



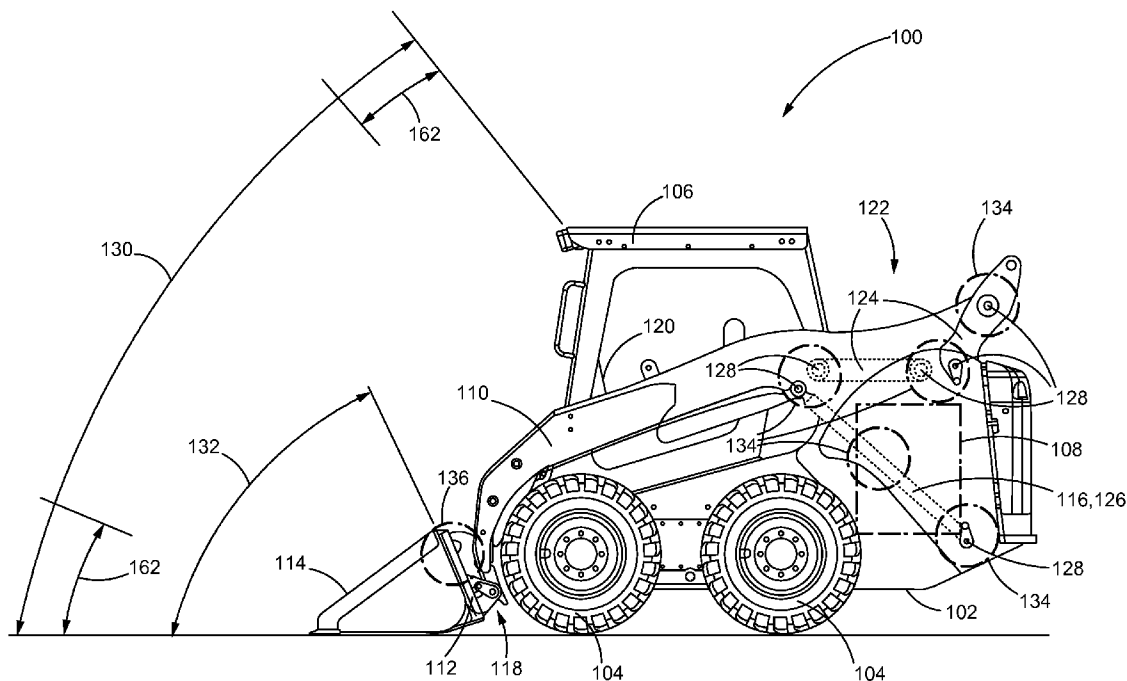
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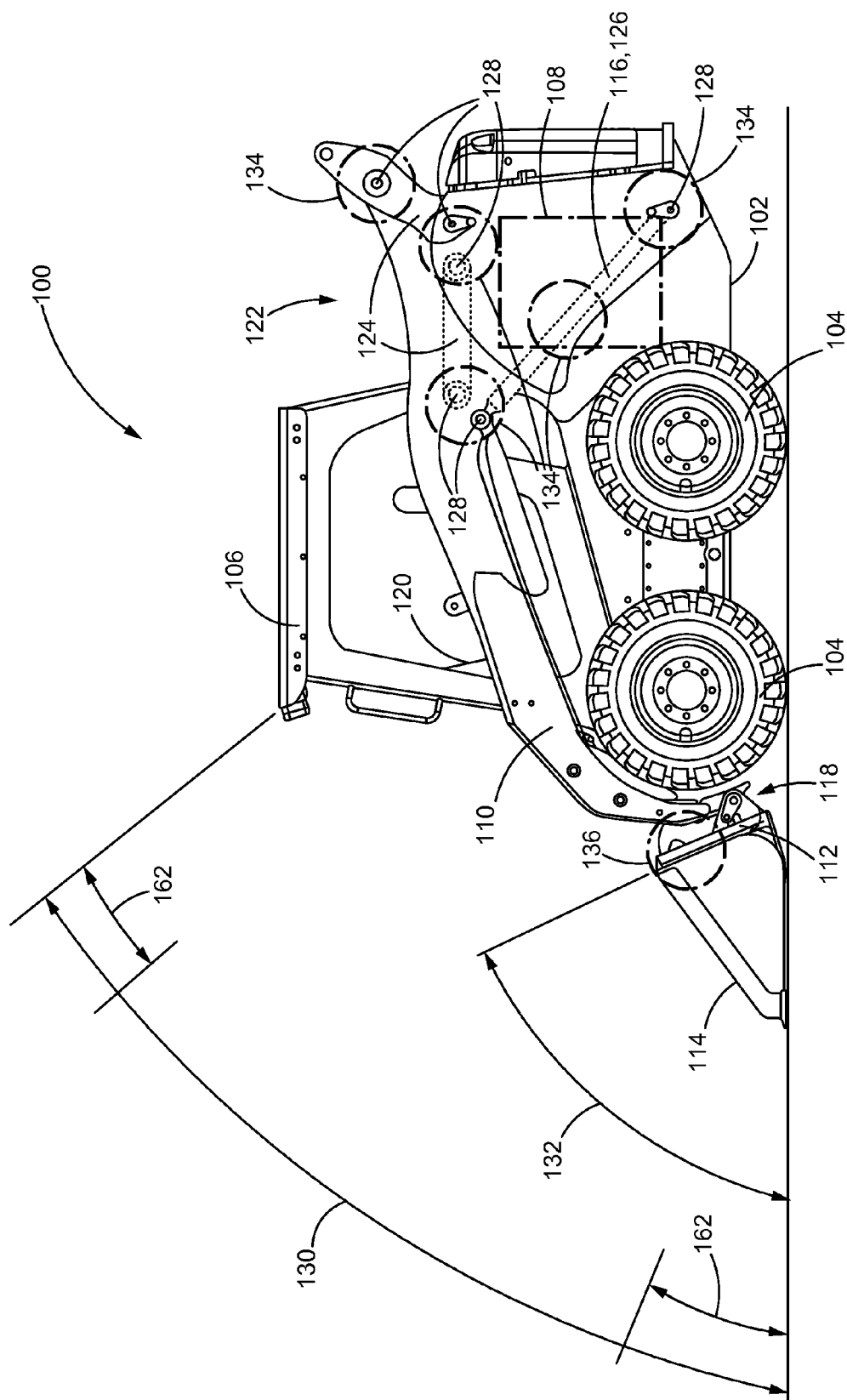
(19) **United States**(12) **Patent Application Publication**  
**Fredrickson et al.**(10) **Pub. No.: US 2015/0275469 A1**(43) **Pub. Date: Oct. 1, 2015**(54) **LIFT ARM AND COUPLER CONTROL SYSTEM**(52) **U.S. Cl.**CPC ..... *E02F 3/431* (2013.01); *E02F 3/3414* (2013.01)(71) Applicant: **Caterpillar Inc.**, Peoria, IL (US)(72) Inventors: **Andrew Fredrickson**, Holly Springs, NC (US); **Jason Mahoney**, Moncure, NC (US); **Cameron Edward Lynch**, Wilmington, NC (US); **George Cart Pinther, II**, Raleigh, NC (US)(73) Assignee: **Caterpillar Inc.**, Peoria, IL (US)(21) Appl. No.: **14/229,101**(22) Filed: **Mar. 28, 2014****Publication Classification**(51) **Int. Cl.***E02F 3/43* (2006.01)*E02F 3/34* (2006.01)

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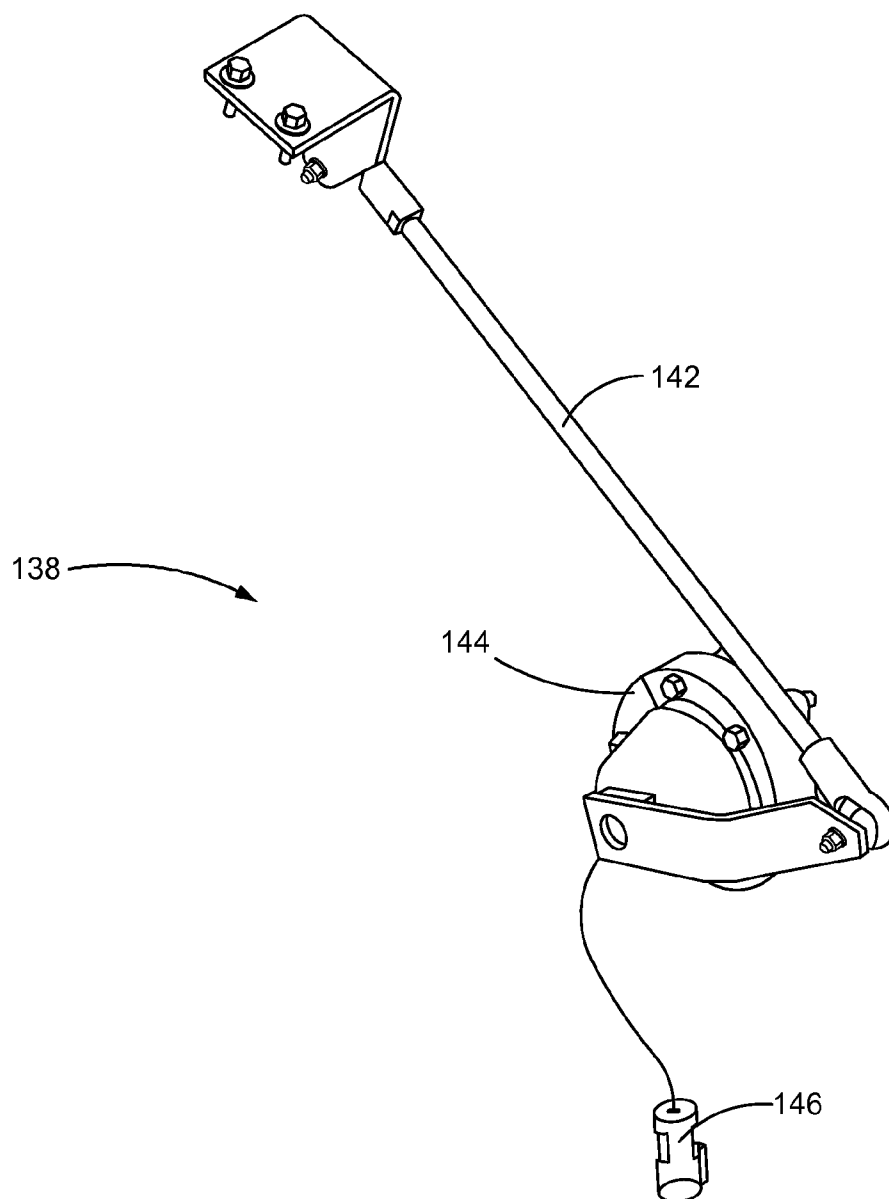
**ABSTRACT**

A control system for a loader having a frame, a lift arm assembly, a coupler, and an operator interface is provided. The control system may include a lift arm position sensor coupled to the lift arm assembly and configured to measure a lift arm position, an inclinometer disposed on the coupler configured to measure a coupler angle, and a controller in electrical communication with each of the lift arm position sensor, the inclinometer and the operator interface. The controller may be configured to receive a baseline command from the operator interface for operating one or more of the lift arm assembly and the coupler, monitor the lift arm position and the coupler angle, and generate at least one command for operating one or more of the lift arm assembly and the coupler based on one or more of the baseline command, the lift arm position and the coupler angle.





**FIG. 1**



**FIG. 2**

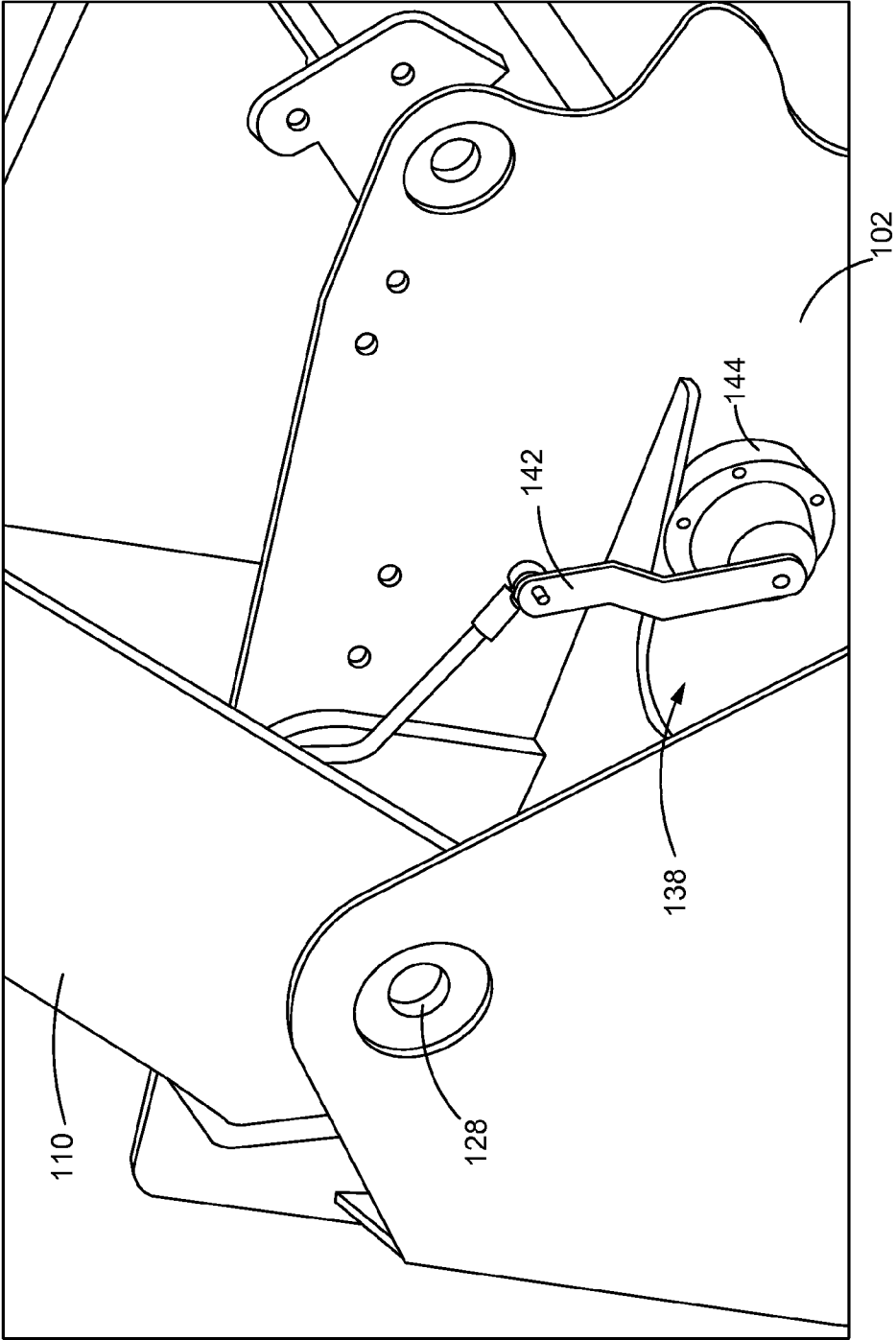
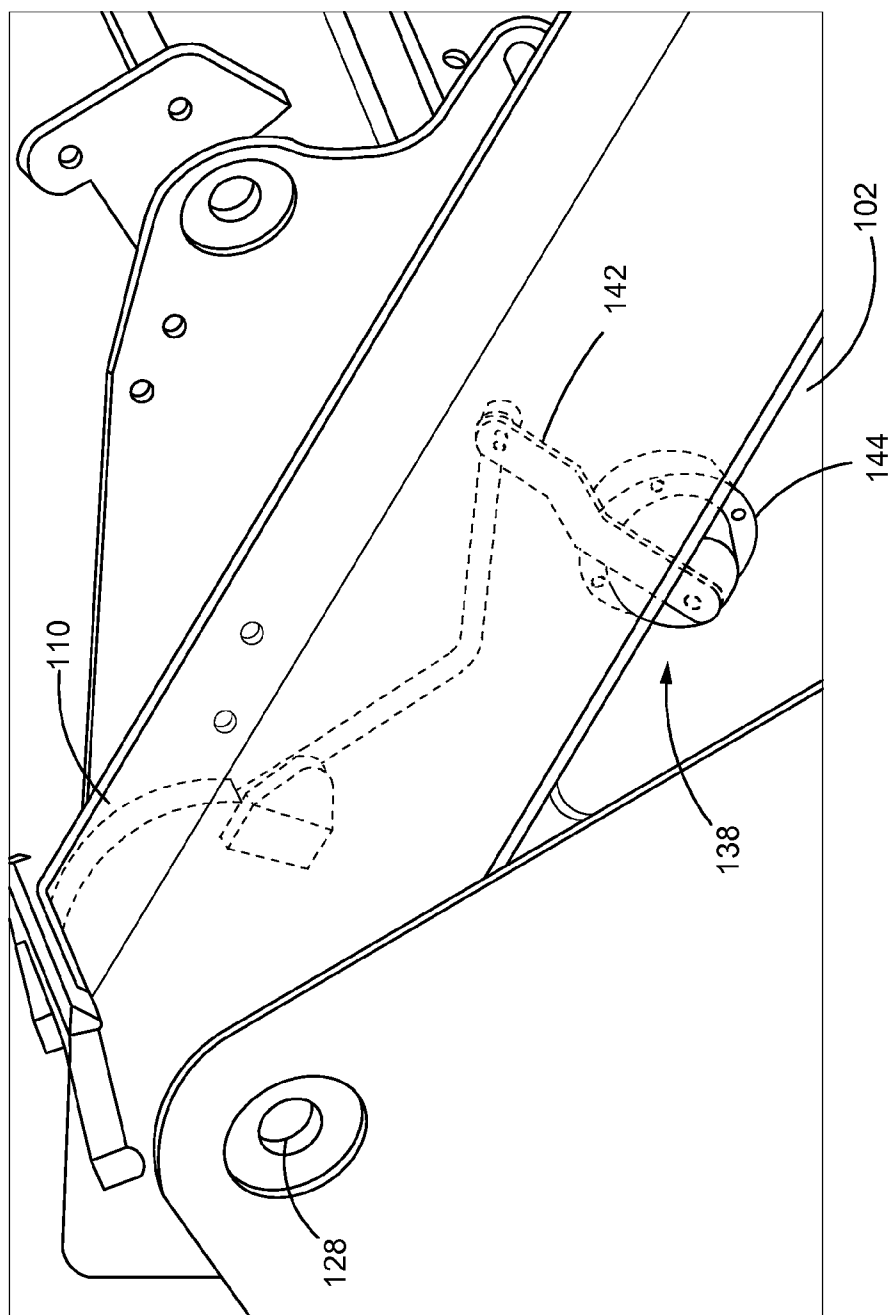
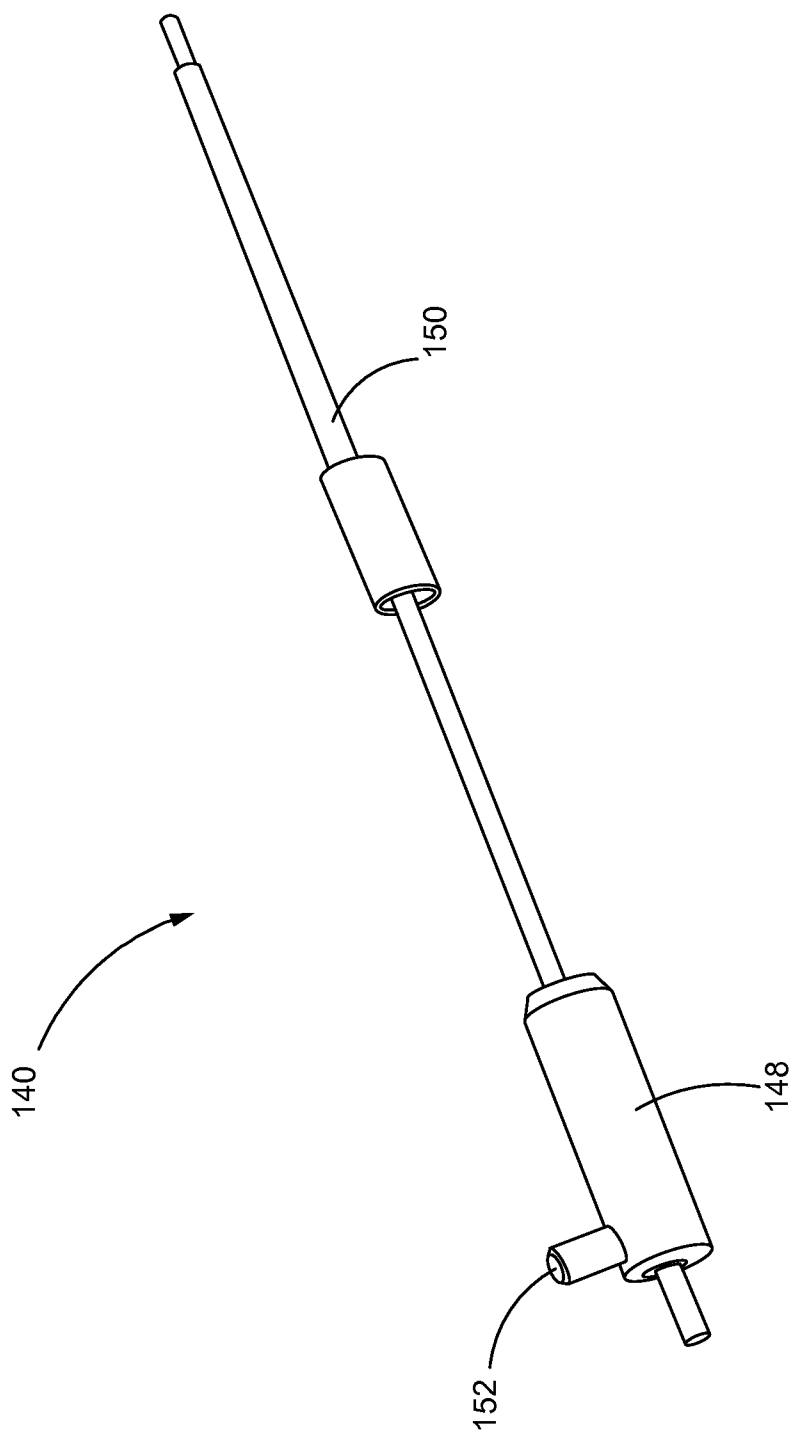


FIG. 3



**FIG. 4**



**FIG. 5**

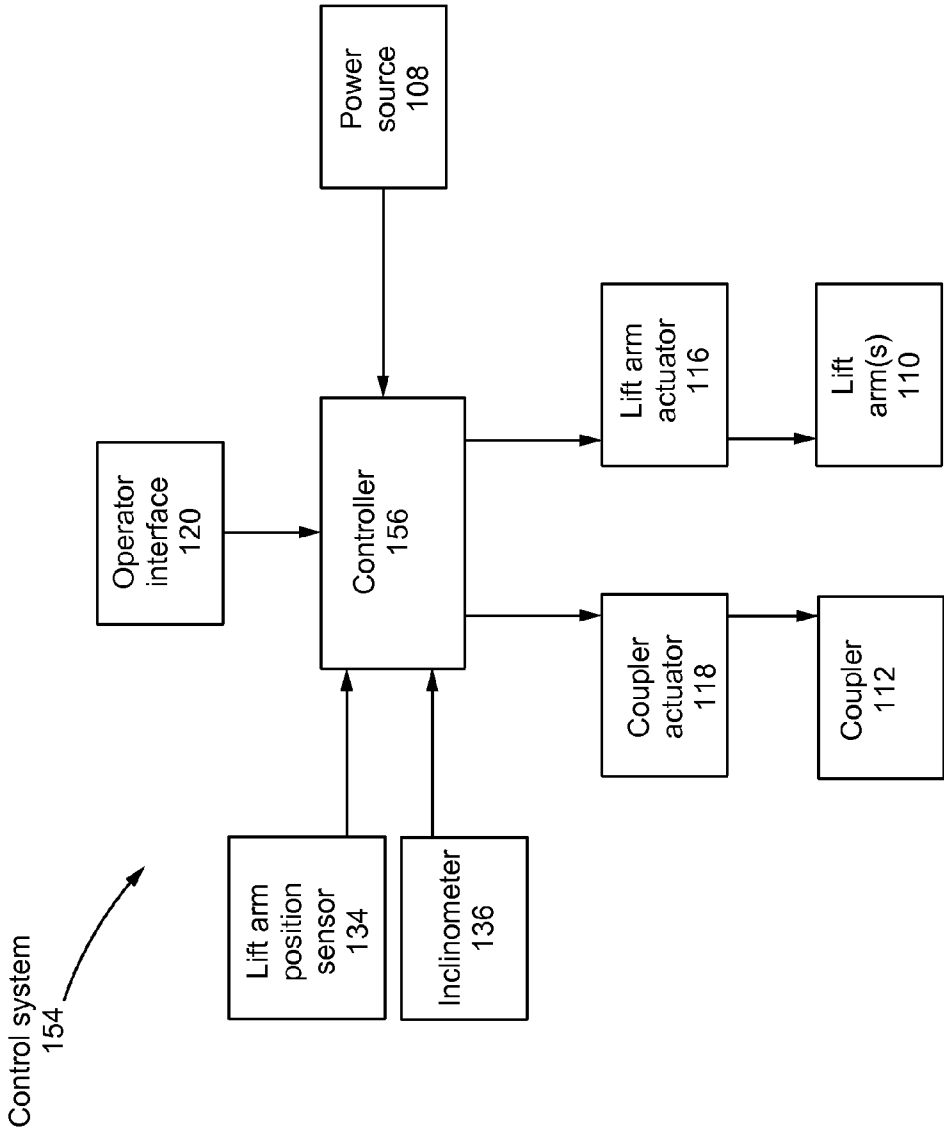
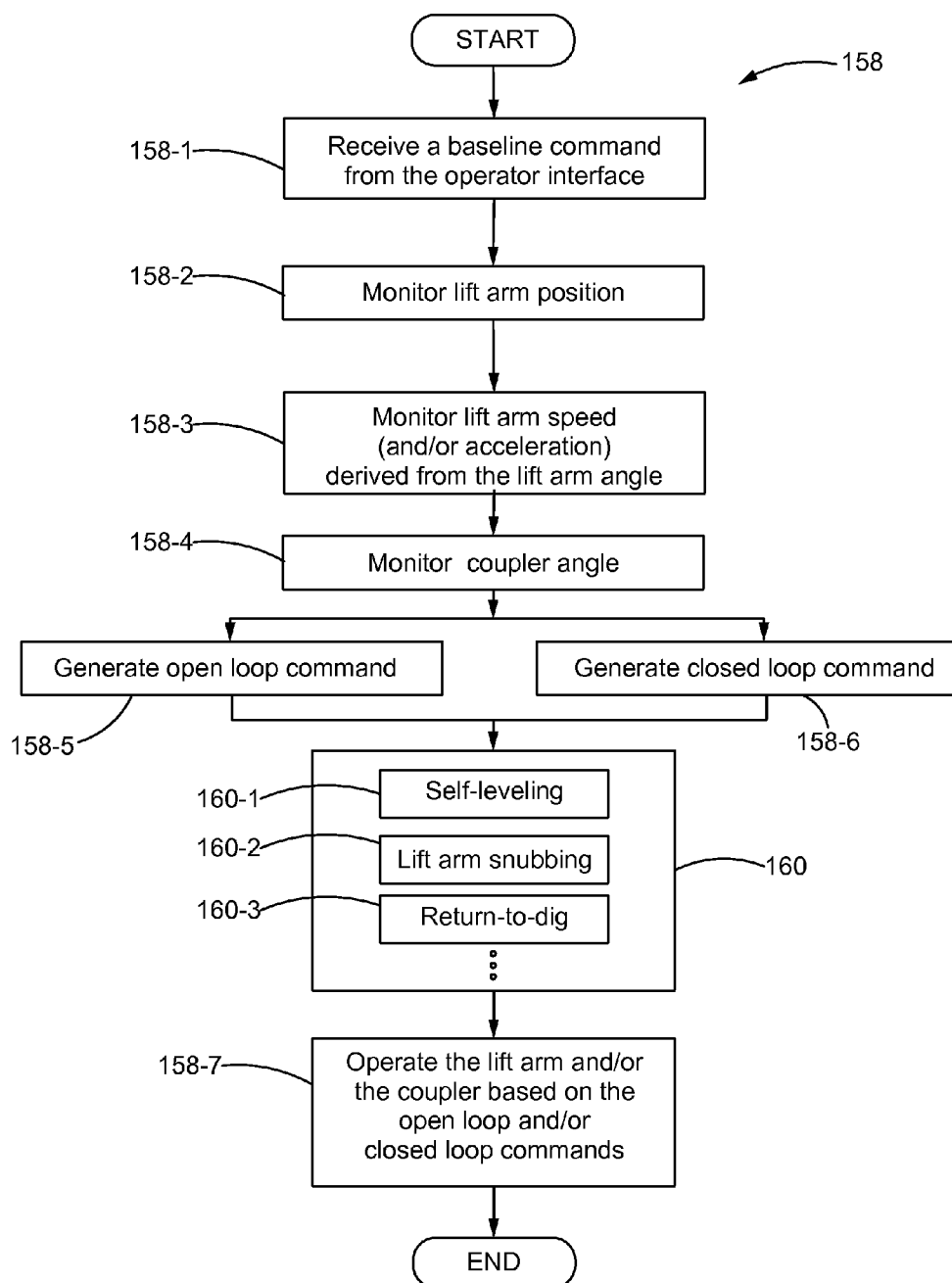


FIG. 6



**FIG. 7**

## LIFT ARM AND COUPLER CONTROL SYSTEM

### TECHNICAL FIELD

[0001] The present disclosure relates generally to lift arm assemblies, and more particularly, to systems and machines for controlling lift arm assemblies.

### BACKGROUND

[0002] Certain machines may be fitted with different implements to be used in industries related to materials handling, construction, and the like. These machines typically include one or more lift arms for moving an implement attached thereto from a starting position to a desired ending position in order to perform a desired task. Such a machine is often used to transport materials, such as by lifting a given load of material from a first site, carrying the load to a second site, and dumping the material at the second site. The machine may often repeat the process by returning to the first site, lowering the implement to the starting position, lifting another load of the material, and so forth.

[0003] Different features have been incorporated into such machines to facilitate operator control and reduce wear. For instance, some conventional lift arm assemblies provide a snubbing feature which automatically slows the movement of the lift arms as they reach a limit of travel to help reduce abrupt motions that can cause wear to the machine as well as spillage of a given load. Certain machines provide self-leveling features which help keep the implement level irrespective of the position and/or movement of the machine and lift arms so as to reduce spillage of a load. Other features include predefined return-to-dig settings which enable the operator to recall and automatically set the machine, lift arms and implement to a desired digging position or orientation.

[0004] Features such as these can be implemented using preprogrammed control algorithms in conjunction with sensors that are provided on the machine. However, control algorithms typically used in these configurations often rely on relatively fragmented sensor data to operate the machine, and may have limited adaptability to changes in the operator input or changes in a given payload. Among other things, these systems may benefit from the ability to more quickly adapt to or correct for deviations between a target operation and the actual resulting operation of the machine and its lift arms, which may be caused by changes in the payload weight for example.

[0005] Other control systems may also be used. For example, the control system of U.S. Pat. No. 8,594,896 to Nicholson, et al. employs limit switches that are positioned relative to the machine frame to detect proximity of the lift arms when they approach or reach an upper or lower limit of travel, and an angle sensor that is placed on the coupling end of the lift arms to detect an angular position of the implement. The control system in Nicholson uses feedback from the limit switches and the angle sensor to provide helpful features. However, it will be appreciated from the following description that additional measures may be implemented to further enhance control of the machine and the lift arms.

[0006] The present disclosure is directed to systems and machines which improve the ability to monitor and track the lift arms and serve to address one or more of the deficiencies set forth above. However, it should be appreciated that the solution of any particular problem is not a limitation on the

scope of this disclosure or of the attached claims except to the extent expressly noted. Additionally, the inclusion of any problem or solution in this Background section is not an indication that the problem or solution represents known prior art except as otherwise expressly noted.

### SUMMARY OF THE DISCLOSURE

[0007] In one aspect of the present disclosure, a control system for a loader having a frame, a lift arm assembly, a coupler, and an operator interface is provided. The control system may include a lift arm position sensor coupled to the lift arm assembly and configured to measure a lift arm position, an inclinometer disposed on the coupler configured to measure a coupler angle, and a controller in electrical communication with each of the lift arm position sensor, the inclinometer and the operator interface. The controller may be configured to receive a baseline command from the operator interface for operating one or more of the lift arm assembly and the coupler, monitor the lift arm position and the coupler angle, and generate at least one command for operating one or more of the lift arm assembly and the coupler based on one or more of the baseline command, the lift arm position and the coupler angle.

[0008] In another aspect of the present disclosure, a machine is provided. The machine may include a lift arm assembly, a lift arm position sensor coupled to the lift arm assembly and configured to measure a lift arm position, and a controller in electrical communication with the lift arm position sensor. The controller may be configured to receive a baseline command corresponding to operator input, monitor the lift arm position, and generate at least one command for operating the lift arm assembly based on the baseline command and the lift arm position.

[0009] In yet another aspect of the present disclosure, a loader is provided. The loader may include a frame, a lift arm assembly movably coupled to the frame, a coupler pivotally coupled to the lift arm assembly, an operator interface configured to generate a baseline command for operating one or more of the lift arm assembly and the coupler in response to operator input, a lift arm position sensor coupled to the lift arm assembly and configured to measure a lift arm position, an inclinometer coupled to the coupler configured to measure a coupler angle, and a controller in electrical communication with each of at least the lift arm position sensor, the inclinometer and the operator interface. The controller may be configured to receive the baseline command from the operator interface, monitor the lift arm position and the coupler angle, and generate at least one command for operating one or more of the lift arm assembly and the coupler based on one or more of the baseline command, the lift arm position and the coupler angle.

### BRIEF DESCRIPTION OF THE DRAWINGS

[0010] FIG. 1 is a diagrammatic view of one embodiment of a machine having a lift arm and coupler control system of the present disclosure incorporated therewith;

[0011] FIG. 2 is a perspective view of one embodiment of a rotary position sensor configured for use with the lift arm and coupler control system of the present disclosure;

[0012] FIG. 3 is a perspective view of another embodiment of a rotary position sensor as installed in a first configuration onto a loader having lift arms in the raised position;

[0013] FIG. 4 is a perspective view of the rotary position sensor of FIG. 3 as installed in the first configuration onto a loader having lift arms in the lowered position;

[0014] FIG. 5 is a perspective view of one embodiment of a linear position sensor configured for use with the lift arm and coupler control system of the present disclosure;

[0015] FIG. 6 is a schematic view of one embodiment of a lift arm and coupler control system for a loader having lift arms and a coupler; and

[0016] FIG. 7 is a diagrammatic view of one embodiment of an algorithm as well as sub-algorithms or routines for controlling the lift arms and coupler of a loader.

#### DETAILED DESCRIPTION

[0017] Reference will now be made in detail to specific embodiments or features, examples of which are illustrated in the accompanying drawings. Generally, corresponding reference numbers will be used throughout the drawings to refer to the same or corresponding parts.

[0018] Referring now to FIG. 1, one exemplary machine or loader 100 is provided. As shown, the loader 100 may generally include a frame 102 which supports traction devices 104, a cab 106, and a power source 108, such as a hydrostatic drive or an engine, and the like. The loader 100 may further include one or more lift arms 110 that are movably coupled to the frame 102 and a coupler 112 that is pivotally coupled or mounted to the working end of the lift arms 110 to which a suitable implement 114, such as a bucket, or the like, may be attached. In particular, the coupler 112 may employ pins, latches, hooks, fasteners, or any other suitable mechanism for interchangeably or non-interchangeably coupling an implement 114 to the working end of the lift arms 110. The loader 100 may also be provided with a lift arm actuator 116 that operatively couples the lift arms 110 to the frame 102, as well as a coupler actuator 118 that operatively couples the coupler 112 and any attached implement 114 to the working end of the lift arms 110. Furthermore, the cab 106 may generally house an operator interface 120 through which an operator may be able to operate any one or more of the traction devices 104, the power source 108, the lift arms 110, the coupler 112 and any attached implements 114, and the like.

[0019] As shown in FIG. 1, the lift arms 110 may be provided as part of a lift arm assembly 122 which additionally includes, for example, one or more linkage members 124, hydraulic cylinders 126, link pins 128, and any other mechanism for indirectly coupling the lift arms 110 to the frame 102. In the particular arrangement shown, the lift arm assembly 122 may enable the lift arms 110 to be moved relative to multiple pivot points. In alternate embodiments, the lift arm assembly 122 may be arranged to directly couple the lift arms 110 to the frame 102 so as to move the lift arms 110 relative to a single pivot point. Furthermore, the lift arm assembly 122 and the lift arms 110 may be movable along a lift range of motion 130, while the coupler 112 may be movable along a tilt range of motion 132. It will be understood that the ranges of motion 130, 132 shown in FIG. 1 are provided for illustrative purposes and not necessarily drawn to scale or drawn to be descriptive of the actual movement of the lift arms 110 and the coupler 112. For instance, a lift arm assembly 122 with a single pivot point may move the lift arms 110 along a substantially arcuate path of motion, while a lift assembly 122 with multiple pivot points may move the lift arms 110 along a non-arcuate path of motion.

[0020] Still referring to FIG. 1, the operator interface 120 may include any combination of joysticks, handles, levers, dials, buttons, switches, and other comparable input devices, as well as any combination of gauges, illumination devices, display screens, monitors, and other comparable output devices commonly used in the art. Specifically, the operator interface 120 may enable the operator to selectively engage the lift arm actuator 116 and pivotally raise or lower the lift arms 110, for instance, through the given lift range of motion 130, or to hold the lift arms 110 in a desired position, height or angle relative to the frame 102 of the loader 100. Similarly, the operator interface 120 may enable the operator to selectively engage the coupler 112, for example, to pivotally tilt the coupler 112 up or down through the given tilt range of motion 132, or to hold the coupler 112 in a desired position or angle relative to the lift arms 110 and/or a gravitational reference. To effectuate such controls, the lift arm actuator 116 and the coupler actuator 118 may employ hydraulic actuators, cylinders, pumps, solenoid valves, or any other electrical, mechanical and/or hydraulic means capable of controlling the lift assembly 122, the lift arms 110 and the coupler 112.

[0021] The loader 100 of FIG. 1 may further include any one or more of a plurality of sensor devices, such as a lift arm position sensor 134 adapted to monitor the lift arms 110, an inclinometer 136 adapted to monitor the coupler 112, and the like. As indicated by example in phantom lines, the lift arm position sensor 134 may be disposed within the lift arm assembly 122 and arranged in any location suited to track the position and/or movement of the lift arms 110. In one embodiment, for example, the lift arm position sensor 134 may include or employ a rotary position sensor 138, as shown in FIG. 2, which may be coupled relative to any of the pivot points and configured to measure an angular displacement within the lift arm assembly 122 that can be used to derive the lift arm position. In another embodiment, the lift arm position sensor 134 may include a linear position sensor 140, as shown in FIG. 5, which may be coupled relative to, for instance, the hydraulic cylinder 126 and configured to measure a linear displacement within the lift arm assembly 122 that can be used to derive the lift arm position. Other types of sensors and other arrangements of sensors not disclosed herein may be implemented in like manner to provide comparable results. Moreover, any suitable range of displacement or other sensed data that is output by a given lift arm position sensor 134 may be calibrated and mapped to a corresponding range of lift arm position, height and/or angle.

[0022] In a first embodiment, the lift arm assembly 122 of FIG. 1 may employ a rotary position sensor 138. While other arrangements may be possible, in a lift arm assembly 122 with a single pivot point, the rotary position sensor 138 may be movably coupled between the frame 102 and the lift arms 110 and configured to measure the lift arm position based on a lift arm angle, or the angle of the lift arms 110 relative to the frame 102. As shown in FIG. 2, for example, the rotary position sensor 138 may be provided with a link arm 142 that rotatably extends from a sensor base 144. Furthermore, while the link arm 142 is shown to be hinged in one location, the link arm 142 may also be hinged in multiple locations, or in other configurations, none at all. Mechanical rotation of the link arm 142 relative to the base 144 may be converted into electrical data or measurements corresponding to angular position, displacement, speed and/or acceleration. Moreover, the rotary position sensor 138 may electrically communicate or

output such measurements in analog and/or digital form via wired connections, such as via the electrical connector 146, wireless means, or the like.

[0023] While the rotary position sensor 138 may be configured in any number of different ways, in one arrangement, as shown in FIGS. 3 and 4, the base 144 of the rotary position sensor 138 may be fixedly or rigidly coupled to the frame 102 of the loader 100 and the link arm 142 may be actuatably coupled to the lift arms 110. Alternatively, in another arrangement, not shown, the base 144 of the rotary position sensor 138 may be fixedly or rigidly coupled to the lift arms 110 and the link arm 142 may be actuatably coupled to the frame 102. The rotary position sensor 138 may be disposed in any other configuration capable of adequately providing the angular displacement of the lift arms 110 relative to the frame 102 or other related feedback. In other alternative embodiments, the rotary position sensor 138 may be similarly arranged in relation to a component of the lift arm actuator 116, such as a hydraulic cylinder 126, or the like. For instance, the rotary position sensor 138 may be disposed between the lift arms 110 and the hydraulic cylinder 126, or between the hydraulic cylinder 126 and the frame 102. In other alternatives, the rotary position sensor 138 may be integrated with a link pin 128 of the lift arm assembly 122 and configured to measure relative angular movement between the link pin 128 and the frame 102, between the link pin 128 and the lift arms 110, between the link pin 128 and one or more hydraulic cylinders 126, or the like.

[0024] In alternative embodiments, such as in a lift arm assembly 122 with multiple pivot points as shown in FIG. 1 for example, the rotary position sensor 138 may be provided relative to any one or more of the lift arms 110, the linkage members 124 and the link pins 128. Similar to the arrangements of FIGS. 3 and 4, for instance, the rotary position sensor 138 may be disposed between the lift arms 110 and a linkage member 124, between two linkage members 124, or between a linkage member 124 and the frame 102. In other alternatives, the rotary position sensor 138 may be arranged in relation to one or more components of the lift arm actuator 116, such as the hydraulic cylinder 126, or the like. For example, the rotary position sensor 138 may be disposed between the lift arms 110 and the hydraulic cylinder 126, between the hydraulic cylinder 126 and the frame 102, or the like. In still further alternative embodiments, the rotary position sensor 138 may be disposed in relation to a link pin 128 and configured to measure relative angular movement between the link pin 128 and the frame 102, between the link pin 128 and a linkage member 124, between the link pin 128 and the lift arms 110, between the link pin 128 and the hydraulic cylinder 126, or the like.

[0025] In another embodiment, the lift arm assembly 122 of FIG. 1 may employ a linear position sensor 140 that may be integrated with one or more components within the lift arm assembly 122, lift arm actuator 116, or the like, and applicable to a lift arm assembly 122 having either single or multiple pivot points. As shown in FIG. 5, for example, the linear position sensor 140 may generally include a sensor base 148 and movable rod 150 linearly extending therefrom. The linear position sensor 140 may be coupled between moving components within the lift arm assembly 122 and/or the lift arm actuator 116, and configured to track lift arm position, speed, acceleration, or the like. For example, in one possible configuration, the sensor base 148 of the linear position sensor 140 may be coupled to the head end of a hydraulic cylinder

126 while the rod 150 of the linear position sensor 140 may be coupled to a rod end of the hydraulic cylinder 126, such that the linear position sensor 140 is able to measure the extension and retraction of the hydraulic cylinder 126. Furthermore, linear displacement of the rod 150 relative to the sensor base 148 may be converted into electrical data or measurements which may further be calibrated and mapped to a corresponding range of lift arm position. Similar to the rotary position sensor 138, the linear position sensor 140 may electrically communicate or output such measurements in analog and/or digital form via wired connections, such as via the electrical connector 152, wireless means, or the like.

[0026] As illustrated in FIG. 1, the inclinometer 136 may be fixedly disposed on or coupled to the coupler 112 in a manner which enables the inclinometer 136 to measure the angular position, displacement, speed and/or acceleration of the coupler 112, and any attached implements 114, with respect to a gravitational reference. Moreover, the inclinometer 136 may be configured to provide substantially consistent feedback pertaining to the orientation and/or motion of the coupler 112 irrespective of the positions, orientations or motions of the lift arms 110 and loader 100 associated therewith. Similar to the lift arm position sensor 134, the inclinometer 136 may be configured to electrically communicate or output such data or measurements in analog and/or digital form through wired or wireless means. Although not shown in detail, it will be understood that the inclinometer 136 may be implemented using any one or more of a variety of sensor devices commonly used in the art to measure angular position, displacement, speed and/or acceleration relative to gravity or any other universal reference.

[0027] Turning to FIG. 6, the loader 100 may include a control system 154 which may be used to manage, monitor and execute operations of at least the lift arms 110 of the lift arm assembly 122 and the associated coupler 112. As shown, the control system 154 may include or implement at least the lift arm position sensor 134, the inclinometer 136 and a controller 156 in electrical communication with each of the lift arm position sensor 134 and the inclinometer 136. The controller 156 may further be in direct or indirect electrical communication with one or more of the operator interface 120, the lift arm actuator 116, the coupler actuator 118, the power source 108, and any other device or system of the loader 100 relevant to the operations of the lift arms 110, the lift arm assembly 122 and the coupler 112. For example, the controller 156 may additionally receive and monitor information indicative of the lift pressure, tilt pressure and/or other pressure differentials in any one or more of hydraulic lines associated the lift arm assembly 122 and/or coupler 112. The controller 156 may also receive and monitor information relating to the speed, acceleration, and the like, associated with the power source 108. Moreover, the controller 156 may be implemented using any one or more of a processor, a microprocessor, a microcontroller, an electronic control module (ECM), an electronic control unit (ECU), or any other suitable means for performing one or more operations for operating the loader 100. Additionally, the controller 156 may perform the operations via the computerized execution of instructions stored on a non-transitory computer-readable medium or memory, such as a disc drive, flash drive, optical memory, ROM, or the like.

[0028] The control system 154 of FIG. 6 may generally be configured in the form of a closed loop system that is supplemented by the open loop system of the present disclosure in

which the controller **156** communicates with various components of the loader **100** to perform functions according to not only preprogrammed algorithms and sub-algorithms, but also in accordance with operator input received via the operator interface **120**. For instance, in response to operator input that is received at the operator interface **120**, the operator interface **120** may generate baseline instructions or commands corresponding to those inputs to be transmitted to the controller **156** in the form of electronic signals, or the like. The controller **156** may receive the baseline instructions or commands from the operator interface **120**, and generate at least one command, such as closed loop and open loop commands which appropriately modify the baseline commands, at least in part, based on sensory data provided by the lift arm position sensor **134** and/or the inclinometer **136**, and any other relevant feedback of the loader **100**. The open loop command may provide at least a lift command for controlling the lift arms **110** and the lift arm assembly **122**, and the closed loop command may provide at least a tilt command for controlling the coupler **112**. Moreover, in generating the closed loop and open loop commands, the controller **156** serve to reduce any deviations which may exist between a target operation desired by the operator and an actual operation as detected by at least the lift arm position sensor **134** and the inclinometer **136**.

**[0029]** By providing a more direct means for measuring lift arm position, the present disclosure is able to more accurately and consistently monitor the state of the lift arms throughout the full range of motion of the lift arms. Furthermore, by enabling substantially continuous monitoring of the lift arm position, the present disclosure also enables monitoring of lift arm speed which may be derived from the rate of change in the lift arm position relative to time, as well as lift arm acceleration which may be derived from the rate of change in the lift arm speed relative to time. Moreover, the lift arm position sensor is located proximate to the pivot point of the lift arms so as to avoid interference caused by exposure to dirt and debris.

**[0030]** In addition, by providing more consistent and reliable feedback regarding the lift arm position, the present disclosure is able to provide the operator with additional features that may not otherwise be feasible. Based on the lift arm position and speeds, for instance, the present disclosure may be able to detect and appropriately correct for inconsistencies in the lift arm motion which may occur during lifting of heavier payloads and/or as a result of limitations in the lift arm actuator. Still further, by relying on more accurate feedback, the present disclosure may be able to offer the operator more customizable options, for instance, related to automatic leveling, snubbing features, return-to-dig settings, or the like, without sacrificing functionality or performance.

#### INDUSTRIAL APPLICABILITY

**[0031]** In general terms, the present disclosure sets forth systems and machines for providing enhanced control of lift arm assemblies associated with loaders, such as wheel loaders, track loaders, skid steer loaders, backhoe loaders, and the like. It will be appreciated that the described principles and techniques apply equally to industrial machines, manufacturing machines, farming machines, mining machines, earth moving machines, and any other type of machine that would benefit from a more accurate control system for operating lift arms and lift arm assemblies.

**[0032]** One exemplary lift arm control process or algorithm **158** is diagrammatically provided in FIG. 7, according to which, for example, the control system **154** and the controller **156** of FIG. 6 may be configured to operate. As shown in block **158-1**, the controller **156** may initially, periodically or continuously receive a baseline command from the operator interface **120**. More specifically, an operator may employ any of the input devices provided at the operator interface **120** to input instructions for performing a desired or target operation of the lift arms **110** and/or the coupler **112**. Based on the operator input, the operator interface **120** may generate a baseline command, for example, in the form of electrical signals, or any other suitable means of effectuating the target operation through the lift arm actuator **116** and/or coupler actuator **118**. Such baseline commands generated by the operator interface **120** are further communicated to and received by the control system **154** and the controller **156** associated therewith.

**[0033]** In addition, as shown in blocks **158-2**, **158-3** and **158-4** of FIG. 7, the controller **156** may be configured to monitor various parameters of the lift arms **110**, the lift arm assembly **122** and the coupler **112** to assess the actual operation of the loader **100**. For example, in block **158-2**, the controller **156** may detect or monitor a lift arm position, or the position of the lift arms **110** relative to the frame **102**, based on measurements taken by the lift arm position sensor **134**, such as a rotary position sensor **138**, a linear position sensor **140**, or the like. The controller **156** may be configured to monitor the lift arm position by sampling data provided by the lift arm position sensor **134** upon demand and/or periodically, or by continuously reading the data for any predefined duration. Additionally, the controller **156** may further be configured to monitor the lift arm speed, or the speed of the lift arms **110** relative to the frame **102**, in block **158-3**. In particular, the controller **156** may derive or calculate the lift arm speed based on a rate of change of the lift arm position, as determined in block **158-2**, with respect to time. Optionally, the controller **156** may additionally derive or calculate lift arm acceleration, or any further derivative, of the lift arms **110** relative to the frame **102** in block **158-3**.

**[0034]** In block **158-4**, the controller **156** may also be configured to monitor a coupler angle, or the angular position or displacement of the coupler **112** relative to gravity. Similar to block **158-2**, the controller **156** in block **158-4** may monitor the coupler angle by sampling data provided by the inclinometer **136** upon demand and/or periodically, or by continuously reading the data for a predefined duration. The controller **156** may also be configured to monitor the coupler speed, acceleration and/or any other derivative of the coupler angle relative to a gravitational reference using the readings by the inclinometer **136**. For example, the controller **156** may derive coupler speed based on a rate of change of the coupler angle with respect to time, or calculate further derivatives to determine coupler acceleration, and the like.

**[0035]** In block **158-5** of FIG. 7, the controller **156** may be configured to generate an open loop command based on any one or more of the baseline command, the lift arm position, the lift arm speed, and optionally, the lift arm acceleration. Moreover, the lift arm angle, the lift arm speed and the lift arm acceleration may be observed to characterize the actual operation of the lift arms **110**. Similarly, in block **158-6**, the controller **156** may be configured to generate a closed loop command based on at least the coupler angle as determined for instance by the inclinometer **136**. The closed loop com-

mand may also be generated based at least partially on information pertaining to the lift arms 110 to the extent such information can be useful in executing certain features which rely upon a closed loop system. The resulting open loop and closed loop commands generated by the controller 156 may be used in conjunction with one another and to reduce any deviations between target operations, preprogrammed or desired by the operator, and the actual operation of the loader 100.

[0036] Furthermore, the controller 156 may be configured to generate the open loop and closed loop commands in accordance with any one or more algorithms or sub-algorithms 160 preprogrammed therein. As shown in FIG. 7, for example, the controller 156 may generate a command based at least partially on any one or more of a self-leveling or an automatic leveling sub-algorithm 160-1, a lift arm snubbing sub-algorithm 160-2 and a return-to-dig sub-algorithm 160-3. In other alternative embodiments, the controller 156 may be configured to operate according to other algorithms or sub-algorithms not shown or according to other variations of the sub-algorithms 160 disclosed in FIG. 7. In addition, the open loop command that is generated in block 158-5 and in accordance with the sub-algorithms 160 may include at least a lift command for operating the lift arms 110 and the associated lift arm assembly 122. The closed loop command that is generated in block 158-6 and in accordance with the sub-algorithms 160 may include at least a tilt command for operating the coupler 112 and any attached implement 114. Based on such commands, the controller 156 may be configured to operate the corresponding lift arms 110 and/or the coupler 112 in block 158-7, for example, via the corresponding lift arm actuator 116 and/or the coupler actuator 118.

[0037] In general, the self-leveling sub-algorithm 160-1 of FIG. 7, if enabled by the operator, may be used to automatically maintain the coupler 112 and any attached implement 114 at a desired position with respect to gravity for a given task, operation and/or duration of time. In particular, the controller 156 may continuously monitor the coupler angle using the inclinometer 136 to determine if self-leveling is required, and if so, adapt control to the coupler actuator 118 to maintain a substantially consistent coupler angle relative to gravity. In a hydraulically driven coupler actuator 118, for example, pressure within the hydraulic lines associated with the coupler 112, or the tilt pressure, may be adjusted via control of one or more hydraulic valves or solenoids leading thereto and/or via adjustments in the speed of an associated hydraulic pump. The coupler actuator 118 may also employ electrical, mechanical and/or any other suitable means to adjust the coupler 112 and thus the coupler angle. The control system 154 may also be configured such that the commands generated by the controller 156 can be partially or fully overridden by operator input. When using a bucket implement 114 to lift a payload, for example, the self-leveling sub-algorithm 160-1 may automatically engage anytime the lift arms 110 are being raised or lowered so as to keep the bucket 114 level relative to gravity, irrespective of changes in the lift arm position, and to prevent spillage. In other modifications, the self-leveling or automatic leveling routine 160-1 may also be engaged to keep the bucket 114 level irrespective of grade changes or ground surface irregularities and to prevent spillage while the loader 100 transports a payload to a destination site.

[0038] The lift arm snubbing sub-algorithm 160-2 of FIG. 7, if enabled by the operator, may be used to automatically

cushion or decelerate the lift arms 110 when the lift arms 110 approach the upper or lower limit of the lift range of motion 130 thereof as they are raised or lowered by the operator. A controller 156 that is enabled with lift arm snubbing features may establish snubbing regions 162, as shown for example in FIG. 1, which are defined within and adjacent to the upper and/or lower limits of the lift range of motion 130 of the lift arms 110. The range of each snubbing region 162 may also be removed, added, or otherwise modified by the operator. When the lift arm snubbing routine 160-2 is enabled, the controller 156 may monitor at least the lift arm position with respect to the frame 102 of the loader 100 via the lift arm position sensor 134 and detect when the lift arms 110 are moved into or proximate to any of the designated snubbing regions 162. Optionally, the controller 156 may also monitor the lift arm speed, lift arm acceleration, and/or other derivatives based on changes in the lift arm position as measured by the lift arm position sensor 134, to determine whether a given action of the lift arms 110 requires snubbing. If the lift arms 110 are moved into or proximate to any of the snubbing regions 162, and approaching a limit of the lift range of motion 130 with sufficient speed or acceleration, the controller 156 may automatically modulate one or more of the closed loop and open loop commands to slow the lift arms 110 via the lift arm actuator 116, or the like.

[0039] In a hydraulically driven lift arm actuator 116, for example, pressure within the hydraulic lines associated with the lift arm assembly 122, or the lift pressure, may be adjusted or dampened via control of one or more hydraulic valves or solenoids leading thereto and/or via adjustments in the speed of an associated hydraulic pump. The lift arm actuator 116 may also employ electrical, mechanical and/or any other suitable means to adjust the lift arms 110 and thus the lift arm position, speed and/or acceleration. Furthermore, the degree of snubbing or damping that is applied, or a snubbing factor, may be varied based on any combination of machine parameters including lift arm position, lift arm speed, lift arm acceleration, lift pressure, tilt pressure, estimated payload weight, and the like. In one embodiment, the controller 156 may be provided with preprogrammed maps, or maps retrievably stored in a memory that is accessible to the controller 156, which relate different sets of possible machine parameters with corresponding optimum snubbing factors. If, for example, the speed of the lift arms 110 is relatively high upon entering one of the snubbing regions 162, the preprogrammed maps may indicate to the controller 156 that a relatively higher snubbing factor should be applied in order to adequately dampen or slow the lift arms 110 as they reach a limit of travel. Alternatively, if the lift arm speed is relatively low or at a minimum speed upon entering a snubbing region 162, the preprogrammed maps may suggest to the controller 156 that minimal or no snubbing factor need be applied. In still further modifications, preprogrammed maps or other suitable predefined relationships may similarly be used by the controller 156 to assess or estimate payload weight based on various machine parameters and/or to adapt control of the lift arms 110 in response to changes in the estimated payload weight.

[0040] The return-to-dig routine or sub-algorithm 160-3 of FIG. 7 enables an operator to recall machine presets which automatically adjust the lift arms 110 and/or the coupler 112 of the loader 100 to preconfigured digging positions and facilitate repetitive digging operations. The machine presets may be assigned or retrievably stored by the operator within

a memory associated with the controller **156** and may include settings corresponding to a coupler angle and/or a lift arm position that may be preferred for digging. The controller **156** may also store a plurality of different presets for digging, and/or a plurality of different presets for operations other than digging. Furthermore, any one or more of the presets may be modified by the operator as well as recalled at any time during operation of the loader **100** using a more simplified means of input via the operator interface **120**. When a preset is recalled, the controller **156** may detect the current state of the lift arms **110** and the coupler **112** via the lift arm position sensor **134** and the inclinometer **136**, and determine the appropriate closed loop and/or open loop commands for adjusting the loader **100** from the current state to the preset configuration. The controller **156** may then automatically engage, for example, any one or more of the lift arm actuator **116**, the coupler actuator **118**, or the like, to adjust the lift arms **110** and/or the coupler **112** to the desired preset configuration.

**[0041]** It will be appreciated that the foregoing description provides examples of the disclosed system and technique. However, it is contemplated that other implementations of the disclosure may differ in detail from the foregoing examples. All references to the disclosure or examples thereof are intended to reference the particular example being discussed at that point and are not intended to imply any limitation as to the scope of the disclosure more generally. All language of distinction and disparagement with respect to certain features is intended to indicate a lack of preference for those features, but not to exclude such from the scope of the disclosure entirely unless otherwise indicated.

**[0042]** From the foregoing, it will be appreciated that while only certain embodiments have been set forth for the purposes of illustration, alternatives and modifications will be apparent from the above description to those skilled in the art. These and other alternatives are considered equivalents and within the spirit and scope of this disclosure and the appended claims.

What is claimed is:

**1.** A control system for a loader having a frame, a lift arm assembly, a coupler, and an operator interface, the control system comprising:

- a lift arm position sensor coupled to the lift arm assembly and configured to measure a lift arm position;
- an inclinometer disposed on the coupler configured to measure a coupler angle; and
- a controller in electrical communication with each of the lift arm position sensor, the inclinometer and the operator interface, the controller being configured to receive a baseline command from the operator interface for operating one or more of the lift arm assembly and the coupler, monitor the lift arm position and the coupler angle, and generate at least one command for operating one or more of the lift arm assembly and the coupler based on one or more of the baseline command, the lift arm position and the coupler angle.

**2.** The control system of claim **1**, wherein the lift arm position sensor includes a rotary position sensor configured to measure the lift arm position based on an angular displacement of the lift arm assembly.

**3.** The control system of claim **1**, wherein the lift arm position sensor includes a linear position sensor configured to measure the lift arm position based on a linear displacement of the lift arm assembly.

**4.** The control system of claim **1**, wherein the inclinometer is configured to measure the coupler angle as an angle of the coupler relative to gravity.

**5.** The control system of claim **1**, wherein the controller is configured to generate the at least one command to include one or more of a lift command for controlling the lift arm assembly and a tilt command for controlling the coupler.

**6.** The control system of claim **5**, wherein the controller is configured to communicate the lift command to a lift arm actuator operatively coupled to the lift arm assembly, and communicate the tilt command to a coupler actuator operatively coupled to the coupler.

**7.** The control system of claim **1**, wherein the controller is configured to generate an open loop command based on at least the baseline command and the lift arm position, and generate a closed loop command based on at least the coupler angle.

**8.** The control system of claim **7**, wherein the controller is configured to monitor a lift arm speed derived from a rate of change in the lift arm position, the controller generating the open loop command based on at least the baseline command and one or more of the lift arm position and the lift arm speed.

**9.** The control system of claim **7**, wherein the controller is configured to generate the open loop command and the closed loop command such that one or more of the lift arm assembly and the coupler is operated in accordance with one or more of an automatic leveling routine, a lift arm snubbing routine, and a return-to-dig routine.

**10.** A machine, comprising:

- a lift arm assembly;
- a lift arm position sensor coupled to the lift arm assembly and configured to measure a lift arm position; and
- a controller in electrical communication with the lift arm position sensor, the controller being configured to receive a baseline command corresponding to operator input, monitor the lift arm position, and generate at least one command for operating the lift arm assembly based on the baseline command and the lift arm position.

**11.** The machine of claim **10**, wherein the lift arm position sensor includes a rotary position sensor configured to measure the lift arm position based on an angular displacement of the lift arm assembly relative to the machine.

**12.** The machine of claim **10**, wherein the lift arm position sensor includes a linear position sensor configured to measure the lift arm position based on a linear displacement of the lift arm assembly relative to the machine.

**13.** The machine of claim **10**, wherein the controller is configured to generate a lift command for controlling a lift arm actuator in order to operate the lift arm assembly, the controller being configured to monitor a lift arm speed derived from a rate of change in the lift arm position, and generate the lift command based on the baseline command and one or more of the lift arm position and the lift arm speed.

**14.** The machine of claim **10**, further comprising a coupler pivotally coupled to the lift arm assembly, and an inclinometer coupled to the coupler configured to measure a coupler angle relative to gravity, the controller being configured to monitor the coupler angle and generate the at least one command for operating one or more of the lift arm assembly and the coupler based on the baseline command, the lift arm position and the coupler angle.

**15.** The machine of claim **14**, wherein the controller is configured to generate an open loop command based on at

least the baseline command and the lift arm position, and generate a closed loop command based on at least the coupler angle.

**16.** A loader, comprising:

- a frame;
- a lift arm assembly movably coupled to the frame;
- a coupler pivotally coupled to the lift arm assembly;
- an operator interface configured to generate a baseline command for operating one or more of the lift arm assembly and the coupler in response to operator input;
- a lift arm position sensor coupled to the lift arm assembly and configured to measure a lift arm position;
- an inclinometer coupled to the coupler configured to measure a coupler angle; and
- a controller in electrical communication with each of at least the lift arm position sensor, the inclinometer and the operator interface, the controller being configured to receive the baseline command from the operator interface, monitor the lift arm position and the coupler angle, and generate at least one command for operating one or more of the lift arm assembly and the coupler based on one or more of the baseline command, the lift arm position and the coupler angle.

**17.** The loader of claim **16**, wherein the inclinometer is configured to measure the coupler angle as an angle of the coupler relative to gravity, and the lift arm position sensor employs one of a rotary position sensor and a linear position

sensor, the rotary position sensor being configured to measure the lift arm position based on an angular displacement of the lift arm assembly, and the linear position sensor being configured to measure the lift arm position based on a linear displacement of the lift arm assembly.

**18.** The loader of claim **16**, wherein the controller is configured to generate an open loop command based on at least the baseline command and the lift arm position, and generate a closed loop command based on at least the coupler angle.

**19.** The loader of claim **18**, further comprising a lift arm actuator operatively coupled to the lift arm assembly and a coupler actuator operatively coupled to the coupler, the controller being configured to generate the open loop command and the closed loop command to include one or more of a lift command for controlling the lift arm actuator and a tilt command for controlling the coupler actuator.

**20.** The loader of claim **19**, wherein the controller is configured to derive one or more of a lift arm speed and an estimated payload weight based on one or more of the baseline command, the lift arm position, the coupler angle, a lift pressure associated with the lift arm assembly, and a tilt pressure associated with the coupler actuator, the controller being configured to generate the open loop command and the closed loop command in accordance with one or more of an automatic leveling routine, a lift arm snubbing routine, and a return-to-dig routine.

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