10, for controlling automatic adaptive loading by applying the method of Figure 2 and at least some embodiments thereof. In this example, driveline 300 of the work machine comprises an electric motor 304 driven by an inverter unit (INU) 302. The INU 302 comprises an inverter, which at least in some instances may also be referred to as frequency converter, alternative current (AC) drive, variable speed drive (VSD), or variable frequency drives (VFD), controlling the voltage and frequency of power supplied to an AC motor to control the torque and rotation speed of the motor 304.

[0041] Wheels 28, such as front wheels and rear wheels of the work machine 10 are rotated by a transmission mechanism 308. The transmission mechanism 308 is rotated by a gear box (or drop) assembly 306. The gear box is driven by the electric motor 304. The INU 302 is powered by electric energy from an electrical supply of the work machine (not shown).

[0042] A control system or unit 310, such as the control unit 30, may be configured to perform the method of Figure 2 and receive (200) information from the driveline 300. The control unit 310 may comprise one or more computing units/processors executing computer program code stored in memory. The control unit may be connected to one or more other control units of a control system of the work machine, in some embodiments by a controller area network (CAN) bus. The control unit 310 may thus obtain the driveline information (e.g. provided to the bus by the INU 302) from the bus system.

[0043] The INU 302 is controlled by the control unit 310 on the basis of parameter(s) in the defined set to control the motor 304 of the work machine. The control unit 310 may be configured to transmit control signals in accordance with the defined set of control parameters to the INU 302 to control the driveline rotational speed and/or torque.

[0044] The control unit 310 may in some embodiments be directly or indirectly connected also to further elements of the driveline, such as the motor 304 or a further controller thereof, or a sensor in the driveline. For example, the RPM (revolutions per minute) of the front wheel(s) can be measured by RPM sensor(s). The control unit 310 may obtain the RPM information from the driveline and process it by an algorithm to detect slippage or spin of the wheels (in case there is a differential lock). The algorithm may be configured to maintain the RPM within a predetermined range. The driveline RPM can be readily obtained and the wheel RPM calculated therefrom.

[0045] The control unit 310 may be connected to an actuator control unit or (sub)system 320, which may be connected to boom actuator (BoA) 322 and bucket actuator (BuA) 324. In block 220, the control unit 310 may issue control signals on the basis of or comprising control parameters in the defined set to the actuator control system 320, which controls the BoA 322 and BuA 324 to accordingly control the boom 14 and the bucket 16. It is to be noted that the boom and the bucket may have separate actuator controls, which may be directly connected to the control unit 310. Actuator control (sub)system may comprise or be connected to hydraulic circuits having lift and tilt actuator control valves for controlling the rate at which pressurized hydraulic fluid flows to respective lift and tilt hydraulic actuators in proportion to control signals.

[0046] A user interface (UI) 330 may be connected to the control unit 310, comprising e.g. a joystick, a touch screen, or other input means by which an input signal from a user may be provided to the control unit for affecting the adaptive loading procedure.

[0047] The control unit 310 may be connected to further units in the work machine, such as further sensors or sensor systems 340 and 350 providing inputs for the control unit 310. Examples of such sensors include boom or bucket limit sensors, boom or bucket position detection sensors, hydraulic pressure sensor hydraulic load sensing pump pressure, and bucket pressure measurement. Sensor 350 may be a wheel rotation sensor.

[0048] The work machine 10 of Figure 1 and the system of Figure 3 are disclosed herein only as examples where the embodiments disclosed herein may be implemented. The embodiments are applicable to various other types and configurations of work machines and control units. Below some further example embodiments are illustrated, at least some of which may be performed by the control unit 30, 310, for example.

[0049] The work machine 10 may define, on the basis of the driveline information and one or more threshold conditions, if redefinition or change of applied set of control parameters and/or automatic loading action is to be triggered. This may be an additional block continued during or after block 220 and repeated during the adaptive loading procedure.

[0050] The work machine 10 may determine, during the second action of the automatic adaptive loading procedure, if a change condition for changing the set of control parameters, a parameter in the defined set of control parameters, or automatic adaptive loading procedure action is met. In an example embodiment, need to adapt one or more parameters in the defined set is detected and may be dynamically adapted during application of the set. In response to the change condition being met, the set of control parameters, a parameter in the defined set, or the action (re)defined and changed.

[0051] The change condition may comprise at least one driveline information threshold value, wheel slip condition or associated threshold value(s), and/or a temporal threshold value.

[0052] Examples of driveline information threshold value include at least one threshold value on driveline or motor rotational speed or RPM, a threshold value on torque, and/or power.

[0053] In some embodiments, the set or only some control parameters in the applied set is defined or changed on the basis of wheel slip condition information indicative of wheel slip during the automatic adaptive loading procedure. In an example embodiment, sensors 350 are arranged at right and left front wheels 28 for determining speed of the front wheels. The control unit 310 may determine speed difference of the front wheels based on signals from the sensors and detect the slip condition in response to the speed difference exceeding a traction control threshold value preconfigured for the loading procedure. Thus, a parameter set with reduced traction may be entered, enabling to reduce tyre wear.

[0054] Time of applying the defined set of control parameters may be monitored. Change of set of control parameters to control position of the boom, position of the bucket, and speed of the work machine may be controlled in response to the time of applying the defined set exceeding a threshold value. This enables to ensure that a parameter set (and associated automatic loading action) is not applied unnecessarily long. In an example embodiment, as already indicated, a parameter in the set is applied for a predefined period of time identified by the set, i.e. some parameters of the set may be applied only for part of the loading action and application time of the parameter set.

[0055] Block 220 may be performed without boom position measurement and/or bucket position measurement. Further, external camera or other surroundings measurement or scanning equipment is not needed for automatic loading. This simplifies the system and enables to avoid problems e.g. due to malfunctioning position sensors. The bucket 16 and/or boom 14 may be equipped a bucket limit switch or detector, configured to indicate when the bucket reaches an extreme or limit position, such as the uppermost position. The work machine 10 may determine a termination condition of the automatic adaptive loading procedure in response to receiving a signal from the bucket limit switch. However, it is to be noted that the termination condition may be arranged and detected without switch or sensor, e.g. based analyzing hydraulic pressure information.

[0056] Further, the present adaptive loading system may be provided without bucket pressure measurement and/or boom bucket pressure measurement. In an example embodiment, hydraulic load sensing pump pressure measurement can, however, be used as support or auxiliary information. The control unit thereof 30, 310 may receive hydraulic pressure information indicative of current pressure of a hydraulic pump system of the work machine 10, e.g. from the sensor 340 or a controller thereof. The set of control parameters may be defined in block 210 and/or redefined further on the basis of the received hydraulic pressure information.

[0057] The work machine 10 and the control unit 30, 310 thereof may record history information of used sets of control parameters. The set of control parameters may be defined (210) further on the basis of the history information. In a simple example, if a given parameter set has been applied consecutively four times, it is not selected any more. Another example is that the system stores information of application of parameter sets sequences that have lead to an error state and applies this information to avoid similar sequence and problem. The automatic adaptive loading system may be configured to learn on the basis of the history information and past behavior during the bucket loading. The system may be configured to teach the automatic adaptive loading procedure and adapt the parameter sets and/or definition of the parameter sets based on the history information.

[0058] Figure 4 illustrates an example adaptive loading method, which may be performed by the work machine 30 and the control unit 30, 310, for example. In response to initiating automatic loading mode or procedure, block 400 may be entered, comprising lowering boom, e.g. from a driving position. The (front part of the) bucket is lowered against the ground in block 410. Associated load sensing (LS) information, such as hydraulic pump pressure, may be monitored during block 410 and the bucket is lowered until reaching or exceeding a LS threshold.

Block 420 comprises driving the work machine forward until meeting a threshold; in an embodiment traction control active time threshold (i.e. traction control has been active in response to detecting wheel slipping for a predetermined period of time).

[0059] Block 430 comprises defining the control parameter set based on the driveline information, by applying at least some of the presently disclosed features. Blocks 400 to 420 are examples of automatic loading initiation stage or action, which may be considered as the first action of block 200, during which driveline information may be received. Block 430 thus does not have to after block 420. Alternatively, the parameter set may be defined based on driveline information as received after block 420.

[0060] Block 440 comprises controlling the position of the boom, position of the bucket, and speed of the work machine on the basis of the defined parameter set. This may be considered to comprise the second automatic adaptive loading procedure stage or action of block 220.

[0061] In some example embodiments, the set of control parameters is configured to cause at least one of:

- maintaining current position of the boom, lifting the bucket, and driving forward,
- lifting the boom, maintaining current position of the bucket, and driving forward,
- lifting the boom, lowering the bucket, and driving forward, or
- lowering the boom, lifting the bucket, and driving forward.

[0062] However, it will be appreciated that these are just some examples of control action combinations, and numerous other control action combinations may be configured by differing control parameter sets.

[0063] Block 450 comprises checking if a change condition (for redefining a parameter set applied for the adaptive loading) is met, such as one or more of the change conditions illustrated above. If yes, block 430 is again entered, whereby a new parameter set better suited for the present loading situation is defined and the work machine is controlled with the new parameter set.

[0064] Block 460 comprises checking if a termination condition for the adaptive loading procedure is met. For example, the termination condition may comprise receiving a signal from the bucket limit switch, a bucket load threshold, hydraulic pressure threshold, and/or a time limit for the procedure. If a termination condition is not met, the procedure may return to block 440.

[0065] If the termination condition is met, the procedure may enter automatic loading completion or finish stage or action, such as example blocks 470 to 490. Block 470 comprises driving the work machine backward and lifting the boom. Block 480 comprises shaking the bucket. Block 490 driving backward, lifting the bucket and lowering the boom (e.g. to driving position). It is to be noted that some of there may be further blocks and modifications to the example of Figure 4.

[0066] The present adaptive system facilitates to improve bucket filling effectivity and obtain full buckets in varying rock pile conditions. Driveline information may reflect loading situation very well. Based on algorithm suitably configured to apply the driveline information, it is possible to have exact knowledge of what is currently happening in the loading process and define appropriate set of control parameters, even better than an experienced operator can. The system has been tested and high bucket filling level has been steadily achieved in various pile conditions due to its highly adaptive capability. In the performed tests, the adaptive system was able to achieve mean weight of 15.1 tons, whereas an experienced operator was able to have mean weight 15.9 tons at the same differing piles.

[0067] When combined with automatic driving and unloading, mine operations of a LHD can be automated completely with the presently disclosed adaptive loading system. The presently disclosed automatic adaptive loading procedure may also well be applied in connection with manual operation, and automatize the most difficult phase of LHD operation, facilitating less experienced operators to operate the machine.

[0068] A very substantial advantage is also that no pretaught or otherwise defined profiles of bucket and/or boom (indicative of positions of the bucket/boom in relation to a distance travelled by the work machine) are required. The dynamically adapting loading procedure may be completely provided without a predefined profile and associated boom/bucket position and distance measurements.

[0069] It is to be appreciated that various further features may be complement or differentiate at least some of the above-illustrated embodiments. For example, there may be further user interaction and/or automation functionality further facilitating the operator to monitor the work machine during the adaptive automatic loading procedure, input appropriate action via the UI 330 to overcome an issue detected during the procedure, e.g. by selecting a control parameter set to overcome the issue.

[0070] An electronic device comprising electronic circuitries may be an apparatus for realizing at least some embodiments illustrated above, such as the method illustrated in connection with Figure 2 and 4 and features illustrated for the control unit 30, 310. The apparatus may be comprised in at least one computing device connected to or integrated into a control system of the work machine. Such control system may be an intelligent on-board control system controlling operation of various sub-systems of the work machine, such as a hydraulic system, a motor, etc, in one example the sub-systems illustrated in Figure 3. Such control systems are often distributed and include many independent modules connected by a bus system of controller area network (CAN) nodes, for example.

[0071] Figure 5 illustrates a simplified example apparatus capable of supporting at least some embodiments of the present invention. Illustrated is a device 500, which may be configured to carry out at least some of the embodiments relating to the adaptive automatic loading related operations illustrated above. In some embodiments, the device 500 comprises or implements the control unit 30, or other module(s), functions and/or unit(s) for performing at least some of the above-illustrated embodiments.

[0072] Comprised in the device 500 is a processor 510, which may comprise, for example, a single- or multi-core processor. The processor 510 may comprise more than one processor. The processor may comprise at least one application-specific integrated circuit, ASIC. The processor may comprise at least one field-programmable gate array, FPGA. The processor may be configured, at least in part by computer instructions, to perform actions.

[0073] The device 500 may comprise memory 520. The memory may comprise random-access memory and/or permanent memory. The memory may be at least in part accessible to the processor 510. The memory may be at least in part comprised in the processor 510. The memory may be at least in part external to the device 500 but accessible to the device. The memory 520 may be means for storing information, such as parameters 522 affecting operations of the device. The parameter information in particular may comprise parameter information affecting the automatic adaptive loading related features, such as threshold values.

[0074] The memory 520 may be a non-transitory computer readable medium comprising computer program code 524 including computer instructions that the processor 510 is configured to execute. When computer instructions configured to cause the processor to perform certain actions are stored in the memory, and the device in overall is configured to run under the direction of the processor using computer instructions from the memory, the processor and/or its at least one processing core may be considered to be configured to perform said certain actions. The processor may, together with the memory and computer program code, form means for performing at least some of the above-illustrated method steps in the device.

[0075] The device 500 may comprise a communications unit 530 comprising a transmitter and/or a receiver. The transmitter and the receiver may be configured to transmit and receive, respectively, i.a. data and control commands within or outside the work machine. The transmitter and/or receiver may be configured to operate in accordance with global system for mobile communication, GSM, wideband code division multiple access, WCDMA, long term evolution, LTE, 3GPP new radio access technology (N-RAT), wireless local area network, WLAN, and/or Ethernet standards, for example.

[0076] The device 500 may comprise or be connected to a UI. The UI may comprise at least one of a display 540, a speaker, an input device 550 such as a keyboard, a joystick, a touchscreen, and/or a microphone. The UI may be configured to display views on the basis of above illustrated embodiments. A user may operate the device and control at least some of above illustrated features. In some embodiments, the user may control the work machine 10 via the UI, for example to manually drive the vehicle, operate a boom, initiate automatic loading, change mode, change parameter set, change display views, modify parameters 522, etc.

[0077] The device 500 may further comprise and/or be connected to further units, devices and systems, such as one or more sensor devices 560 configured to detect environment of the device 500 or properties of the work machine, such as wheel rotation or hydraulic pressure.

[0078] The processor 510, the memory 520, the communications unit 530 and the UI may be interconnected by electrical leads internal to the device 500 in a multitude of different ways. For example, each of the aforementioned devices may be separately connected to a master bus internal to the device, to allow for the devices to exchange information. However, as the skilled person will appreciate, this is only one example and depending on the embodiment various ways of interconnecting at least two of the aforementioned devices may be selected without departing from the scope of the present invention.

[0079] It is to be understood that the embodiments of the invention disclosed are not limited to the particular structures, process steps, or materials disclosed herein, but are extended to equivalents thereof as would be recognized by those ordinarily skilled in the relevant arts. It should also be understood that terminology employed herein is used for the purpose of describing particular embodiments only and is not intended to be limiting.

[0080] Reference throughout this specification to one embodiment or an embodiment means that a particular feature, structure, or characteristic described in connection with the embodiment is included in at least one embodiment of the present invention. Thus, appearances of the phrases "in one embodiment" or "in an embodiment" in various places throughout this specification are not necessarily all referring to the same embodiment. Where reference is made to a numerical value using a term such as, for example, about or substantially, the exact numerical value is also disclosed.

[0081] As used herein, a plurality of items, structural elements, compositional elements, and/or materials may be presented in a common list for convenience. However, these lists should be construed as though each member of the list is individually identified as a separate and unique member. Thus, no individual member of such list should be construed as a de facto equivalent of any other member of the same list solely based on their presentation in a common group without indications to the contrary. In addition, various embodiments and example of the present invention may be referred to herein along with alternatives for the various components thereof. It is understood that such embodiments, examples, and alternatives are not to be construed as de facto equivalents of one another, but are to be considered as separate and autonomous representations of the present invention.

[0082] Furthermore, the described features, structures, or characteristics may be combined in any suitable manner in one or more embodiments. In the preceding description, numerous specific details are provided, such as examples of lengths, widths, shapes, etc., to provide a thorough understanding of embodiments of the invention. One skilled in the relevant art will recognize, however, that the invention can be practiced without one or more of the specific details, or with other methods, components, materials, etc. In other instances, well-known structures, materials, or operations are not shown or described in detail to avoid obscuring aspects of the invention.

[0083] While the forgoing examples are illustrative of the principles of the present invention in one or more particular applications, it will be apparent to those of ordinary skill in the art that numerous modifications in form, usage and details of implementation can be made without the exercise of inventive faculty, and without departing from the principles and concepts of the invention. Accordingly, it is not intended that the invention be limited, except as by the claims set forth below.

[0084] The verbs "to comprise" and "to include" are used in this document as open limitations that neither exclude nor require the existence of also un-recited features. The features recited in depending claims are mutually freely combinable unless otherwise explicitly stated. Furthermore, it is to be understood that the use of "a" or "an", that is, a singular form, throughout this document does not exclude a plurality.

Claims

1. An apparatus comprising means configured for performing:

- receiving (200), during a first action of an automatic adaptive loading procedure by a work machine (10) equipped with a boom (14) and a bucket (16) connected to the boom, driveline information of at least one driveline component of the work machine,
- defining (210) a set of control parameters on the basis of the received driveline information, and
- controlling (220) position of the boom, position of the bucket, and speed of the work machine on the basis of the defined set of control parameters during a second action of the automatic adaptive loading procedure.

2. The apparatus of claim 1, wherein the driveline information is indicative of at least one of driveline rotational speed and torque status.

3. The apparatus of claim 1 or 2, wherein the apparatus is configured to determine, during the second action of the automatic adaptive loading procedure, if a change condition for changing at least one of the set of control parameters, a parameter in the defined set of control parameters, or automatic adaptive loading procedure action is met, and the apparatus is configured to change at least one of the set of control parameters, a parameter in the defined set of control parameters, or automatic adaptive loading procedure action in response to the change condition being met.

4. The apparatus of claim 3, wherein the change condition comprises at least one driveline information threshold value, wheel slip condition threshold value, and/or a temporal threshold value.

5. The apparatus of any preceding claim, wherein the apparatus is configured to define or change the set of control parameters on the basis of wheel slip condition information indicative of wheel slip during the automatic adaptive loading procedure.

6. The apparatus of any preceding claim, wherein the apparatus is further configured to monitor time of applying the defined set of control parameters, and control change of set of control parameters to control position of the boom (14), position of the bucket (16), and speed of the work machine (10) in response to the time of applying the defined set exceeding a threshold value.

7. The apparatus of any preceding claim, wherein the set of control parameters is configured to cause:

- maintaining current position of the boom (14), lifting the bucket (16), and driving forward,
- lifting the boom, maintaining current position of the bucket, and driving forward,
- lifting the boom, lowering the bucket, and driving forward, or
- lowering the boom, lifting the bucket, and driving forward.

8. The apparatus of any preceding claim, wherein the apparatus is configured to record history information of used sets of control parameters, and define the set of control parameters on the basis of the history information.

9. The apparatus of any preceding claim, wherein the apparatus is configured to control the position of the boom (14), position of the bucket (16), and the speed of the work machine (10) without one or more of bucket and/or boom pressure measurement, without bucket and/or boom position measurement, and/or without a predefined profile indicative of positions of the boom of the work machine in relation to a distance travelled by the work machine.

10. The apparatus of any preceding claim, wherein the apparatus is further configured to receive hydraulic pressure information indicative of current pressure of a hydraulic pump system (24) of the work machine (10), and define the set of control parameters further on the basis of the received hydraulic pressure information.

11. A work machine (10), comprising the apparatus of any preceding claim.

12. A method for controlling loading by a work machine (10), comprising:

- receiving (200), during a first action of an automatic adaptive loading procedure by the work machine equipped with a boom (14) and a bucket (16) connected to the boom, driveline information of at least one driveline component of the work machine,
- defining (210) a set of control parameters on the basis of the received driveline information, and
- controlling (220) position of the boom, position of the bucket, and speed of the work machine on the basis of the defined set of control parameters during a second action of the automatic adaptive loading procedure.

13. The method of claim 12, further comprising:

- determining (450), during the second action of the automatic adaptive loading procedure, if a change condition for changing at least one of the set of control parameters, a parameter in the defined set of control parameters, or automatic adaptive loading procedure action is met, and
- changing at least one of the set of control parameters, a parameter in the defined set of control parameters, or automatic adaptive loading procedure action in response to the change condition being met.

14. The method of claim 12 or 13, wherein the set of control parameters is defined or changed on the basis of wheel slip condition information indicative of wheel slip during the automatic adaptive loading procedure.

15. A computer program comprising code for, when executed in a data processing apparatus (500), causing a method in accordance with claim 12 to 14 to be performed.

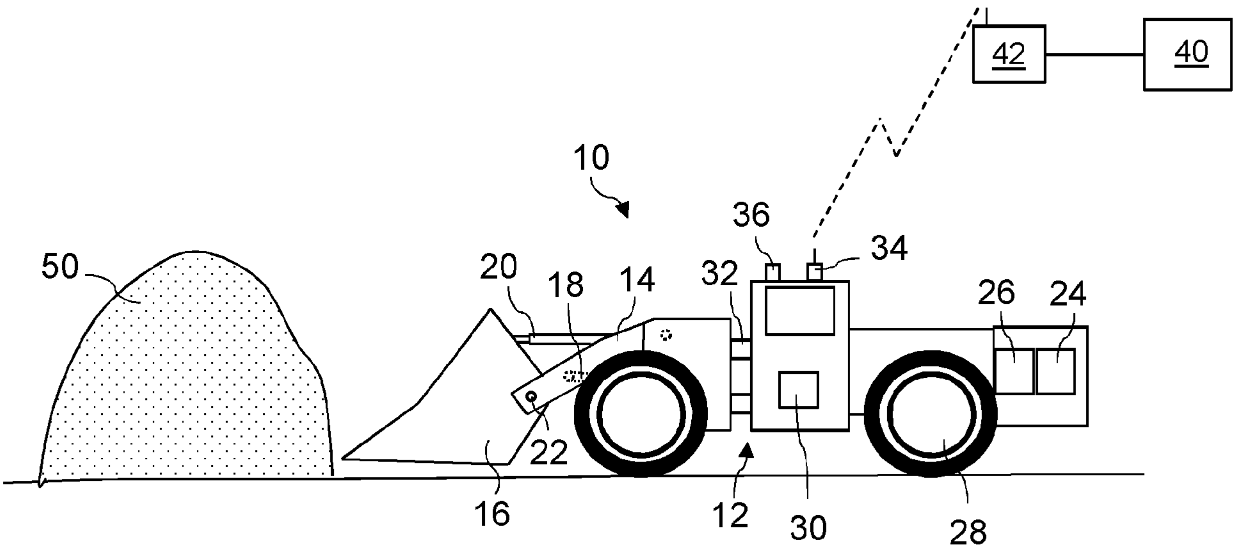
10
50
20
18
14
36
32
34
26
24
42
40
22
16
12
30
28

Fig. 1

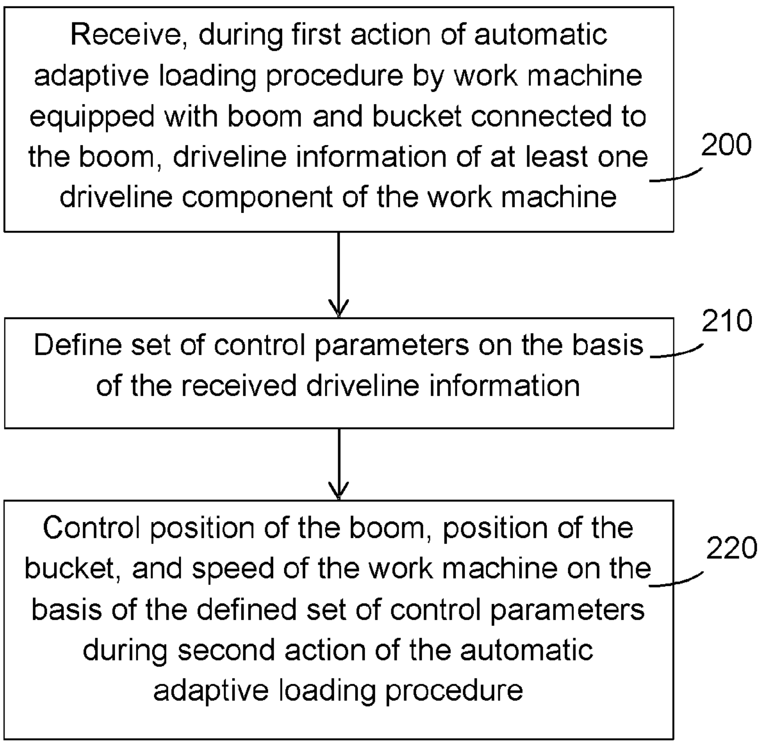
Receive, during first action of automatic adaptive loading procedure by work machine equipped with boom and bucket connected to the boom, driveline information of at least one driveline component of the work machine
200
Define set of control parameters on the basis of the received driveline information
210
Control position of the boom, position of the bucket, and speed of the work machine on the basis of the defined set of control parameters during second action of the automatic adaptive loading procedure
220

Fig. 2

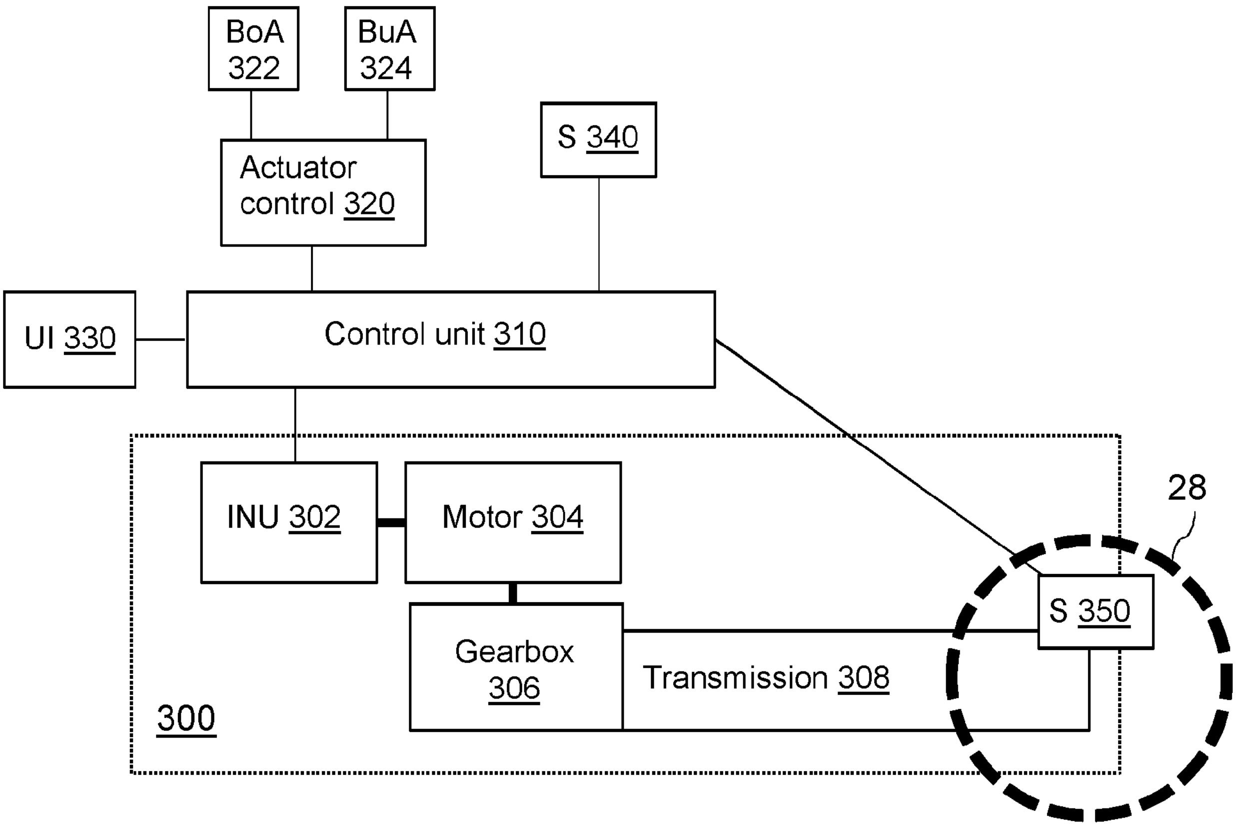
BoA
322
BuA
324
S 340
Actuator
control 320
UI 330
Control unit 310
INU 302
Motor 304
28
S 350
Gearbox
306
Transmission 308
300

Fig. 3

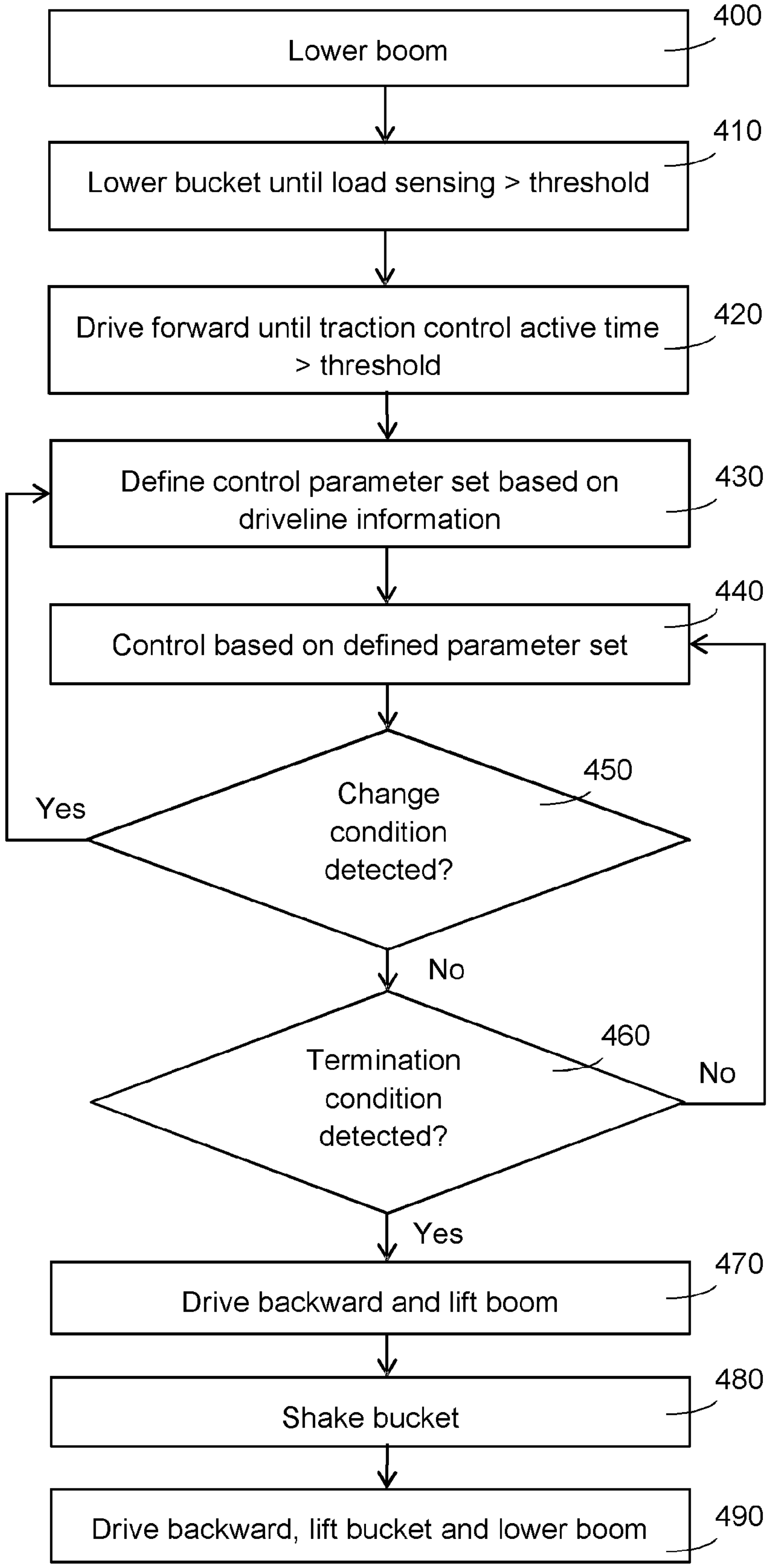
Lower boom
400
Lower bucket until load sensing > threshold
410
Drive forward until traction control active time > threshold
420
Define control parameter set based on driveline information
430
Control based on defined parameter set
440
Change condition detected?
450
Yes
No
Termination condition detected?
460
No
Yes
Drive backward and lift boom
470
Shake bucket
480
Drive backward, lift bucket and lower boom
490

Fig. 4

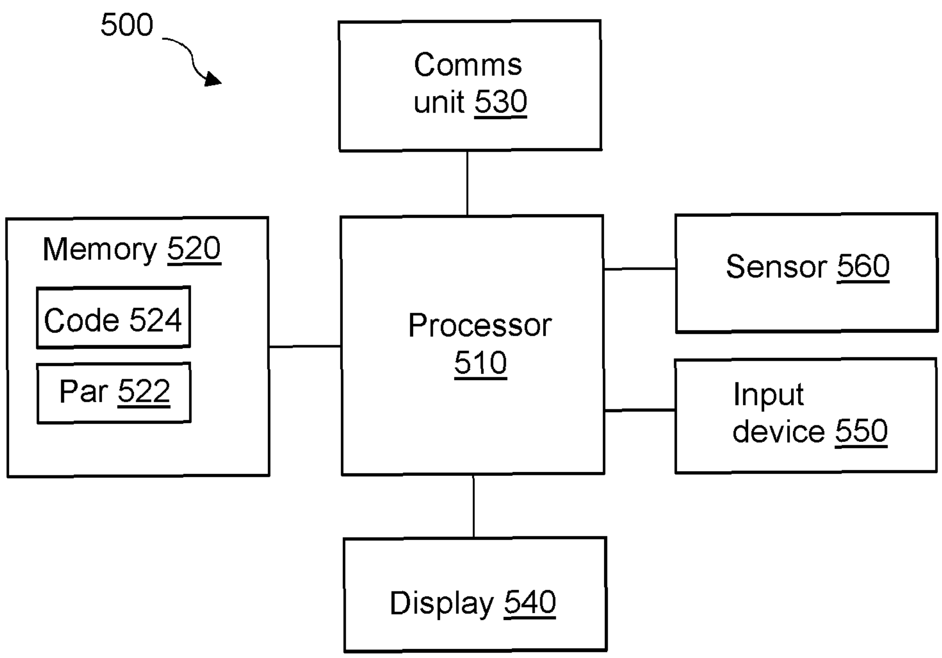
500
Comms unit 530
Memory 520
Code 524
Par 522
Processor 510
Sensor 560
Input device 550
Display 540

Fig. 5

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EUROPEAN SEARCH REPORT

Application Number
EP 20 17 3119

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E21C
E21F
G05B

The present search report has been drawn up for all claims

1

Place of search	Date of completion of the search	Examiner
Munich	8 September 2020	Papadimitriou, S

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