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CONTROL OF MULTIPLE POWER MACHINES

Abstract

A power machine system includes a first power machine with a first work element, a first power source to power the first work element, a first user input device to control the first work element, and a first processing device. The first processing device cooperatively controls the first power machine and a second power machine to complete a task. The cooperative control includes controlling the first power machine via local control of the first work element by the first user input device of the first power machine, and controlling the second power machine via remote control of a second work element of the second power machine by the first user input device of the first power machine.

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Background/Summary

CROSS-REFERENCE TO RELATED APPLICATIONS [0001] This application claims priority to U.S. Non-Provisional patent application Ser. No. 18/145,519, filed on Dec. 22, 2022, which claims the benefit of U.S. Provisional Patent Application No. 63/292,772, filed on Dec. 22, 2021, each of which are herein incorporated by reference in their entirety.

BACKGROUND
[0002] This disclosure is directed toward power machines. More particularly, this disclosure relates to remote and local control of power machines. Power machines, for the purposes of this disclosure, include any type of machine that generates power to accomplish a particular task or a variety of tasks. One type of power machine is a work vehicle. Work vehicles are generally self-propelled vehicles that have a work device, such as a lift arm (although some work vehicles can have other work devices) that can be manipulated to perform a work function. Work vehicles include loaders, excavators, utility vehicles, tractors including compact tractors, and trenchers, to name a few examples. Other types of power machines can include mini-loaders (e.g., mini track loaders), and mowers.
[0003] Conventional power machines can use human-machine interfaces (HMIs) to allow a user to control various operations of the power machine. For example, HMIs can allow an operator to control a speed and a direction of movement of the power machine, and to manipulate a work element that is supported by the power machine (e.g., by actuating one or more actuators). Human-machine interfaces can be provided within a cab or can be included in other types of operator stations of a power machine.
[0004] The discussion above is merely provided for general background information and is not intended to be used as an aid in determining the scope of the claimed subject matter.
SUMMARY
[0005] Embodiments of the invention, as generally disclosed herein, can relate to control systems and methods for selectively executing local control of operation of a first power machine (e.g., of a first type) and remote control of operation of a second power machine (e.g., of a second different type), including based on user inputs at a human-machine interface of the first power machine that is operable to control both power machines. In some embodiments, an integrated user input device on board a first power machine can be selectively operated in different control modes, including a first control mode in which the device provides signals to command (e.g., exclusively) local control of the first power machine, and a second control mode in which the device provides signals to command (e.g., exclusively) remote control of a second power machine.
[0006] According to one aspect of the present disclosure, a power machine system can include a first power machine. The first power machine can include a first work element, a first power source to power the first work element, a first user input device to control the first work element, and a first processing device. The first processing device can cooperatively control the first power machine and a second power machine to complete a task. This can include controlling the first power machine via local control of the first work element by the first user input device of the first power machine, and controlling a second power machine via remote control of a second work element of the second power machine by the first user input device of the first power machine.
[0007] In some examples, the first and second work elements can each include a workgroup work element or a tractive element.
[0008] In some examples, the first power machine can be configured to receive and display a video

transmission from the second power machine during the cooperative control to complete the task.

[0009] In some examples, the first user input device can include a joystick within the first power machine that receives first inputs for the local control of the first work element and second inputs for the remote control of the second work element.

[0010] In some examples, the first power machine can be an excavator and the second power machine can be a loader.

[0011] In some examples, the task can be a work task and the cooperative control to complete the task can include control of one or more workgroup work elements of the first and second power machines by the first user input device.

[0012] In some examples, the cooperative control can further include control of one or more tractive elements of the first and second power machines by the first user input device.

[0013] According to another aspect of the present disclosure, a control system for cooperatively controlling a first power machine and a second power machine to complete a task can include a first user input device within the first power machine and a processor device. The processor device can be configured to receive a first user input via the first user input device and, in response to receiving the first user input, selectively control a first work element of the first power machine, based on the first user input, to execute a first work operation of the task with the first power machine, or control a second work element of the second power machine, based on the first user input, to execute a second work operation of the task with the second power machine.

[0014] In some examples, the processor device can control the first and second power machines to cooperatively complete the task by selectively locally controlling the first power machine via first inputs to the first user input device, and remotely controlling the second power machine via second inputs to the first user input device.

[0015] In some examples, the first power machine can be configured to receive and display a video transmission from the second power machine during the remote control of the second power machine via the second inputs to the first user input device.

[0016] In some examples, the first user input device can include a joystick within the first power machine, and a control signal from the first user input device can be implemented with a first mapping to control actuators of the first power machine during the local control of the first power machine, and with a second mapping, different from the first mapping, to control actuators of the second power machine during the remote control of the second power machine.

[0017] In some examples, the first power machine can be an excavator and the second power machine can be a loader.

[0018] In some examples, the first work element can include one or more of a first workgroup work element of the excavator or a first tractive element of the excavator, and the second work element can include one or more of a second workgroup work element of the loader or a second tractive element of the loader.

[0019] In some examples, the task can be a digging operation, the first workgroup element can include the first workgroup work element of the first power machine and the second work element can include the second tractive element of the loader.

[0020] According to yet another aspect of the present disclosure, a method for cooperatively controlling a first power machine and a second power machine to complete a task can include selecting between local control of the first power machine via a first user input interface within the first power machine, and remote control of the second power machine via the first user input interface within the first power machine. The method can also include, during the selected local control of the first power machine, controlling operation of a first work element of the first power machine, based on a first user input at the first user input interface, to cooperatively execute the task. The method can further include, during the selected remote control of the second power machine, controlling operation of a second work element of the second power machine, based on a second user input at the first user input interface, to cooperatively execute the task.

[0021] In some examples, the method can include, during the selected remote control of the second power machine, receiving a video transmission from the second power machine and displaying the video transmission at the first power machine.
[0022] In some examples, a first mapping of user inputs at the first user input interface can correspond to control of the first work element and a second mapping of user inputs at the first user input interface, different from the first mapping, can correspond to control of the second work element.
[0023] In some examples, the first work element can include a workgroup work element of the first power machine and the second work element can include a tractive element of the second power machine.
[0024] In some examples, the first power machine and the second power machine can be different types of power machines.
[0025] In some examples, the task can be a digging operation.
[0026] This Summary and the Abstract are provided to introduce a selection of concepts in a simplified form that are further described below in the Detailed Description. This Summary is not intended to identify key features or essential features of the claimed subject matter, nor are they intended to be used as an aid in determining the scope of the claimed subject matter.

Description

DRAWINGS
[0027] The following drawings are provided to help illustrate various features of non-limiting examples of the disclosure and are not intended to limit the scope of the disclosure or exclude alternative implementations.
[0028] FIG. **1** is a block diagram illustrating functional systems of a representative power machine on which embodiments of the present disclosure can be advantageously practiced.
[0029] FIGS. **2-3** illustrate perspective views of a representative power machine in the form of a skid-steer loader of the type on which the disclosed embodiments can be practiced.
[0030] FIG. **4** is a block diagram illustrating components of a power system of a loader such as the loader illustrated in FIGS. **2-3**.
[0031] FIG. **5** is a schematic block diagram illustrating aspects of a control system for control of a first power machine and a second power machine according to embodiments of the present disclosure.
[0032] FIG. **6** is a flow chart diagram of an example method for controlling multiple power machines according to embodiments of the present disclosure.
DETAILED DESCRIPTION
[0033] The concepts disclosed in this discussion are described and illustrated by referring to exemplary embodiments. These concepts, however, are not limited in their application to the details of construction and the arrangement of components in the illustrative embodiments and are capable of being practiced or being carried out in various other ways. The terminology in this document is used for the purpose of description and should not be regarded as limiting. Words such as “including,” “comprising,” and “having” and variations thereof as used herein are meant to encompass the items listed thereafter, equivalents thereof, as well as additional items.
[0034] In some cases, work operations on one or more job sites may require, or at least benefit from, controlled operation of multiple power machines. For example, a power machine of a first type (e.g., an excavator) may be useful to execute certain operations on a job site (e.g., trenching or other digging), whereas a power machine of a second type (e.g., a loader) may be useful to execute certain other operations on the job site (e.g., transporting dirt from a spoil pile to a dump truck). Or it may be useful for a single user to be able to coordinate operation of multiple power machines of

the same type (or different types), including for operation of multiple excavators, multiple loaders, etc. including, in some instances, controlling machines that are out of the line of sight or even in a remote location from the user.

[0035] Discussion herein of different “types” of power machines indicates power machines that have different overall functional configurations, as recognized by those of skill in the art. Thus, for example power machines configured as loaders are of a different type than power machines configured as excavators, as forestry power machines (e.g., feller-bunchers), as telehandlers, etc., and vice versa. Power machines of different types generally exhibit different workgroup configurations. For example, power machines configured as loaders may include a main lift arm configured for radial- or vertical-path movement, with workgroup actuators to separately control raising and lowering of the lift arm and changes in an attitude of an attached implement (e.g., a set of one or more lift actuators, and a set of one or more tilt actuators). In contrast, power machines configured as excavators may include a lift arm structure with a boom that pivotally supports a stick, with the stick in turn pivotally supporting an attached implement, and with workgroup actuators to control raising and lowering of the boom, pivoting of the stick relative to the boom, and changes in an attitude of an attached implement (e.g., with a set of one or more boom actuators, a set of one or more stick actuators, and a set of one or more tilt actuators). In this light, those of skill in the art will appreciate that control of different types of power machines typically requires different types of control inputs and outputs. Correspondingly, conventional operator interfaces may typically be configured for control of only a single type of power machine (e.g., with different operator interfaces for loaders and for excavators, respectively, including differently configured input devices for control of the different respective configurations of workgroup actuators or other work elements).

[0036] Some examples below focus in particular on remote control of a loader using an operator interface of an excavator. This may be useful, for example, so that operators of excavators can selectively remotely control a loader to assist in digging operations with the excavator (e.g., to scoop, transport, and then dump material that has been dug by the excavator). In other examples, however, other combinations of power machine types are possible, including implementations with remote control of an excavator using an operator interface of a loader, remote control of various types of machines that may provide a work function. In one example, a tamper (e.g., a plate compactor) can be controlled using an operator interface of a loader or an excavator, etc. Accordingly, unless otherwise indicated or required, discussion herein of examples that include particular types of power machines are intended to also disclose similar local and remote control with other combinations of power machines types.

[0037] Some embodiments of the disclosed technology can provide improved systems for control of multiple power machines by a single operator or from a single location. In particular, some embodiments can provide systems with which an operator can engage with a human-machine interface of an operator station of a first power machine (e.g., a joystick within a cab of the first power machine) to selectively control operations of the first power machine or of a second power machine. Thus, for example, some embodiments include control systems that allow an operator to control a first power machine and a second power machine by providing command inputs at an input device of the first power machine (e.g., while not providing any command inputs at a human-machine interface of the second power machine). In some embodiments, an operator can selectively operate in a local control mode, in which providing input commands via a joystick (or other device) in the cab of an excavator (or other type of power machine) can control operation of the excavator (or other machine), and in a remote control mode, in which input commands provided via the same joystick (or other device) can control operation of a loader (or other type of power machine). In different implementations, a second (remote) power machine (e.g., a loader) can be located at the same job site as a first (local) power machine (e.g., an excavator), or can be a located at a different job site. Correspondingly, remote control of a second power machine may or may not require line-of-sight communication with a first power machine, depending on the particular implementation. In some embodiments, the second power machine can be power machine that has an operator compartment with an HMI that a user can use to control the second power machine when it is not being controlled by the first power machine. In other embodiments, the second power machine may not be equipped with any HMI to control operation of the second power machine and may be completely reliant on commands from an external source or from a pre-programmed routine loaded into a control system of the second power machine.

[0038] These concepts can be practiced on various power machines, as will be described below. A representative power machine on which the embodiments can be practiced is illustrated in diagram form in FIG. **1** and one example of such a power machine is illustrated in FIGS. **2-3** and described below before any embodiments are disclosed. For the sake of brevity, only one power machine is illustrated and discussed as being a representative power machine. However, as mentioned above, the embodiments below can be practiced on any of a number of power machines, including power machines of different types from the representative power machine shown in FIGS. **2-3**. Power machines, for the purposes of this discussion, include a frame, at least one work element, and a power source that can provide power to the work element to accomplish a work task. One type of power machine is a self-propelled work vehicle. Self-propelled work vehicles are a class of power machines that include a frame, work element, and a power source that can provide power to the work element. At least one of the work elements is a motive system for moving the power machine under power.

[0039] FIG. **1** is a block diagram that illustrates the basic systems of a power machine **100**, which can be any of a number of different types of power machines, upon which the embodiments discussed below can be advantageously incorporated. The block diagram of FIG. **1** identifies various systems on power machine **100** and the relationship between various components and systems. As mentioned above, at the most basic level, power machines for the purposes of this discussion include a frame, a power source, and a work element. The power machine **100** has a frame **110**, a power source **120**, and a work element **130**. Because power machine **100** shown in FIG. **1** is a self-propelled work vehicle, it also has tractive elements **140**, which are themselves work elements provided to move the power machine over a support surface and an operator station **150** that provides an operating position for controlling the work elements of the power machine. A control system **160** is provided to interact with the other systems to perform various work tasks at least in part in response to control signals provided by an operator. As used herein, discussion of work tasks refers to sets of work operations (e.g., lifting, digging, etc.) using workgroup work elements (as further discussed below).

[0040] Certain work vehicles have work elements that can perform a dedicated task. For example, some work vehicles have a lift arm to which an implement such as a bucket is attached such as by a pinning arrangement. The work element, i.e., the lift arm can be manipulated to position the implement to perform the task. The implement, in some instances can be positioned relative to the work element, such as by rotating a bucket relative to a lift arm, to further position the implement. Under normal operation of such a work vehicle, the bucket is intended to be attached and under use. Such work vehicles may be able to accept other implements by disassembling the implement/work element combination and reassembling another implement in place of the original bucket. Other work vehicles, however, are intended to be used with a wide variety of implements and have an implement interface such as implement interface **170** shown in FIG. **1**. At its most basic, implement interface **170** is a connection mechanism between the frame **110** or a work element **130** and an implement, which can be as simple as a connection point for attaching an implement directly to the frame **110** or a work element **130** or more complex, as discussed below.

[0041] On some power machines, implement interface **170** can include an implement carrier, which is a physical structure movably attached to a work element. The implement carrier has engagement features and locking features to accept and secure any of a number of different implements to the work element. One characteristic of such an implement carrier is that once an implement is attached to it, it is fixed to the implement (i.e. not movable with respect to the implement) and when the implement carrier is moved with respect to the work element, the implement moves with the implement carrier. The term implement carrier as used herein is not merely a pivotal connection point, but rather a dedicated device specifically intended to accept and be secured to various different implements. The implement carrier itself is mountable to a work element **130** such as a lift arm or the frame **110**. Implement interface **170** can also include one or more power sources for providing power to one or more work elements on an implement. Some power machines can have a plurality of work element with implement interfaces, each of which may, but need not, have an implement carrier for receiving implements. Some other power machines can have a work element with a plurality of implement interfaces so that a single work element can accept a plurality of implements simultaneously. Each of these implement interfaces can, but need not, have an implement carrier.

[0042] Frame **110** includes a physical structure that can support various other components that are attached thereto or positioned thereon. The frame **110** can include any number of individual components. Some power machines have frames that are rigid. That is, no part of the frame is movable with respect to another part of the frame. Other power machines have at least one portion that can move with respect to another portion of the frame. For example, excavators can have an upper frame portion that rotates with respect to a lower frame portion. Other work vehicles have articulated frames such that one portion of the frame pivots with respect to another portion for accomplishing steering functions.

[0043] Frame **110** supports the power source **120**, which is configured to provide power to one or more work elements **130** including the one or more tractive elements **140**, as well as, in some instances, providing power for use by an attached implement via implement interface **170**. Power from the power source **120** can be provided directly to any of the work elements **130**, tractive elements **140**, and implement interfaces **170**. Alternatively, power from the power source **120** can be provided to a control system **160**, which in turn selectively provides power to the elements that capable of using it to perform a work function. Power sources for power machines typically include an engine such as an internal combustion engine and a power conversion system such as a mechanical transmission or a hydraulic system that is configured to convert the output from an engine into a form of power that is usable by a work element. Other types of power sources can be incorporated into power machines, including electrical sources or a combination of power sources, known generally as hybrid power sources.

[0044] FIG. **1** shows a single work element designated as work element **130**, but various power machines can have any number of work elements. Work elements are typically attached to the frame of the power machine and movable with respect to the frame when performing a work task. For example, the power machine can be a mower with a mower deck or other mower component as a work element, which may be movable with respect to the frame of the mower. In addition, tractive elements **140** are a special case of work element in that their work function is generally to move the power machine **100** over a support surface. Tractive elements **140** are shown separate from the work element **130** because many power machines have additional work elements besides tractive elements, although that is not always the case. Power machines can have any number of tractive elements, some or all of which can receive power from the power source **120** to propel the power machine **100**. Tractive elements can be, for example, track assemblies, wheels attached to an axle, and the like. Tractive elements can be mounted to the frame such that movement of the tractive element is limited to rotation about an axle (so that steering is accomplished by a skidding action) or, alternatively, pivotally mounted to the frame to accomplish steering by pivoting the tractive element with respect to the frame. In contrast to tractive actuators and other tractive work elements, workgroup actuators and other workgroup work elements are configured to provide powered movement of one or more components of a power machine for work operations (i.e., operations other than for travel of the power machine over terrain). Correspondingly, discussion of workgroup functions refers to one or more functions that relate to movement of one or more work elements or other components of a power machine, other than tractive elements or other components for travel of the power machine over terrain.

[0045] Power machine **100** includes an operator station **150** that includes an operating position from which an operator can control operation of the power machine. In some power machines, the operator station **150** is defined by an enclosed or partially enclosed cab. Some power machines on which the disclosed embodiments may be practiced may not have a cab or an operator compartment of the type described above. For example, a walk behind loader may not have a cab or an operator compartment, but rather an operating position that serves as an operator station from which the power machine is properly operated. More broadly, power machines other than work vehicles may have operator stations that are not necessarily similar to the operating positions and operator compartments referenced above. Further, some power machines such as power machine **100** and others, whether or not they have operator compartments or operator positions, may be capable of being operated remotely (i.e., from a remotely located operator station) instead of or in addition to an operator station adjacent or on the power machine. This can include applications where at least some of the operator-controlled functions of the power machine can be operated from an operating position associated with an implement that is coupled to the power machine. Alternatively, with some power machines, a remote-control device can be provided (i.e., remote from both of the power machine and any implement to which is it coupled) that is capable of controlling at least some of the operator-controlled functions on the power machine.

[0046] FIGS. **2-3** illustrate a loader **200**, which is one particular example of a power machine of the type illustrated in FIG. **1** where the embodiments discussed below can be advantageously employed. Loader **200** is a skid-steer loader, which is a loader that has tractive elements (in this case, four wheels) that are mounted to the frame of the loader via rigid axles. Here the phrase “rigid axles” refers to the fact that the skid-steer loader **200** does not have any tractive elements that can be rotated or steered to help the loader accomplish a turn. Instead, a skid-steer loader has a drive system that independently powers one or more tractive elements on each side of the loader so that by providing differing tractive signals to each side, the machine will tend to skid over a support surface. These varying signals can even include powering tractive element(s) on one side of the loader to move the loader in a forward direction and powering tractive element(s) on another side of the loader to mode the loader in a reverse direction so that the loader will turn about a radius centered within the footprint of the loader itself. The term “skid-steer” has traditionally referred to loaders that have skid steering as described above with wheels as tractive elements. However, it should be noted that many track loaders also accomplish turns via skidding and are technically skid-steer loaders, even though they do not have wheels. For the purposes of this discussion, unless noted otherwise, the term skid-steer should not be seen as limiting the scope of the discussion to those loaders with wheels as tractive elements. Correspondingly, although some example power machines discussed herein are presented as skid-steer power machines, some embodiments disclosed herein can be implemented on a variety of other power machines. For example, some embodiments can be implemented on compact loaders or compact excavators that do not accomplish turns via skidding.

[0047] Loader **200** is one particular example of the power machine **100** illustrated broadly in FIG. **1** and discussed above. To that end, features of loader **200** described below include reference numbers that are generally similar to those used in FIG. **1**. For example, loader **200** is described as having a frame **210**, just as power machine **100** has a frame **110**. Skid-steer loader **200** is described herein to provide a reference for understanding one environment on which the embodiments described below related to track assemblies and mounting elements for mounting the track assemblies to a power machine may be practiced. The loader **200** should not be considered limiting especially as to the description of features that loader **200** may have described herein that are not essential to the disclosed embodiments and thus may or may not be included in power machines other than loader **200** upon which the embodiments disclosed below may be advantageously practiced. Unless specifically noted otherwise, embodiments disclosed below can be practiced on a variety of power machines, with the loader **200** being only one of those power machines. For example, some or all of the concepts discussed below can be practiced on many other types of work vehicles such as various other loaders, excavators, trenchers, and dozers, to name but a few examples.

[0048] Loader **200** includes frame **210** that supports a power system **220**, the power system being capable of generating or otherwise providing power for operating various functions on the power machine. Power system **220** is shown in block diagram form, but is located within the frame **210**. Frame **210** also supports a work element in the form of a lift arm assembly **230** that is powered by the power system **220** and that can perform various work tasks. As loader **200** is a work vehicle, frame **210** also supports a traction system **240**, which is also powered by power system **220** and can propel the power machine over a support surface. The lift arm assembly **230** in turn supports an implement interface **270**, which includes an implement carrier **272** that can receive and secure various implements to the loader **200** for performing various work tasks and power couplers **274**, to which an implement can be coupled for selectively providing power to an implement that might be connected to the loader. Power couplers **274** can provide sources of hydraulic or electric power or both. The loader **200** includes a cab **250** that defines an operator station **255** from which an operator can manipulate various control devices **260** to cause the power machine to perform various work functions. Cab **250** can be pivoted back about an axis that extends through mounts **254** to provide access to power system components as needed for maintenance and repair.

[0049] The operator station **255** includes an operator seat **258** and a plurality of operation input devices, including control levers **260** that an operator can manipulate to control various machine functions. Operator input devices can include buttons, switches, levers, sliders, pedals and the like that can be stand-alone devices such as hand operated levers or foot pedals or incorporated into hand grips or display panels, including programmable input devices. Actuation of operator input devices can generate signals in the form of electrical signals, hydraulic signals, or mechanical signals. Signals generated in response to operator input devices are provided to various components on the power machine for controlling various functions on the power machine. Among the functions that are controlled via operator input devices on power machine **200** include control of the tractive elements **219**, the lift arm assembly **230**, the implement carrier **272**, and providing signals to any implement that may be operably coupled to the implement.

[0050] Loaders can include HMIs including display devices that are provided in the cab **250** to give indications of information relatable to the operation of the power machines in a form that can be sensed by an operator, such as, for example audible or visual indications. Audible indications can be made in the form of buzzers, bells, and the like or via verbal communication. Visual indications can be made in the form of graphs, lights, icons, gauges, alphanumeric characters, and the like. Displays can provide dedicated indications, such as warning lights or gauges, or dynamic to provide programmable information, including programmable display devices such as monitors of various sizes and capabilities. Display devices can provide diagnostic information, troubleshooting information, instructional information, and various other types of information that assists an operator with operation of the power machine or an implement coupled to the power machine. Other information that may be useful for an operator can also be provided. Other power machines, such walk behind loaders may not have a cab nor an operator compartment, nor a seat. The operator position on such loaders is generally defined relative to a position where an operator is best suited to manipulate operator input devices.

[0051] Various power machines that can include or can interact with the embodiments discussed below can have various different frame components that support various work elements. The elements of frame **210** discussed herein are provided for illustrative purposes and frame **210** is not the only type of frame that a power machine on which the embodiments can be practiced can employ. Frame **210** of loader **200** includes an undercarriage or lower portion **211** of the frame and a mainframe or upper portion **212** of the frame that is supported by the undercarriage. The mainframe **212** of loader **200**, in some embodiments is attached to the undercarriage **211** such as with fasteners or by welding the undercarriage to the mainframe. Alternatively, the mainframe and undercarriage can be integrally formed. Mainframe **212** includes a pair of upright portions **214**A and **214**B located on either side and toward the rear of the mainframe that support lift arm assembly **230** and to which the lift arm assembly **230** is pivotally attached. The lift arm assembly **230** is illustratively pinned to each of the upright portions **214**A and **214**B. The combination of mounting features on the upright portions **214**A and **214**B and the lift arm assembly **230** and mounting hardware (including pins used to pin the lift arm assembly to the mainframe **212**) are collectively referred to as joints **216**A and **216**B (one is located on each of the upright portions **214**) for the purposes of this discussion. Joints **216**A and **216**B are aligned along an axis **218** so that the lift arm assembly is capable of pivoting, as discussed below, with respect to the frame **210** about axis **218**. Other power machines may not include upright portions on either side of the frame or may not have a lift arm assembly that is mountable to upright portions on either side and toward the rear of the frame. For example, some power machines may have a single arm, mounted to a single side of the power machine or to a front or rear end of the power machine. Other machines can have a plurality of work elements, including a plurality of lift arms, each of which is mounted to the machine in its own configuration. Frame **210** also supports a pair of tractive elements in the form of wheels **219**A-D on either side of the loader **200**.

[0052] The lift arm assembly **230** shown in FIGS. **2-3** is one example of many different types of lift arm assemblies that can be attached to a power machine such as loader **200** or other power machines on which embodiments of the present discussion can be practiced. The lift arm assembly **230** is what is known as a vertical lift arm, meaning that the lift arm assembly **230** is moveable (i.e., the lift arm assembly can be raised and lowered) under control of the loader **200** with respect to the frame **210** along a lift path **237** that forms a generally vertical path. Other lift arm assemblies can have different geometries and can be coupled to the frame of a loader in various ways to provide lift paths that differ from the radial path of lift arm assembly **230**. For example, some lift paths on other loaders provide a radial lift path. Other lift arm assemblies can have an extendable or telescoping portion. Other power machines can have a plurality of lift arm assemblies attached to their frames, with each lift arm assembly being independent of the other(s). Unless specifically stated otherwise, none of the inventive concepts set forth in this discussion are limited by the type or number of lift arm assemblies that are coupled to a particular power machine.

[0053] The lift arm assembly **230** has a pair of lift arms **234** that are disposed on opposing sides of the frame **210**. A first end **232**A of each of the lift arms **234** is pivotally coupled to the power machine at joints **216** and a second end **232**B of each of the lift arms is positioned forward of the frame **210** when in a lowered position as shown in FIG. **2**. Joints **216** are located toward a rear of the loader **200** so that the lift arms extend along the sides of the frame **210**. The lift path **237** is defined by the path of travel of the second end **232**B of the lift arms **234** as the lift arm assembly **230** is moved between a minimum and maximum height.

[0054] Each of the lift arms **234** has a first portion **234**A of each lift arm **234** is pivotally coupled to the frame **210** at one of the joints **216** and the second portion **234**B extends from its connection to the first portion **234**A to the second end **232**B of the lift arm assembly **230**. The lift arms **234** are each coupled to a cross member **236** that is attached to the first portions **234**A. Cross member **236** provides increased structural stability to the lift arm assembly **230**. A pair of actuators **238**, which on loader **200** are hydraulic cylinders configured to receive pressurized fluid from power system **220**, are pivotally coupled to both the frame **210** and the lift arms **234** at pivotable joints **238**A and **238**B, respectively, on either side of the loader **200**. The actuators **238** are sometimes referred to individually and collectively as lift cylinders. Actuation (i.e., extension and retraction) of the

actuators **238** cause the lift arm assembly **230** to pivot about joints **216** and thereby be raised and lowered along a fixed path illustrated by arrow **237**. Each of a pair of control links **217** are pivotally mounted to the frame **210** and one of the lift arms **232** on either side of the frame **210**. The control links **217** help to define the fixed lift path of the lift arm assembly **230**.
[0055] Some lift arms, most notably lift arms on excavators but also possible on loaders, may have portions that are controllable to pivot with respect to another segment instead of moving in concert (i.e., along a pre-determined path) as is the case in the lift arm assembly **230** shown in FIG. **2**. Some power machines have lift arm assemblies with a single lift arm, such as is known in excavators or even some loaders and other power machines. Other power machines can have a plurality of lift arm assemblies, each being independent of the other(s).
[0056] An implement interface **270** is provided proximal to a second end **232**B of the lift arm assembly **234**. The implement interface **270** includes an implement carrier **272** that is capable of accepting and securing a variety of different implements to the lift arm **230**. Such implements have a complementary machine interface that is configured to be engaged with the implement carrier **272**. The implement carrier **272** is pivotally mounted at the second end **232**B of the arm **234**. Implement carrier actuators **235** are operably coupled the lift arm assembly **230** and the implement carrier **272** and are operable to rotate the implement carrier with respect to the lift arm assembly. Implement carrier actuators **235** are illustratively hydraulic cylinders and often known as tilt cylinders.
[0057] By having an implement carrier capable of being attached to a plurality of different implements, changing from one implement to another can be accomplished with relative ease. For example, machines with implement carriers can provide an actuator between the implement carrier and the lift arm assembly, so that removing or attaching an implement does not involve removing or attaching an actuator from the implement or removing or attaching the implement from the lift arm assembly. The implement carrier **272** provides a mounting structure for easily attaching an implement to the lift arm (or other portion of a power machine) that a lift arm assembly without an implement carrier does not have.
[0058] Some power machines can have implements or implement like devices attached to it such as by being pinned to a lift arm with a tilt actuator also coupled directly to the implement or implement type structure. A common example of such an implement that is rotatably pinned to a lift arm is a bucket, with one or more tilt cylinders being attached to a bracket that is fixed directly onto the bucket such as by welding or with fasteners. Such a power machine does not have an implement carrier, but rather has a direct connection between a lift arm and an implement.
[0059] The implement interface **270** also includes an implement power source **274** available for connection to an implement on the lift arm assembly **230**. The implement power source **274** includes pressurized hydraulic fluid port to which an implement can be removably coupled. The pressurized hydraulic fluid port selectively provides pressurized hydraulic fluid for powering one or more functions or actuators on an implement. The implement power source can also include an electrical power source for powering electrical actuators or an electronic controller on an implement. The implement power source **274** also exemplarily includes electrical conduits that are in communication with a data bus on the excavator **200** to allow communication between a controller on an implement and electronic devices on the loader **200**.
[0060] Frame **210** supports and generally encloses the power system **220** so that the various components of the power system **220** are not visible in FIGS. **2-3**. FIG. **4** includes, among other things, a diagram of various components of the power system **220**. Power system **220** includes one or more power sources **222** that are capable of generating or storing power for use on various machine functions. On power machine **200**, the power system **220** includes an internal combustion engine. Other power machines can include electric generators, rechargeable batteries, various other power sources or any combination of power sources that can provide power for given power machine components. The power system **220** also includes a power conversion system **224**, which

is operably coupled to the power source **222**. Power conversion system **224** is, in turn, coupled to one or more actuators **226**, which can perform a function on the power machine. Power conversion systems in various power machines can include various components, including mechanical transmissions, hydraulic systems, and the like. The power conversion system **224** of power machine **200** includes a pair of hydrostatic drive pumps **224**A and **224**B, which are selectively controllable to provide a power signal to drive motors **226**A and **226**B. The drive motors **226**A and **226**B in turn are each operably coupled to axles, with drive motor **226**A being coupled to axles **228**A and **228**B and drive motor **226**B being coupled to axles **228**C and **228**D. The axles **228**A-D are in turn coupled to tractive elements **219**A-D, respectively. The drive pumps **224**A and **224**B can be mechanically, hydraulic, or electrically coupled to operator input devices to receive actuation signals for controlling the drive pumps.

[0061] The arrangement of drive pumps, motors, and axles in power machine **200** is but one example of an arrangement of these components. As discussed above, power machine **200** is a skid-steer loader and thus tractive elements on each side of the power machine are controlled together via the output of a single hydraulic pump, either through a single drive motor as in power machine **200** or with individual drive motors. Various other configurations and combinations of hydraulic drive pumps and motors can be employed as may be advantageous.

[0062] The power conversion system **224** of power machine **200** also includes a hydraulic implement pump **224**C, which is also operably coupled to the power source **222**. The hydraulic implement pump **224**C is operably coupled to work actuator circuit **238**C. Work actuator circuit **238**C includes lift cylinders **238** and tilt cylinders **235** as well as control logic to control actuation thereof. The control logic selectively allows, in response to operator inputs, for actuation of the lift cylinders or tilt cylinders. In some machines, the work actuator circuit **238**C also includes control logic to selectively provide a pressurized hydraulic fluid to an attached implement. The control logic of power machine **200** includes an open center, 3 spool valve assembly in a series arrangement. The spools are arranged to give priority to the lift cylinders, then the tilt cylinders, and then pressurized fluid to an attached implement.

[0063] The description of power machine **100** and loader **200** above is provided for illustrative purposes, to provide illustrative environments on which the embodiments discussed below can be practiced. While the embodiments discussed can be practiced on a power machine such as is generally described by the power machine **100** shown in the block diagram of FIG. **1** and more particularly on a loader such as track loader **200**, unless otherwise noted or recited, the concepts discussed below are not intended to be limited in their application to the environments specifically described above.

[0064] As noted generally above, some of the disclosed embodiments can allow a user input device (e.g., any known type of HMI) that is associated with a first power machine to be used to selectively control operations of the first power machine or a second power machine that is remote from the first power machine (e.g., spaced apart from and configured to move independently from the first power machine, without a mechanical tether between the two machines). In this regard, FIG. **5** shows a schematic illustration of a power machine system **300** in which a leader power machine (e.g., a first power machine) is configured to selectively remotely control one or more follower power machines (e.g., one or more second power machines). That is, the leader power machine can generally be used to selectively control the operation of the leader power machine or the operation of the one or more follower power machines.

[0065] More specifically, as will be discussed in greater detail below, the leader power machine can selectively operate in a local control mode or a remote control mode. In the local control mode, an input device of the leader power machine can be used to execute one or more power machine operations (e.g., control an actuator) of the leader power machine. In the remote control mode, the same input device of the leader power machine (alone or in combination with other input devices) can be used to execute one or more operations of a separate (e.g., spaced apart and not structurally tethered) follower power machine. In some cases, an operator may selectively (e.g., manually) switch between the local control mode and the remote control mode. In some cases, operation in local and remote control modes may not be mutually exclusive, and a set of power machines can be configured to operate in a hybrid control mode, wherein some inputs or operations are performed under a local control mode and others are performed under a remote control mode.

[0066] As illustrated, the power machine system **300** includes a leader (e.g., first) power machine **400**, which can be any of a number of different types of power machines, including any of the types generally discussed above (e.g., wheeled or tracked skid-steer loaders, excavators, articulated loaders, etc.). Accordingly, the leader power machine **400** can generally include a frame **404** (e.g., a main frame of the power machine). The frame **404** can be configured to support various components of the leader power machine **400**. In particular, in the illustrated example, the frame **404** can be configured to support a power source **408** (e.g., an engine or battery system), a work element **416**, an actuator **412** (e.g., electric or hydraulic actuators, including rotary actuators, linear actuators, and combinations thereof) that are configured to articulate the work element **416**, an operator station **420** (e.g., an enclosed cab), and a control device **424** (e.g., a general or special purpose computing device or a distributed system of such devices). Although only a single block is used to represent various components of the power machine **400** (and other components) in FIG. **5**, it is contemplated that one or more of any of these components (e.g., actuators, work elements, etc.) can be included on any particular power machine.

[0067] The power source **408** can be configured to provide power to the various components of the leader power machine **400**. In some embodiments, the power source **408** includes an internal combustion engine that can be configured to provide hydraulic and electric power to the various components either alone, or in combination with an electric power source such as a battery in a hybrid power source arrangement. In other embodiments, the power source **408** is an electrical power source, for example, a battery pack that includes one or more battery cells (e.g., lithium-ion batteries), or other electrical storage devices (e.g., capacitors). Accordingly, the power source **408** can be configured to supply power to operate the actuator **412**, the work element **416**, and the control device **424**, as well as any other components of the leader power machine **400**.

[0068] Relatedly, the control device **424** can be configured to control the operation of the one or more actuators **412** and the work element **416**, as powered by the power source **408**. In some cases, the control device **424** can be an integrated control device of the leader power machine **400**, although some embodiments may include a control device with one or more components (e.g., dedicated computing devices) disposed remotely from the power machine. Correspondingly, the control device **424** can be implemented in a variety of different ways. For example, the control device **424** can be implemented as one or more known types of processor devices **428**, (e.g., microcontrollers, field-programmable gate arrays, programmable logic controllers, logic gates, etc.), including as part of general or special purpose computers. In addition, the control device **424** can also include other generally known computing components, including memory, inputs, output devices, etc. (not shown), as appropriate. In this regard, the control device **424** can be configured to implement some or all of the operations of the control processes described herein, which can, as appropriate, be executed based on instructions or other data retrieved from memory. In some embodiments, the control device **424** can include multiple control devices (or modules) that can be integrated into a single component or arranged as multiple separate components. In some embodiments, the control device **424** can be part of a larger control system (e.g., the control system **160** of FIG. **1**) and can accordingly include or be in electronic communication with a variety of control modules, including hub controllers, engine controllers, drive controllers, etc.

[0069] In different embodiments, the control device **424** can control the operation of a power machine in response to an input from an operator. As further detailed below, such control can sometimes be implemented for the leader power machine **400** in a local control mode or a follower power machine in a remote control mode. Generally, operator input can be provided via a human-machine interface that can relay a corresponding control signal to a relevant controller for further processing and, eventually, commanded control of one or more actuators. For example, as illustrated, the leader power machine **400** includes input devices **430**, **432** (e.g., first user input devices), which can be supported by the operator station **420** (e.g., within a cab). In some embodiments, the input devices **430**, **432** can be configured to allow an operator to send an input signal (i.e., a user input signal) over a CAN bus **436** (or otherwise) to the control device **424**, to command operations of a power machine (e.g., the leader power machine **400** or a follower power machine).

[0070] In some embodiments, it can be beneficial to use an integrated input device of a leader power machine to control the leader power machine and a follower power machine. As used herein, an "integrated" input device is an input device that is non-removably included as part of an operator station of a power machine. For example, a factory-installed joystick for a loader that cannot (or is not intended to) be removed by a user during normal operation of the loader can be considered an integrated input device. Implementing control using integrated input devices can usefully permit an operator to use an input device that they are already comfortable with (i.e., for the leader power machine) to control a follower power machine. Further, use of an integrated input device can streamline operations because it may be possible to selectively implement local or remote control without requiring substantial physical changes to a control interface of an operator station that might not be easily implemented due to space constraints or ergonomic considerations. However, in some embodiments, removable input devices can be used, including as further discussed below.

[0071] In the illustrated example, the input device **430** (e.g., a first or primary input device) can be a mechanically actuatable input device (e.g., a joystick, pushbutton, switch, etc.) that is integrated with the leader power machine **400** (e.g., integrated with a seat, control panel, or other system within the operator station **420**). Thus, for example, the input device **430** may sometimes be a joystick that is specifically configured to control workgroup or drive operations of the leader power machine **400**. The input device **430** of the illustrated example communicates with (e.g., sends input signals to) the control device **424** via the CAN bus **436**. Other known communication modes or protocols can be used without departing from the scope of the disclosed embodiments.

[0072] In some implementations, removable input devices may be used. Use of removable input devices can be beneficial in some cases because they can provide input functionality that may allow a leader power machine to control functions of a follower power machine that cannot otherwise be controlled by an integrated input device of the leader power machine. For example, input devices for a loader (as a leader machine) may not necessarily provide sufficient degrees of freedom to control all desired operations of an excavator (as a follower machine). In this regard, for example, the input device **432** (e.g., a second input device) can be configured as a removable input device (e.g., a removable joystick or button assembly) that can be connected with the leader power machine **400** by an operator as needed. Correspondingly, the input device **432** can sometimes be coupled (e.g., electrically or physically) to the leader power machine **400** by a harness **438** that can receive part or all of the input device **432** to secure the input device **432** for operation and place the input device **432** in operational communication with the control device **424**.

[0073] In some embodiments, the harness **438** can be configured to supply power to the input device **432** (e.g., via a 12 volt connection in a cab or the operator station **420**) or to allow the input device **432** to connect to the CAN bus **436** or other data systems to send input signals to the control device **424**. In other implementations, a removeable input device may be configured for wireless communication with a control device (e.g., a control device of a leader power machine or a follower power machine). For example, a removable input device may be configured as a mobile computing device (e.g., a cell phone) or may include known wireless communication modules to allow wireless communication with a control device of a relevant power machine. In some cases, a mount (e.g., as shown schematically via the illustrated block **438** for the harness) can be provided to allow an operator to secure a removeable input device to the power machine during use (e.g., an operator station, cab, or frame).

[0074] Although the input devices **430**, **432** can generally be used to control operations of the power machine **400**, the input signals from the input devices **430**, **432** can be selectively interrupted by the control device **424** depending on the selected control mode. For example, if the leader power machine **400** is in a local control mode, the input signals from the input devices **430**, **432** can be used to execute a power machine operation of the leader power machine **400**. However, if the leader power machine **400** is in a remote control mode, as further discussed below, the leader power machine **400** can send a wireless control signal **440** to a follower power machine in response to input signals at one or more of the input devices **430**, **432**, in order to execute a power machine operation of the follower power machine. Accordingly, to prevent inadvertent or otherwise undesired operation, the control device **424** may sometimes interrupt control of the power machine **400** based on the input signals.

[0075] Generally, to allow the leader power machine **400** to communicate with and control a follower power machine, the control device **424** can sometimes include a modem **442** configured for sending and receiving wireless communication. In some embodiments, the modem **442** can be configured for 5G cellular communication. In some embodiments, a modem can be configured differently, for example, to allow Wi-Fi, Bluetooth, or other wireless communication.

[0076] With continued reference to FIG. **5**, the power machine system **300** is configured so that inputs at the leader power machine **400** can selectively remotely control a follower power machine **500**, including via inputs received at the same input device(s) that can be used to locally control the leader power machine **400**. Generally, the follower power machine **500** can be the same type of power machine as the leader power machine **400** (e.g. both the leader power machine **400** and the follower power machine **500** can be wheeled skid-steer loaders), or the leader and follower power machines **400**, **500** can be different types of power machines (e.g., the leader power machine **400** can be an excavator and the follower power machine **500** can be a wheeled loader, or vice versa). As illustrated, and similar to leader power machine **400**, the follower power machine **500** can generally include a frame **504** that can be configured to support a power source **508**, an actuator **512** (e.g., electrical or hydraulic actuators, including rotary actuators, linear actuators, and combinations thereof) configured to articulate a work element **516**, an operator station **520** (e.g., a cab), and a control device **524** for controlling one or more operations of the follower power machine **500** (e.g., controlling the actuator **512** or the work element **516**). Likewise, the control device **524** can include one or more processor devices **528** and a modem **542** (or other wireless communication device) for sending and receiving wireless signals **440** to and from the leader power machine **400** (or other remote system).

[0077] In some embodiments, the follower power machine **500** can be remotely operated by an operator in the leader power machine **400**, and can also (e.g., selectively) be locally controlled by an operator of (e.g., in a cab of) the follower power machine **500**. Accordingly, the follower power machine **500** can include input devices **530**, **532** (e.g., integrated input devices or removeable input devices optionally connected by a harness **538**) configured to control the follower power machine **500** (or another power machine). Generally, the input devices **530**, **532** can provide an input signal to the control device **524** over a CAN bus **536** or wirelessly to command particular power machine operations (e.g., movement of the actuator **512**). Although the embodiment shown in FIG. **5** illustrates a follower power machine **500** with input devices **530** and **532**, and various features related to a follower power machine having such input devices are described herein, in some embodiment, the follower power machine may not have such inputs and operational control may only be accomplished via remote control, via an autonomous control system resident on the follower power machine, or a combination of both.

[0078] In some cases, a follower machine may include a lockout system (e.g., lockout device) that can limit (e.g., prevent) remote control of the follower machine unless certain lockout conditions are met. Thus, for example, undesirable remote operation of the follower machine can be generally avoided. For example, to prevent remote control of the follower power machine **500** when the follower power machine **500** is being locally operated by another operator (in instances where the follower power machine is equipped and configured for local operation) or otherwise not prepared for remotely controlled operation, the follower power machine **500** can include a lockout system **544** configured to control whether or not remote control of the follower power machine **500** is permitted. The lockout system **544** can be configured to prevent remote control of the follower power machine **500** unless the lockout system **544** is disabled or otherwise configured to allow remote control by the leader power machine **400**. As one example, and as further discussed below, the lockout system **544** can be configured to prevent remote control of the follower power machine **500** unless the power machine **500** satisfies one or more physical state conditions (e.g., particularly input devices have been manually actuated, particularly safety systems are in a particular state, etc.).

[0079] In some cases, the follower power machine **500** can be configured to convey status information to bystanders that the follower power machine **500** is being remotely operated or is ready for operation in a remote control mode. For example, the follower power machine **500** can include an indicator device **548** (e.g., a lighting device, mechanical flag, general purpose display device, etc.) that is configured to provide a status indicator. The indicator device **548** can be configured to emit visual or audible signals to indicate that the follower power machine **500** is or can be remotely operated. In particular, the indicator device **548** may include a light or beacon (e.g., mounted to the outside of a frame or cab) that can flash in various patterns or sequences or change color depending on a current mode of operation. Additionally, or alternatively, the indicator device **548** can be configured to emit an audible beep or other noise, which may be emitted in different patterns or sequences to indicate the current mode of operation. Relatedly, the leader power machine **400** may also be configured to indicate or show an operator that the leader power machine **400** is in a remote control mode. Accordingly, the leader power machine can include an indicator device **448** (e.g., a light), which may be provided in the operator station **420** and operated by the processor device **428** to provide a status indicator that can communicate to an operator information associated with a current mode of operation (e.g., to indicate operation in a remote control mode, a local control mode, or a hybrid control mode).

[0080] With appropriately configured communication devices (e.g., the modems **442**, **542**), a follower power machine can be remotely operated at any distance away from a leader power machine. For example, the follower power machine **500** can be remotely operated within a line of sight of an operator positioned in the operator station **420** of the leader power machine **400**. Alternatively, the follower power machine **500** can be remotely operated when it is located beyond a line of sight of the operator.

[0081] In some cases, to facilitate effective remote operation, including for operation beyond a line of sight of an operator, the follower power machine **500** can have a camera module **552** having one or more cameras (e.g., visual-spectrum video cameras) mounted to the frame **504**, the operator station **520** (e.g., a cab), or any other appropriate part of the follower power machine **500**. The camera(s) of the camera module **552** can be selectively placed on the follower power machine **500** by an operator, or they may be fixedly mounted to the follower power machine **500** in specific locations, for example, to provide an operator with a view of a work area for an implement or to provide a 360-degree field of view around the follower power machine **500**. In some embodiments, four cameras are provided to show views in front of, behind, to the left and to the right of the machine. Other or additional camera arrangements and angles can be used to provide specific views that might be advantageous for an operator of the leader machine to see. The camera module **552** can be configured to send a video signal to the leader machine **400** for display by the leader machine **400**. For example, the camera module **552** can transmit a video signal directly to the leader machine **400** or can transmit a video signal to the control device **524**, which can then transmit the video signal (e.g., via wireless signal **440**) to the leader power machine **400**. Correspondingly, the leader power machine **400** can include a screen or heads-up display to allow the operator to view the video feed from the camera module **552**, including as may be provided on one or more input devices of the power machine **400**. In some embodiments, as shown schematically in FIG. **5**, the leader power machine **400** can include a window **420**A (e.g., part of a door or windshield of the operator station **420**) on which the control device **424** can cause display of a video that is received from the follower machine **500**.

[0082] In some implementations, devices or systems disclosed herein (e.g., as discussed relative to FIG. **5**) can be utilized, manufactured, installed, etc. using methods embodying aspects of the invention. Correspondingly, any description herein of particular features, capabilities, or intended purposes of a device or system is generally intended to include disclosure of a method of using such devices for the intended purposes, of a method of otherwise implementing such capabilities, of a method of manufacturing relevant components of such a device or system (or the device or system as a whole), and of a method of installing disclosed (or otherwise known) components to support such purposes or capabilities. Similarly, unless otherwise indicated or limited, discussion herein of any method of manufacturing or using for a particular device or system, including installing the device or system, is intended to inherently include disclosure, as embodiments of the invention, of the utilized features and implemented capabilities of such device or system.

[0083] In this regard, with additional reference to FIG. **6**, a method **600** of operating a power machine system is illustrated, according to some aspects of this disclosure. While the method **600** will be discussed in reference to the power machine system **300**, the method **600** is also applicable to other power machine systems not expressly discussed herein (e.g., as may include differently configured leader or follower power machines). Additionally, operations of the method **600** need not be carried out in the specific order discussed below and may in some cases be implemented by local, remote, or a combination of local and remote processor devices.

[0084] At block **604**, the method **600** can include a control device (e.g., of a leader power machine) receiving an operator input. The operator input may be provided by an operator interacting with an input device (e.g., an integrated or removable input device) of the leader power machine to generate an input signal. For example, an operator located within the operator station **420** of the leader power machine **400** can manipulate or otherwise interact with the integrated input device **430** to generate an input signal. The input signal can then be transmitted via the CAN bus **436** to the control device **424**. In some cases, an input signal can also be provided by a removeable input device, for example, the removable input device **432**, which may send a corresponding input signal to the control device **424** via the harness **438** and the CAN bus **436**. In other embodiments, a removeable input device can be configured to communicate wirelessly and may or may not be electrically coupled with a leader power machine.

[0085] At block **608**, a control device of a first, leader power machine can receive a selection of a local control mode or a remote control mode. In some cases, the leader power machine **400** may require an affirmative action by an operator to enable a remote control mode. For example, an operator of the leader power machine **400** may be required to interact with one of the input devices **430**, **432** to select a remote control mode or a local control mode (e.g., only one of the modes). More specifically, the input devices **430**, **432** can include a button (e.g., a button provided on a joystick), toggle, switch, or other interface to allow the user to select between a local control mode or a remote control mode. The selection made by the user can be communicated to the control device **424**, and more specifically the processor device **428**, for example, via the CAN bus **436**. That is, the input devices **430**, **432** can produce a control signal corresponding to a selected mode of operation, which can be sent to the control device **424**. In other embodiments, a processor device may automatically select a mode of operation based on a control signal or on a source of a control signal or may receive a selection of a mode of operation from other input devices or systems.

[0086] In some cases, in particular, when an operator has selected the remote control mode via the input devices **430**, **432** (or a remote control mode has been otherwise selected), operations at block **608** can further include establishing a communication link with the follower power machine **500** (i.e., initiating the link, or sending an initiation signal via an already connected but dormant link). For example, when the control device **424** receives a control signal to operate in the remote control mode, the control device **424** can initiate a communication link (e.g., a wireless communication link or channel) with the follower power machine **500** to allow wireless signals **440** to be transmitted between the leader power machine **400** and follower power machine **500**. The wireless signals **440** may contain any type of data and can be sent using any type of communication protocol, for example, a standardized communication protocol or a proprietary communication protocol.

[0087] Relatedly, an operator may need to be pre-authorized to remotely control the follower power machine **500** using an input device of the leader follower machine **400**. In that regard, for example, an operator may be prompted by the control device **424** to select the follower power machine **500** from a list of pre-authorized follower power machines, or otherwise indicate that remote control of the power machine **500** is authorized. The prompt may be displayed to the operator at one of the input devices **430**, **432** (e.g., via a touch screen mounted in the operator station **420**), or at another device, for example, a mobile device that can send a corresponding authorization signal to the processor device **424** (or to the power machine **500**).

[0088] Where a pre-authorization is required, if the follower power machine **500** is not pre-authorized, the control device **424** may terminate the request by the user to operate the follower power machine **500** in the remote control mode (e.g., in response to a corresponding signal sent by the follower power machine **500** or an input device **430**, **432**). Accordingly, the control device **424** may be configured to display a message or otherwise indicate to the operator (e.g., via the input device **430**, **432** or another device) that remote control of the follower power machine **500** is unavailable or being prevented. Where remote control is not allowed, the leader power machine **400** may be configured to revert or default to the local control mode, including automatically selecting the local control mode. However, in some cases, an operator may be required to manually select operation in the local control mode, rather than operate in that mode as a default.

[0089] Relatedly, operations at block **608** can also include determining whether remote control of the follower power machine **500** is enabled at the follower power machine **500**. For example, a control device on the leader or follower power machine **400**, **500** may be configured to determine whether the lockout system **544** is in an appropriate state to allow remote operation of the follower power machine **500** via the leader power machine **400**. For example, in some cases, the lockout system **544** may require that the follower power machine **500** be put into a particular physical state (i.e., matches a particular physical state condition) to allow for remote control. More specifically, to permit remote control, the lockout system **544** may require that, in the follower power machine **500**: an ignition be turned off, a lap bar be placed in an “up” position, a door of a cab be in a closed position, a remote control button be pushed, other operator presence indicator be in a non-activated state, a key be inserted (e.g., and turned to a standby or activated position), one or more user inputs may be used to unlock a machine's functions (in the case of keyless machines), or any combinations thereof.

[0090] If the lockout system **544** is not engaged or is otherwise in a state that does not allow for remote control, the follower power machine **500**, and more specifically, the processor device **528** of the control device **524** can be configured to send a corresponding signal (e.g., a termination signal) to the control device **424** of the leader power machine **400**. In response to this signal, the control device **424** of the leader power machine **400** can be configured to terminate the communication link and to display a message or otherwise indicate to the operator (e.g., via the input device **430**, **432** or another device) that remote control of the follower power machine **500** is unavailable.

[0091] Conversely, if the lockout system **544** is engaged or otherwise in a condition to allow remote control, the follower power machine **500**, and more specifically, the processor device **528** of the control device **524**, can send a corresponding wireless signal **440** (e.g., a confirmation signal) to the control device **424** of the leader power machine **400**. Accordingly, the control device **424** of the leader power machine **400** can be configured to display a message or otherwise indicate to the operator (e.g., via the input device **430**, **432**, the status indicator **448**, or another device) that remote control of the follower power machine **500** is available or has been established. In some embodiments, however, these or other conditions may or may not be required to allow remote control of a follower power machine by a leader power machine.

[0092] In some cases, a power machine that is to be remotely controlled may be in a standby state, in which the power machine is not enabled to executed powered operations with one or more work elements. For example, a power machine in a standby mode may be unpowered, except as needed to initially establish a communications link, verify authorization, etc., as described above, or may be otherwise configured so that powered operation of workgroup elements, tractive elements, or other components may not be permitted. Thus, for example, for a power machine in standby mode, an engine or other power source may not be operating or operationally connected to various actuators of the power machine to power operation thereof. As another example, an engine or other power source may be operating but a control system of the power machine may be configured to prevent use of power from the power source to power one or more actuators of the power machine or to execute one or more particular power machine operations (e.g., operations with a lift arm or implement, or other workgroup operations).

[0093] Correspondingly the method **600** can include waking the remote (e.g., second) power machine from the standby state. For example, as illustrated at optional block **614** in FIG. **6**, once a selection of a remote-control mode has been received and a communications link has been established between the first and second power machines, the second power machine can be woken from a standby state so that the second power machine can be remotely controlled for various power machine operations. In some cases, the second power machine can be woken at block **614** immediately in response to the establishing of the communications link between the power machines. For example, a valid authenticating handshake or other initial communication between the power machines can cause the control system of the second power machine to enable operation of particular work operations or work elements on the second power machine.

[0094] In some cases, a power machine may be woken from a standby state only by another power machine that has previously established a control connection with the power machine to be woken (e.g., has been previously authenticated or otherwise authorized for remote control of the relevant remote power machine). In some cases, a power machine to be woken may authenticate the identity or permissions of another power machine based on transmissions between the power machines to establish a communications link (e.g., as discussed relative to block **608**), or may authenticate the other power machine based on other transmissions once a communications link has been established (e.g., an exchange of credentials after an initial handshake, to authorize the starting of an engine of the power machine to be woken, etc.). In some cases, other state conditions may be similarly required to authorize establishing a communication channel between two power machines, or remotely controlling a power machine in general. For example, a power machine to be remotely controlled may be woken only if a physical key is present (or activated) for the power machine, or subject to other physical state indicators as discussed above.

[0095] As also generally discussed to above, waking the second power machine from a standby state (e.g., at block **614**) can cause the second power machine to enable execution of operations that were not enabled in the standby state (e.g., workgroup operations that were not powered or not permitted by a control system in the standby state). Thus for example, waking the second power machine can include starting a power source of the second power machine, causing the second power machine to operatively connect the power source to a work element of the second power machine, or otherwise causing an electronic control system of the second power machine to enable (e.g., permit) particular operations that were not possible in the standby state.

[0096] Correspondingly, as one potential implementation, a loader (or other power machine) may be in a standby state with an engine of the loader not operating, or an electrical power of the loader not operationally connected so as to power workgroup or tractive actuators of the loader. An operator of a different power machine configured as an excavator (or otherwise) can thus control the excavator to execute various excavator work operations, without the loader expending fuel or draining battery power and with the loader spaced apart from the excavator so as not to interfere with the excavator operations (e.g., parked outside a relevant work zone). Once the loader is needed, the operator can then select a remote control mode via a control interface of the excavator, as corresponds to remote operation of the loader. This selection can cause the control system of the excavator to establish a wireless communication link with the loader (as needed), and the communication link can then be used to command the loader to wake from the standby state (e.g., to start an engine, enable hydraulic flow to a relevant hydraulic actuator, or enable flow of electrical power from a battery to a relevant electrical actuator). The loader can then be controlled for work operations by the operator, from the cab of the excavator, as further detailed above and below.

[0097] Continuing, as mentioned above, in some cases a follower power machine may be provided with a camera module to allow for effective operation of a follower power machine, including for operation beyond a line of sight of the operator in the leader power machine. In some cases, a camera module can also be used even when the follower power machine is within the line of sight of the operator in the leader power machine, as may improve the ability of the operator to control the follower power machine where precision movements of a work element are required.

[0098] In any case, as desired, operations based on a received selection of a control mode at the block **608** can further include initiating a video feed of the camera module **552** (see FIG. **5**), so that a video signal can be transmitted via the wireless signal **440** (e.g., communication link) to the processor device **428** of the leader power machine **400**. Correspondingly, the processor device **428** can be configured to display the video feed to the operator, for example, by powering a screen or projecting the video feed onto a window or window panel on a door of the leader power machine **400** (e.g., the window **420**A).

[0099] In some cases, if a camera module is provided but a video feed cannot be established (or terminates) before remote control is otherwise ceased, the processor device **428** may be configured to terminate or disallow operation under the remote control mode. Correspondingly, the input devices **430**, **432** may be configured to allow the operator to override these aspects, for example, to allow continued operation of the follower power machine **500** when it is within a line of sight of the operator.

[0100] Where a mode of operation is selected (and enabled, as appropriate), a control device can be configured to execute or control an operation of a power machine at block **612** based on input received at a leader power machine at block **604**. In particular, where the control device **424** of the leader power machine **400** is operating under the remote control mode according to block **608**, the control device **424**, and more specifically the processor device **428**, can be configured to control a power machine operation (e.g., a drive or workgroup operation) of the follower power machine **500** at block **616**. For example, the control device **424** can control the actuator **512**, based on a control signal from the leader power machine **400** (as based on operator inputs at the leader power machine **400**), to move the work element **516** relative to the frame **504** of the follower power machine **500**. More specifically, the processor device **428** can receive a control signal from the operator via one or both of the input devices **430**, **432** and can send corresponding command signals for operation of the actuator **512**.

[0101] In some cases, it is possible that the leader power machine **400** may not necessarily be “on” (e.g., in an “engine on” state) to operate the follower power machine **500** in the remote control mode. In some cases, a leader power machine may only be permitted to control a specific power machine operation or subset of power machine operations of a follower power machine. In other cases, a leader power machine may be permitted to control any power machine operation of a follower power machine.

[0102] As one particular example of operation in a remote control mode, the operator may manipulate a joystick or push a button, which then transmits a control signal to the control device **424**, where the control signal can be interrupted by the processor device **428** (e.g., based on a temporarily updated address scheme for CAN bus communication). Accordingly, the processor device **428** can generally prevent the control signal from being executed by the leader power machine **400**, although this may not always be the case. The processor device **428**, in accordance with the selected remote control mode, can be further configured to send a corresponding wireless signal **440** to the follower power machine **500** to execute the desired power machine operation with the follower power machine **500**.

[0103] Continuing, in some cases, a control device (e.g., either of the processor devices **428**, **528**) can be configured to translate (e.g., remap) a control signal produced by the input devices **430**, **432** to correspond with a control signal for actuators of the follower power machine **500**, which may differ from actuators of the leader power machine **400** that would be controlled by that same control signal under a local control mode. In particular, where the control signal is a CAN signal, re-mapping of the control signal can include modifying one or more bits of the CAN signal, for example, to modify a CAN address or other aspect of the CAN signal. In other cases, the processor device **428** can be configured to re-route a control signal produced by the input devices **430**, **432** to the follower power machine **500**. In either case, the processor device **528** may receive the corresponding wireless signal **440** and use it to execute the desired power machine operation of the follower power machine **500**. However, in yet other cases, the processor device **428** can be configured to directly control the actuators **512** or work element **516** of the follower power machine **500** using the control signal from the input devices **430**, **432** to execute the desired power machine operation. In still other cases, a control signal produced by the input devices **430**, **432** that does not have a corresponding function on the follower power machine **500** may be stopped or terminated at the processor device **428** (or otherwise). Moreover, in some embodiments in which a removeable input device or other type of input device (e.g., a mobile device) is provided, the removeable device may be configured to communicate directly with a follower power machine.

[0104] When the leader power machine **400** is operating under a local control mode based on the received selection at block **608**, the control device **424**, and more specifically, the processor device **428**, can be configured to control a power machine operation of the leader power machine **400** at block **620**, for example, by controlling the actuator **412**, based on a control signal from the leader power machine **400**, to move the work element **416** relative to the frame **404** of the leader power machine **400**. In particular, the processor device **428** can receive a control signal from the operator via one or both of the input devices **430**, **432** (e.g., by the operator manipulating a joystick or pushing a button). Accordingly, the processor device **428** can be configured to use the control signal to carry out the power machine function. Carrying out the power machine function may, for example, include the processor device **428** directly controlling the actuator **412**, or using the control signal to send one or more corresponding signals to one or more control modules or other control devices of the leader power machine **400**.

[0105] As also mentioned above, the power machine system **300** may not always operate exclusively in only the remote control mode or only the local control mode. Rather, in some cases, a leader power machine **400** can be configured to operate in a hybrid control mode at block **612**, in which some control signals can be carried out under only the remote control mode or only under the local control mode, or under both the remote control mode and the local control mode at the same time. For example, the leader power machine **400**, configured as an excavator, may control the follower power machine **500**, configured as a loader. Accordingly, the leader power machine **400** may include input devices **430**, **432**, for example, foot pedals, which have no corresponding control or input device on the follower power machine **500**. In this case and similar other cases, although the processor device **428** of the leader power machine **400** could be configured to terminate or ignore the un-mapped or unused control signals, the processor device **428** could alternatively be configured to allow the un-mapped or unused control signals to pass through to execute a corresponding power machine operation of the leader power machine **400**. In some embodiments, such operational schemes can be used regardless of the type of power machines being used as the leader power machine **400** and the follower power machine **500**.

[0106] In some cases, the leader power machine **400**, and more specifically, the processor device **428** of the leader power machine **400**, can be configured to cause continued operation of the follower power machine **500** under the remote control mode (e.g., a semi-autonomous control mode), while the operator actively uses the input device **430**, **432** to control the leader power machine **400** under the local control mode. As one particular example, an operator might enable a “lock” function before switching from the remote control mode to the local control mode, which would set the follower power machine **500** to continue operating according to a particular (e.g., current) set of parameters. This could be used, for example, to direct somewhat autonomous, remotely initiated operations, including low-speed, straight-line concrete cutting, repeatable tasks (e.g., scoop-and-dump operations, etc.), or other low-speed or simple tasks. In some cases, a “lock” function could lock the follower power machine **500** into a repeated sequence of actions (e.g., a pre-recorded scoop-and-dump operation that includes repeated travel between a spoil pile and a dump truck). In that regard, the processor device **428** can be configured to send out a repeated sequence of wireless signals **440** to control the follower power machine **500**, or can send an initial signal that places the power machine **500** into a particular operational mode or sequence of operations. Relatedly, the processor devices **428**, **528** may be pre-programed to execute one or more pre-recorded or pre-programmed (i.e., “canned”) routines. In some cases, a pre-recorded or canned operation may be stored on the follower power machine **500** so that the routine can be executed by the processor device **528** without continued (or continuous) input from the leader power machine **400**.

[0107] Thus, under some embodiments of the disclosure, an operator can usefully operate multiple power machines using a common input device, including an input device that may be integrated into or otherwise associated primarily with (e.g., operably connected to) a leader power machine. In some cases, for example, an operator can use an integrated joystick of an operator station of a leader power machine to locally control operations of the leader power machine and to remotely control operations of a follower power machine. Accordingly, for example, a single operator may be able to execute complex or other multi-machine tasks without having to leave the confines of a cab or operator station of a leader machine, or having to otherwise directly (e.g., manually) interface with input devices of the follower machine.

[0108] In some embodiments, aspects of the invention, including computerized implementations of methods according to the invention, can be implemented as a system, method, apparatus, or article of manufacture using standard programming or engineering techniques to produce software, firmware, hardware, or any combination thereof to control a processor device (e.g., a serial or parallel general purpose or specialized processor chip, a single- or multi-core chip, a microprocessor, a field programmable gate array, any variety of combinations of a control unit, arithmetic logic unit, and processor register, and so on), a computer (e.g., a processor device operatively coupled to a memory), or another electronically operated controller to implement aspects detailed herein. Accordingly, for example, embodiments of the invention can be implemented as a set of instructions, tangibly embodied on a non-transitory computer-readable media, such that a processor device can implement the instructions based upon reading the instructions from the computer-readable media. Some embodiments of the invention can include (or utilize) a control device such as an automation device, a special purpose or general purpose computer including various computer hardware, software, firmware, and so on, consistent with the discussion below. As specific examples, a control device can include a processor, a microcontroller, a field-programmable gate array, a programmable logic controller, logic gates etc., and other typical components that are known in the art for implementation of appropriate functionality (e.g., memory, communication systems, power sources, user interfaces and other inputs, etc.).

[0109] The term “article of manufacture” as used herein is intended to encompass a computer program accessible from any computer-readable device, carrier (e.g., non-transitory signals), or media (e.g., non-transitory media). For example, computer-readable media can include but are not limited to magnetic storage devices (e.g., hard disk, floppy disk, magnetic strips, and so on), optical disks (e.g., compact disk (CD), digital versatile disk (DVD), and so on), smart cards, and flash memory devices (e.g., card, stick, and so on). Additionally, it should be appreciated that a carrier wave can be employed to carry computer-readable electronic data such as those used in transmitting and receiving electronic mail or in accessing a network such as the Internet or a local area network (LAN). Those skilled in the art will recognize that many modifications may be made to these configurations without departing from the scope or spirit of the claimed subject matter.

[0110] Certain operations of methods according to the invention, or of systems executing those methods, may be represented schematically in the FIGs. or otherwise discussed herein. Unless otherwise specified or limited, representation in the FIGs. of particular operations in particular spatial order may not necessarily require those operations to be executed in a particular sequence corresponding to the particular spatial order. Correspondingly, certain operations represented in the FIGs., or otherwise disclosed herein, can be executed in different orders than are expressly illustrated or described, as appropriate for particular embodiments of the invention. Further, in some embodiments, certain operations can be executed in parallel, including by dedicated parallel processing devices, or separate computing devices configured to interoperate as part of a large system.

[0111] As used herein in the context of computer implementation, unless otherwise specified or limited, the terms “component,” “system,” “module,” “block,” and the like are intended to encompass part or all of computer-related systems that include hardware, software, a combination of hardware and software, or software in execution. For example, a component may be, but is not limited to being, a processor device, a process being executed (or executable) by a processor device, an object, an executable, a thread of execution, a computer program, or a computer. By way of illustration, both an application running on a computer and the computer can be a component. One or more components (or system, module, and so on) may reside within a process or thread of execution, may be localized on one computer, may be distributed between two or more computers or other processor devices, or may be included within another component (or system, module, and so on).

[0112] Also as used herein, unless otherwise limited or defined, “or” indicates a non-exclusive list of components or operations that can be present in any variety of combinations, rather than an exclusive list of components that can be present only as alternatives to each other. For example, a list of “A, B, or C” indicates options of: A; B; C; A and B; A and C; B and C; and A, B, and C. Correspondingly, the term “or” as used herein is intended to indicate exclusive alternatives only when preceded by terms of exclusivity, such as “either,” “one of,” “only one of,” or “exactly one of.” Further, a list preceded by “one or more” (and variations thereon) and including “or” to separate listed elements indicates options of one or more of any or all of the listed elements. For example, the phrases “one or more of A, B, or C” and “at least one of A, B, or C” indicate options of: one or more A; one or more B; one or more C; one or more A and one or more B; one or more B and one or more C; one or more A and one or more C; and one or more of each of A, B, and C. Similarly, a list preceded by “a plurality of” (and variations thereon) and including “or” to separate listed elements indicates options of multiple instances of any or all of the listed elements. For example, the phrases “a plurality of A, B, or C” and “two or more of A, B, or C” indicate options of: A and B; B and C; A and C; and A, B, and C. In general, the term “or” as used herein only indicates exclusive alternatives (e.g. “one or the other but not both”) when preceded by terms of

exclusivity, such as “either,” “one of,” “only one of,” or “exactly one of.”
[0113] Although the present invention has been described by referring to certain preferred embodiments, workers skilled in the art will recognize that changes may be made in form and detail without departing from the scope of the discussion.

Claims

1. A power machine system, comprising: a first power machine, including: a first work element; a first power source to power the first work element; a first user input device to control the first work element; and a first processing device that cooperatively controls the first power machine and a second power machine to complete a task, including by controlling: the first power machine, via local control of the first work element by the first user input device of the first power machine; and a second power machine, via remote control of a second work element of the second power machine by the first user input device of the first power machine.
2. The power machine system of claim 1, wherein the first and second work elements each include: a workgroup work element; or a tractive element.
3. The power machine system of claim 1, wherein the first power machine is configured to receive and display a video transmission from the second power machine during the cooperative control to complete the task.
4. The power machine system of claim 1, wherein the first user input device includes a joystick within the first power machine that receives first inputs for the local control of the first work element and second inputs for the remote control of the second work element.
5. The power machine system of claim 1, wherein the first power machine is an excavator and the second power machine is a loader.
6. The power machine system of claim 5, wherein the task is a work task and the cooperative control to complete the task includes control of one or more workgroup work elements of the first and second power machines by the first user input device.
7. The power machine system of claim 6, wherein the cooperative control further includes control of one or more tractive elements of the first and second power machines by the first user input device.
8. A control system for cooperatively controlling a first power machine and a second power machine to complete a task, the control system comprising: a first user input device within the first power machine; and a processor device to: receive a first user input via the first user input device; in response to receiving the first user input, selectively: control a first work element of the first power machine, based on the first user input, to execute a first work operation of the task with the first power machine; or control a second work element of the second power machine, based on the first user input, to execute a second work operation of the task with the second power machine.
9. The control system of claim 8, wherein the processor device controls the first and second power machines to cooperatively complete the task by selectively: locally controlling the first power machine via first inputs to the first user input device; and remotely controlling the second power machine via second inputs to the first user input device.
10. The control system of claim 9, wherein, the first power machine is configured to receive and display a video transmission from the second power machine during the remote control of the second power machine via the second inputs to the first user input device.
11. The control system of claim 9, wherein the first user input device includes a joystick within the first power machine; and wherein a control signal from the first user input device is implemented: with a first mapping, to control actuators of the first power machine during the local control of the first power machine; and with a second mapping, different from the first mapping, to control actuators of the second power machine during the remote control of the second power machine.
12. The control system of claim 8, wherein the first power machine is an excavator and the second

power machine is a loader.

13. The control system of claim 12, wherein the first work element includes one or more of a first workgroup work element of the excavator or a first tractive element of the excavator; and wherein the second work element includes one or more of a second workgroup work element of the loader or a second tractive element of the loader.

14. The control system of claim 13, wherein the task is a digging operation, the first workgroup element includes the first workgroup work element of the first power machine and the second work element includes the second tractive element of the loader.

15. A method for cooperatively controlling a first power machine and a second power machine to complete a task, the method comprising: selecting between: local control of the first power machine via a first user input interface within the first power machine; and remote control of the second power machine via the first user input interface within the first power machine; during the selected local control of the first power machine, controlling operation of a first work element of the first power machine, based on a first user input at the first user input interface, to cooperatively execute the task; and during the selected remote control of the second power machine, controlling operation of a second work element of the second power machine, based on a second user input at the first user input interface, to cooperatively execute the task.

16. The method of claim 15, further comprising: during the selected remote control of the second power machine, receiving a video transmission from the second power machine and displaying the video transmission at the first power machine.

17. The method of claim 15, wherein a first mapping of user inputs at the first user input interface corresponds to control of the first work element and a second mapping of user inputs at the first user input interface, different from the first mapping, corresponds to control of the second work element.

18. The method of claim 15, wherein the first work element includes a workgroup work element of the first power machine and the second work element includes a tractive element of the second power machine.

19. The method of claim 18, wherein the first power machine and the second power machine are different types of power machines.

20. The method of claim 19, wherein the task is a digging operation.