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COORDINATED CONTROL OF STEERABLE ATTACHMENTS

Abstract

Traditionally, for certain grading tasks in which a motor grader is not suitable or available, a grader attachment, with caster wheels and a blade, may be attached to a work machine, such as a skid steer. Such systems have difficulty operating due to lateral forces on the blade. Accordingly, a steerable attachment is disclosed with ground-engaging members (e.g., wheels) that can be steered and/or driven via an attachment electronic control module, which is in communication with a machine electronic control module of the work machine. In particular, attachment electronic control module and machine electronic control module may coordinate the steering of the work machine and steerable attachment, using a feedback loop, to ensure that the steering of the work machine does not exceed the capabilities of the steerable attachment.

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Background/Summary

TECHNICAL FIELD

[0001] The embodiments described herein are generally directed to coordinated control attachments, and, more particularly, to the coordinated control of steerable attachments in a work machine.

BACKGROUND

[0002] Motor graders are used to flatten a surface during grading projects, and can also be used for other tasks (e.g., snow removal, mixing and spreading materials, etc.). However, a large motor grader may not be suitable for all tasks, such as those in tight spaces, on rough terrain, using novice operators, and/or the like.

[0003] In these cases, a grader attachment may be affixed to the front of a skid steer, wheel loader, or other work machine. The attachment will generally comprise a fastening portion, configured to be attached to the front of the work machine, at one end, caster wheels at the opposite end, and a blade, also referred to as a moldboard, between the opposing ends. The blade is configured to flatten a surface, remove materials, mix and spread materials, and the like.

[0004] Work machines with such attachments may face challenges. In particular, the caster wheels on the attachment offer no lateral resistance to the lateral forces generated by the blade when the blade is yawed or unevenly loaded. These lateral forces may cause the caster wheels to lose traction, leading to difficulties in maintaining a consistent grading depth and achieving the desired smoothness in road construction or maintenance projects.

[0005] Accordingly, a steerable attachment would offer a variety of benefits. Steerable attachments have been used in other contexts. For example, U.S. Pat. No. 9,062,940 describes an example of a steerable attachment that is used for mine detonation. However, while a steerable attachment can provide the necessary lateral resistance for grading operations, a work machine, such as a skid steer, is generally capable of a tighter turn radius than the steerable attachment. If the work machine attempts a turn that is not within the capability of the steerable attachment, the steerable attachment may lose traction. The present disclosure is directed toward a steerable attachment, in the context of grading and similar tasks, that overcomes this and other problems discovered by the inventors.

SUMMARY

[0006] In an embodiment, a steerable attachment comprises: an attachment body, wherein the attachment body comprises a fastening portion, and wherein the fastening portion is configured to attach to a work machine; a blade connected to the attachment body and configured to flatten a surface; at least one ground-engaging member; a steerable axle system connected to the attachment body and configured to steer and rotate the at least one ground-engaging member; and an attachment electronic control module configured to receive one or more steering commands from a machine electronic control module in the work machine, actuate the steerable axle system according to the one or more steering commands, measure a position of the steerable axle system, calculate a steering radius of the steerable axle system based on the measured position, and send the calculated steering radius to the machine electronic control module.

[0007] In an embodiment, a steerable attachment comprises: an attachment body, wherein the attachment body comprises a fastening portion, and wherein the fastening portion is configured to attach to a work machine; a blade connected to the attachment body and configured to flatten a surface, wherein the blade is joined to the attachment body along a central axis, and configured to rotate around the central axis; at least one ground-engaging member; a steerable axle system connected to the attachment body and configured to steer and rotate the at least one ground-engaging member, wherein the steerable axle system comprises at least one all-wheel drive hub,

and wherein the at least one ground-engaging member is driven by the at least all-wheel drive hub; and an attachment electronic control module configured to receive one or more steering commands from a machine electronic control module in the work machine, actuate the steerable axle system according to the one or more steering commands, measure a position of the steerable axle system, calculate a steering radius of the steerable axle system based on the measured position, and send the calculated steering radius to the machine electronic control module.
[0008] In an embodiment, a method of controlling an steerable attachment that is attached to a work machine, comprises: by a machine electronic control module in the work machine, receiving a steering control from one or more machine controls in the work machine, sending one or more steering commands to an attachment electronic control module in the steerable attachment based on the steering control, receiving a steering radius from the attachment electronic control module, and matching a steering radius of the work machine to the received steering radius; and by the attachment electronic control module in the steerable attachment, receiving the one or more steering commands from the machine electronic control module, actuating a steerable axle system of the steerable attachment according to the one or more steering commands, measuring a position of the steerable axle system, calculating a steering radius of the steerable axle system based on the measured position, and sending the calculated steering radius to the machine electronic control module.

Description

BRIEF DESCRIPTION OF THE DRAWINGS
[0009] The details of embodiments of the present disclosure, both as to their structure and operation, may be gleaned in part by study of the accompanying drawings, in which like reference numerals refer to like parts, and in which:
[0010] FIG. **1** illustrates a side view of a work machine with a steerable attachment, according to an embodiment;
[0011] FIG. **2** illustrates a top-down schematic of a steerable attachment for a work machine, according to an embodiment;
[0012] FIG. **3** illustrates a schematic of a steerable axle system in isolation, according to an embodiment;
[0013] FIG. **4** illustrates a process for steering control, according to an embodiment;
[0014] FIG. **5** illustrates a process for actuating a steerable axle system, according to an embodiment; and
[0015] FIG. **6** illustrates an example of a controller, according to an embodiment.
DETAILED DESCRIPTION
[0016] The detailed description set forth below, in connection with the accompanying drawings, is intended as a description of various embodiments, and is not intended to represent the only embodiments in which the disclosure may be practiced. The detailed description includes specific details for the purpose of providing a thorough understanding of the embodiments. However, it will be apparent to those skilled in the art that embodiments of the invention can be practiced without these specific details. In some instances, well-known structures and components are shown in simplified form for brevity of description. In addition, it should be understood that the various components illustrated herein are not necessarily drawn to scale. In other words, the features disclosed in various embodiments may be implemented using different relative dimensions within and between components than those illustrated in the drawings.
[0017] FIG. **1** illustrates a side view of a work machine **100** with a steerable attachment **200**, according to an embodiment. Work machine **100** is illustrated as a skid steer, and particularly, a compact track loader. Examples of compact track loaders include the Models **239**, **349**, **359**, **255**,

265, **279**, **289**, and **299** of compact track loaders, offered by Caterpillar Inc. of Irving, Texas. Work machine **100** could also be a skid steer loader, such as Models **226**, **232**, **236**, **242**, **246**, **262**, and **272** of skid steer loaders, offered by Caterpillar Inc. More generally, work machine **100** may be any type or model of equipment that can use steerable attachment **200**, for instance, in an industrial site in which construction, mining, agriculture, forestry, paving, and/or the like are performed. Work machine **100** may be operated by a human (e.g., locally or remotely) or by an autonomous system. In addition, work machine **100** may be powered by an internal combustion engine and/or may be electrically powered by an on-board battery pack.

[0018] Work machine **100** may comprise a machine body **110**. Machine body **110** may comprise a sturdy frame that supports the cabin, engine, transmission, battery pack, actuators, and/or other components of work machine **100**.

[0019] Machine body **110** may support a pair of loader arms **120**. Loader arms **120** may be raised and lowered via a hydraulic system. The hydraulic system may comprise a cylindrical housing and a piston that extends out of and retracts into the cylindrical housing, according to hydraulic pressure applied to the piston. Alternatively, loader arms **120** may be raised and lowered and/or otherwise manipulated via a different actuating mechanism.

[0020] Loader arms **120** are configured to be equipped with a standard work implement. In the case that work machine is a skid steer or wheel loader, this standard work implement may be a bucket for digging, scraping, lifting, carrying, or otherwise moving material. In the illustrated embodiment, the bucket or other standard work implement has been removed, and loader arms **120** have been equipped with steerable attachment **200**, as discussed elsewhere herein. In an alternative embodiment, work machine **100** may comprise a different mechanism from loader arms **120** for attaching steerable attachment **200**.

[0021] Work machine **100** may comprise at least one, and generally a plurality of, ground-engaging members **130**. Ground-engaging members **130** are illustrated as a track or pair of tracks. In an alternative embodiment, ground-engaging members **130** may comprise wheels with tires. More generally, ground-engaging member(s) **130** may comprise any mechanism for supporting work machine **100** above the ground, and preferably moving work machine **100** relative to the ground.

[0022] Work machine **100** may comprise one or more machine controls **140**. Machine control(s) **140** may be designed to provide a local operator, remote operator, or autonomous system command over the various functions of work machine **100**, including turning work machine **100** on and off, steering work machine **100**, increasing and decreasing the speed of work machine **100**, raising and lowering loader arms **120**, and/or the like. Machine control(s) **140** can be housed within the cabin of work machine **100**, in which case machine control(s) **140** may be designed for use by a local operator. In this case, machine control(s) **140** may include one or more joysticks, a steering wheel, one or more pedals, one or more levers, and/or the like, which control various functions of work machine **100**. Alternatively or additionally, work machine **100** may comprise electronic interfaces (e.g., touchscreen console(s)) that enable the local operator to access various functions of work machine **100** and/or provide real-time information about the operation of work machine **100**. In an embodiment, machine control(s) **140** may also provide command over one or more functions of steerable attachment **200**.

[0023] Work machine **100** may comprise a machine electronic control module (ECM) **150**. It should be understood that the illustrated position of machine electronic control module **150** is merely representative, and that the actual position of machine electronic control module **150** may be any suitable location on or within machine body **110**. Machine electronic control module **150** may be configured to receive commands from machine control(s) **140**, calculate one or more control parameters from these commands, and utilize the control parameters to actuate one or more components of work machine **100**, such as loader arms **120** and ground-engaging members **130**. The control parameter(s) may comprise a turn radius of ground-engaging members **130** (e.g., tracks) and/or a differential speed between the pair of ground-engaging members **130**. In an embodiment, machine electronic control module **150** is further configured to utilize the control parameters to actuate one or more components of steerable attachment **200**, coordinate turning with steerable attachment **200**, and/or the like, as will be discussed elsewhere herein.

[0024] Steerable attachment **200** may comprise an attachment body **210** with a fastening portion **215**. Fastening portion **215** is configured to fasten to work machine **100**, so as to attach steerable attachment **200** to work machine **100**. For example, fastening portion **215** may be configured to be secured to loader arms **120**. In an embodiment, fastening portion **215** utilizes the same fastening mechanism as the standard work implement that work machine **100** utilizes. In the case of a skid steer or wheel loader, fastening portion **215** may comprise a pair of engagement members, that are identical or similar to the engagement members on the bucket. Each engagement member may be configured to connect to the front end of a respective one of the pair of loader arms **120**, via one or more pins, screws, bolts, and/or the like.

[0025] Steerable attachment **200** may comprise one or more ports or cables that connect to corresponding cables or ports on work machine **100**, through fastening portion **215**. These physical connections may be used for communications between work machine **100** and steerable attachment **200** and/or for supplying power and/or hydraulic fluid from work machine **100** to components of steerable attachment **200**. In a particular implementation, a 14-pin connector is used to electronically connect steerable attachment **200** to work machine **100**.

[0026] Steerable attachment **200** may comprise a blade **220**, which may also be referred to as a moldboard. It should be understood that blade **220** serves as the primary tool for grading and other tasks. Blade **220** is positioned below attachment body **210** and connected to attachment body **210**. Blade **220** may be configured to pivot (roll), relative to attachment body **210**, within a range of angles around a horizontal longitudinal axis X that bisects blade **220**. Blade **220** may also be configured to pivot (yaw), relative to attachment body **210**, within a range of angles around a vertical central axis Y that bisects blade **220**. Blade **220** may also be configured to pivot (pitch), relative to attachment body **210**, within a range of angles around a horizontal lateral axis Z through blade **220**. In each case, blade **220** may be pivoted by one or more hydraulic systems. Each hydraulic system may comprise a cylindrical housing and a piston that extends out of and retracts into the cylindrical housing, according to hydraulic pressure applied to the piston, to thereby push or pull an end of blade **220** around the respective axis. In an alternative embodiment, steerable attachment **200** may comprise a different mechanism for pivoting blade **220** around longitudinal axis X, central axis Y, or lateral axis Z. Blade **220** may also be configured to be raised or lowered, relative to attachment body **210**, within a range of distances along vertical central axis Y. Thus, blade **220** can be angled, tilted, raised, and/or lowered to move, cut, and/or otherwise shape materials. Different types of blade **220** may be swapped in or out of steerable attachment **200**, such as straight blades for general grading and V-shaped blades for cutting through tough materials.

[0027] Steerable attachment **200** may comprise a steerable axle system **300** at the opposite end of attachment body **210** as fastening portion **215**. Steerable axle system **300**, which will be described in further detail elsewhere herein, may drive at least one, and preferably a pair of, ground-engaging members **230** on either side of steerable axle system **300**. Each ground-engaging member **230** may comprise a wheel with a tire.

[0028] Steerable attachment **200** may comprise an attachment electronic control module **250**. It should be understood that the illustrated position of attachment electronic control module **250** is merely representative, and that the actual position of attachment electronic control module **250** may be any suitable location on or within attachment body **210**. Attachment electronic control module **250** may be configured to control one or more components of steerable attachment **200**, including blade **220** and/or steerable axle system **300**. Of particular relevance to disclosed embodiments, attachment electronic control module **250** may be configured to receive steering commands from machine electronic control module **150** in work machine **100**, actuate steerable axle system **300** according to the steering commands, measure the position of steerable axle system **300**, calculate a steering radius of steerable axle system **300** based on the measured position, and send the calculated steering radius to machine electronic control module **150** to coordinate the turning of ground-engaging member(s) **230** of steerable attachment **200** with the turning of ground-engaging member(s) **130** of work machine **100**. In this case, the steering commands may comprise a turn radius of ground-engaging members **130** (e.g., two tracks) and/or a differential speed between ground-engaging members **130** of work machine **100**. In addition, attachment electronic control module **250** may be configured to receive control parameters for actuating blade **220** (e.g., to rotate around axes X, Y, and/or Z) from machine electronic control module **150**, and actuate blade **220** according to the control parameter(s). Alternatively, blade **220** could be actuated by direct hydraulic control through machine electronic control module **150**.

[0029] Attachment electronic control module **250** may be configured to communicate with machine electronic control module **150** (e.g., to receive steering commands and/or other control parameters, send the calculated steering radius, etc.) via a wired connection. For example, one or more cables may be run from attachment electronic control module **250**, through the interface between fastening portion **215** and work machine **100**, to machine electronic control module **150**. Alternatively or additionally, attachment electronic control module **250** may be configured to communicate with machine electronic control module **150** via wireless communication. For example, attachment electronic control module **250** may comprise a wireless receiver or transceiver, and machine electronic control module **150** may comprise a wireless transmitter or transceiver that is configured to communicate with the wireless receiver or transceiver of attachment electronic control module **250** via a standard or non-standard wireless communication protocol.

[0030] FIG. **2** illustrates a top-down schematic of a steerable attachment **200** for a work machine **100**, according to an embodiment. As described above, steerable attachment **200** may comprise an attachment body **210** with a fastening portion **215**, a blade **220** that is configured to pivot around axes X, Y, and/or Z under the control of attachment electronic control module **250** or machine electronic control module **150**, and one or more ground-engaging members **230** (e.g., one or two wheels) that can be steered and driven by steerable axle system **300**.

[0031] FIG. **3** illustrates a schematic of a steerable axle system **300** in isolation, according to an embodiment. Steerable axle system **300**, which is connected to attachment body **210**, may comprise a rod **310** and at least two all-wheel drive (AWD) hubs **320**. Rod **310** may extend between AWD hubs **320**. Each end of rod **310** may be attached to a respective one of AWD hubs **320** by a respective spindle **330**. In particular, each spindle **330** may be fixed to the respective AWD hub **320** and joined to rod **310** by a respective kingpin **340**, which enables spindle **330** and AWD hub **320** to pivot, relative to rod **310**, for steering. For example, the left end of rod **310** may be connected to the left AWD hub **320**L via left spindle **330**L, which is joined to the left end of rod **310** via left kingpin **340**L, and the right end of rod **310** may be connected to the right AWD hub **320**R via right spindle **330**R, which is joined to the right end of rod **310** via right kingpin **340**R.

[0032] As used herein, a reference numeral without an appended letter, but with the same numerical component as a reference numeral with an appended letter, will be used to refer to that component generically. For example, the term “AWD hub **320**” may refer to either AWD hub **320**R or AWD hub **320**L, and the term “AWD hubs **320**” may refer collectively to AWD hub **320**R and AWD hub **320**L.

[0033] Each ground-engaging member **230** (e.g., wheel) of steerable attachment **200** may be driven by a respective one of AWD hubs **320**. For example, a left wheel may be mounted on and driven by left AWD hub **320**L, and a right wheel may be mounted on and driven by a right AWD hub **320**R. Each AWD hub **320** may comprise a motor that is configured to drive a respective ground-engaging member **230**, independently of the other AWD hub **320** and ground-engaging member **230**. Thus, for example, left AWD hub **320**L may drive the left ground-engaging member **230** at a different speed than the speed at which right AWD hub **320**R drives the right ground-engaging member **230**. In other words, there may be a speed differential between a pair of ground-engaging members **230**.

[0034] Steerable axle system **300** may comprise a tie rod **350** connected between at least two steering arms **370**. Each steering arm **370** is connected to a respective one of ground-engaging members **230** (e.g., wheels) by virtue of being connected to a respective one of AWD hubs **320**. For instance, the left end of tie rod **350** is connected to left AWD hub **320**L via left steering arm **370**L, and the right end of tie rod **350** is connected to right AWD hub **320**R via right steering arm **370**R. Tie rod **350** ensures that steering arms **370**, and therefore, AWD hubs **320** and their respective ground-engaging members **230**, move in unison and in parallel. For example, when left steering arm **370**L moves, tie rod **350** fixes the distance between left steering arm **370**L and right steering arm **370**R, such that right steering arm **370**R moves in an identical manner to left steering arm **370**L.
[0035] Steerable axle system **300** may comprise at least two steering actuators **360**. Each steering actuator **360** may comprise a hydraulic system that is connected between a frame of steerable axle system **300** and a respective steering arm **370**. The hydraulic system may comprise a cylindrical housing and a piston, connected to a respective steering arm **370**, that extends out of and retracts into the cylindrical housing, according to hydraulic pressure applied to the piston. When the piston of steering actuator **360** extends, the piston may push a respective steering arm **370** laterally outward, to thereby steer the connected AWD hub **320** in a first direction. Conversely, when the piston of steering actuator **360** retracts, the piston may pull the end of a respective steering arm **370** laterally inward, to thereby steer the connected AWD hub **320** in a second direction that is opposite the first direction. It should be understood that tie rod **350** fixes the distance between the ends of steering arms **370** that are pushed or pulled, such that steering arms **370** and their respective AWD hubs **320** move in unison and in parallel. Thus, a pair of steering actuators **360** may operate in conjunction to steer ground-engaging members **230** in the first or second direction. For example, right steering actuator **360**R may extend and left steering actuator **360**L may retract to steer ground-engaging members **230**, mounted on AWD hubs **320**, to the right. Similarly, right steering actuator **360**R may retract and left steering actuator **360**L may extend to steer ground-engaging members **230**, mounted on AWD hubs **320**, to the left. In an alternative embodiment, steering actuators **360** may comprise a different actuating mechanism.
[0036] Steerable axle system **300** may comprise a steering sensor **380** that measures the position of steerable axle system **300**. In particular, steering sensor **380** may measure the position of one or both of steering actuators **360**. Steering sensor **380** may communicate the measured position(s), in real time, via wired or wireless communication, to attachment electronic control module **250**.
[0037] It should be understood that this is simply one example of steerable axle system **300**. There are numerous other architectures for implementing a steerable axle system **300** that is capable of steering and/or rotating one or more ground-engaging members **230**. For example, in an alternative embodiment, instead of being steered together, each ground-engaging member **230** may be independently steered. In particular, each ground-engaging member **230** may be connected to a separate electric or hydraulic motor that is configured to steer that ground-engaging member **230**, independently of any other ground-engaging member **230**. In any embodiment, ground-engaging member(s) **230** may be rotated by independent AWD hubs **320**, may be rotated by some other mechanism, or may be castor wheels that are not directly rotated with wheel torque (e.g., but are indirectly rotated by ground-engaging members **130** of work machine **100**).
[0038] FIG. **4** illustrates a process **400** for steering control, according to an embodiment. Process **400** may be implemented by machine electronic control module **150**. While process **400** is illustrated with a certain arrangement and ordering of subprocesses, process **400** may be implemented with fewer, more, or different subprocesses and a different arrangement and/or ordering of subprocesses. In addition, it should be understood that any subprocess, which does not depend on the completion of another subprocess, may be executed before, after, or in parallel with that other independent subprocess, even if the subprocesses are described or illustrated in a particular order.

[0039] In subprocess **410**, it is determined whether or not work machine **100** has been shutdown. When work machine **100** is shutdown (i.e., "Yes" in subprocess **410**), process **400** may end. Otherwise, when work machine **100** remains operating (i.e., "No" in subprocess **410**), process **400** may proceed to subprocess **420**. It should be understood that process **400** executes in real time as work machine **100** is operated, and therefore, may be executed many times a second.

[0040] In subprocess **420**, it is determined whether or not work machine **100** is operating in an attachment mode. The attachment mode may be a setting that can be manually activated and deactivated by the operator of work machine **100**. For example, machine control(s) **140** may comprise a button, switch, or other input for turning the attachment mode on and off. Alternatively or additionally, the attachment mode may be automatically activated whenever a connection between work machine **100** and steerable attachment **200** is detected. This connection may be automatically detected based on a sensor that detects a physical connection (e.g., via fastening portion **215**), the completion of a "handshake" protocol or pairing between machine electronic control module **150** and attachment electronic control module **250**, and/or the like. When work machine **100** is operating in the attachment mode (i.e., "Yes" in subprocess **420**), process **400** may proceed to subprocess **430**. Otherwise, when work machine **100** is not operating in the attachment mode (i.e., "No" in subprocess **420**), process **400** may operate in the normal mode in subprocess **470**. It should be understood that the normal mode is the standard mode of operation for work machine **100**.

[0041] In subprocess **430**, it is determined whether or not a steering control has been received. Steering control may be received from one or more machine controls **140** in work machine **100** (e.g., being operated by a local operator). For example, the steering control may comprise the position(s) of machine control(s) **140** (e.g., a joystick), which represent turning work machine **100** (e.g., left or right), changing a speed of steering work machine **100** (e.g., via acceleration or deceleration), and/or the like. When a steering control is received (i.e., "Yes" in subprocess **430**), process **400** proceeds to subprocess **440**. Otherwise, process **400** may return to subprocess **410**.

[0042] In subprocess **440**, one or more steering commands, representing the steering control received in subprocess **430**, are sent from machine electronic control module **150** to attachment electronic control module **250**. The steering commands may be sent via a wired connection through fastening portion **215**. In this case, the same electronic connection between machine electronic control module **150** and steerable attachment **200**, which is used to control blade **220**, may also be used to communicate the steering commands. Alternatively, the steering commands may be sent via wireless communication from a transmitter of machine electronic control module **150** to a receiver of attachment electronic control module **250**.

[0043] The steering commands may comprise the steering control or be otherwise derived from the steering control. For example, one or more control parameters, such as the turn radius and/or differential speed (e.g., differential track speed) for ground-engaging members **130** of work machine **100**, may be determined based on the steering control that was received in subprocess **410**. These values may be determined using a map, stored in a memory of machine electronic control module **150**, that maps the position(s) of machine control(s) **140**, as represented in the steering control, to values of turn radius and/or differential speed. For example, machine control(s) **140** may comprise a joystick that moves in a forward-aft axis for changing the speed of work machine **100** and a left-right axis for steering work machine **100**. In this case, the stored map may comprise a two-dimensional map that specifies the relative speed of the right and left ground-engaging members **130** (e.g., tracks) for all positions of the joystick in the forward-aft and left-right axes. In an alternative embodiment, the turn radius and/or differential speed may be determined in a different manner, or the values of additional or different control parameter(s) may be determined. In any case, the steering commands for steerable attachment **200** may comprise or be derived from the values of these control parameter(s).

[0044] In subprocess **450**, the steering radius of steerable axle system **300** is received from attachment electronic control module **250**. This steering radius represents feedback about the turn radius that steerable axle system **300** is capable of achieving, given the steering commands sent in subprocess **440**. The steering radius of steerable axle system **300** may be calculated by attachment electronic control module **250**, as discussed elsewhere herein.

[0045] In subprocess **460**, the steering radius of work machine **100** is matched to the steering radius of steerable axle system **300** that was received in subprocess **450**. For instance, the steering control for work machine **100**, which was received in subprocess **430**, may be changed, constrained, or otherwise manipulated, to prevent the turn radius of work machine **100** from exceeding the capability of steerable attachment **200**. In a simple example, the steering radius for work machine **100** may be changed to the steering radius of steerable axle system **300**. In a more complicated example, the steering radius of work machine **100** may be mapped or calculated from the steering radius of steerable axle system **300**. Notably, subprocesses **430-460** form a closed feedback loop that ensures that the steering capability of work machine **100** does not exceed the steering capability of steerable attachment **200**.

[0046] FIG. **5** illustrates a process **500** for actuating steerable axle system **300**, according to an embodiment. Process **500** may be implemented by attachment electronic control module **250**. While process **500** is illustrated with a certain arrangement and ordering of subprocesses, process **500** may be implemented with fewer, more, or different subprocesses and a different arrangement and/or ordering of subprocesses. In addition, it should be understood that any subprocess, which does not depend on the completion of another subprocess, may be executed before, after, or in parallel with that other independent subprocess, even if the subprocesses are described or illustrated in a particular order.

[0047] In subprocess **510**, it is determined whether or not steerable attachment **200** has been shutdown. When steerable attachment **200** is shutdown (i.e., “Yes” in subprocess **510**), process **500** may end. Otherwise, when steerable attachment **200** remains operating (i.e., “No” in subprocess **510**), process **500** may proceed to subprocess **520**. It should be understood that process **500** executes in real time as steerable attachment **200** is operated, and therefore, may be executed many times a second.

[0048] In subprocess **520**, it is determined whether or not one or more steering commands have been received. Steering command(s) may be received from machine electronic control module **150**, as the reception side of the sending in subprocess **440** of process **400**. The steering command(s) may comprise the turn radius and/or differential speed, control commands for the steerable attachment **200** based on the turn radius and/or differential speed, and/or the like. When steering command(s) are received (i.e., “Yes” in subprocess **520**), process **500** proceeds to subprocess **530**. Otherwise, when no steering command(s) are received (i.e., “No” in subprocess **520**), process **500** may return to subprocess **510**.

[0049] In subprocess **530**, steerable axle system **300** is actuated according to the steering command(s) that were received in subprocess **520**. In an embodiment in which the steering command(s) include control commands, attachment electronic control module **250** may execute the control commands. In an embodiment in which the steering command(s) include the turn radius, differential speed, and/or other parameter values, attachment electronic control module **250** may determine control commands from these parameter values. For example, attachment electronic control module **250** may derive a turn radius and/or differential speed for ground-engaging members **230** based on the turn radius and/or differential speed for ground-engaging members **130** of work machine **100**. In this case, the turn radius and/or differential speed for ground-engaging members **230** may be the same as the turn radius and/or differential speed for ground-engaging members **130** of work machine **100**. Alternatively, attachment electronic control module **250** may comprise a map, stored in a memory of attachment electronic control module **250**, that maps the turn radius, differential speed, and/or other parameter values, received from machine electronic control module **150**, to the turn radius, differential speed, and/or other parameter values for ground-engaging members **230**. In any case, the derived parameter values may be used to generate control commands that are then executed by attachment electronic control module **250** to actuate components of steerable axle system **300** to steer and drive ground-engaging members **230**. For example, the control commands may actuate steering actuators **360** to steer ground-engaging members **230**, and/or actuate AWD hubs **320** to drive ground-engaging members **230**.

[0050] In subprocess **540**, the position of steerable axle system **300** may be measured. In particular, the position of one or both of steering actuators **360** and/or other components of steerable axle system **300** may be measured by steering sensor **380** and communicated from steering sensor **380** to attachment electronic control module **250**, via wired or wireless communication.

[0051] In subprocess **550**, the steering radius of steerable axle system **300** is calculated based on the position(s) measured in subprocess **540**. For example, the steering radius of steerable axle system **300** may be mapped or calculated from the measured position(s). This steering radius represents feedback about the turn radius that steerable axle system **300** is capable of achieving.

[0052] In subprocess **560**, the steering radius, calculated in subprocess **550**, is sent from attachment electronic control module **250** to machine electronic control module **150**. Subprocess **560** represents the transmission side of the receiving in subprocess **450** of process **400**. Notably, subprocesses **520-560** form a closed feedback loop that ensures that the steering of steerable attachment **200** is coordinated with the steering of work machine **100**.

[0053] FIG. **6** illustrates an example of a controller **600**, according to an embodiment. Controller **600** may represent machine electronic control module **150** and/or attachment electronic control module **250**.

[0054] Controller **600** may comprise one or more processors **610**. Processor(s) **610** may comprise a central processing unit (CPU). Additional processors may be provided, such as a graphics processing unit (GPU), an auxiliary processor to manage input/output, an auxiliary processor to perform floating-point mathematical operations, a special-purpose microprocessor having an architecture suitable for fast execution of signal-processing algorithms (e.g., digital-signal processor), a subordinate processor (e.g., back-end processor), an additional microprocessor or controller for dual or multiple processor systems, and/or a coprocessor. Such auxiliary processors may be discrete processors or may be integrated with a main processor **610**. Examples of processors which may be used include, without limitation, any of the processors (e.g., Pentium™, Core i7™, Xeon™, etc.) available from Intel Corporation of Santa Clara, California, any of the processors available from Advanced Micro Devices, Incorporated (AMD) of Santa Clara, California, any of the processors (e.g., A series, M series, etc.) available from Apple Inc. of Cupertino, any of the processors (e.g., Exynos™) available from Samsung Electronics Co., Ltd., of Seoul, South Korea, any of the processors available from NXP Semiconductors N.V. of Eindhoven, Netherlands, and/or the like.

[0055] Processor **610** may be connected to a communication bus **605**. Communication bus **605** may include a data channel for facilitating information transfer between storage and other peripheral components of machine electronic control module **150**. Furthermore, communication bus **605** may provide a set of signals used for communication with processor **610**, including a data bus, address bus, and/or control bus (not shown). Communication bus **605** may comprise any standard or non-standard bus architecture such as, for example, bus architectures compliant with industry standard architecture (ISA), extended industry standard architecture (EISA), Micro Channel Architecture (MCA), peripheral component interconnect (PCI) local bus, standards promulgated by the Institute of Electrical and Electronics Engineers (IEEE) including IEEE 488 general-purpose interface bus (GPIB), IEEE 696/S-100, and/or the like.

[0056] Controller **600** may comprise main memory **615**. Main memory **615** provides storage of instructions and data for programs executing on processor **610**, such as one or more of the processes or functions discussed herein, such as process **400** or **500**. It should be understood that programs stored in the memory and executed by processor **610** may be written and/or compiled according to any suitable language, including without limitation C/C++, Java, JavaScript, Perl, Python, Visual Basic, .NET, and the like. Main memory **615** is typically semiconductor-based memory such as dynamic random access memory (DRAM) and/or static random access memory (SRAM). Other semiconductor-based memory types include, for example, synchronous dynamic random access memory (SDRAM), Rambus dynamic random access memory (RDRAM), ferroelectric random access memory (FRAM), and the like, including read only memory (ROM).

[0057] Controller **600** may comprise secondary memory **620**. Secondary memory **620** is a non-transitory computer-readable medium having computer-executable code and/or other data (e.g., software implementing any process or function described herein) stored thereon. In this description, the term “computer-readable medium” is used to refer to any non-transitory computer-readable storage media used to provide computer-executable code and/or other data to or within controller **600**. The computer software stored on secondary memory **620** is read into main memory **615** for execution by processor **610**. Secondary memory **620** may include, for example, semiconductor-based memory, such as programmable read-only memory (PROM), erasable programmable read-only memory (EPROM), electrically erasable read-only memory (EEPROM), and flash memory (block-oriented memory similar to EEPROM).

[0058] Controller **600** may comprise an input/output (I/O) interface **635**. I/O interface **635** provides an interface between one or more components of controller **600** and one or more input and/or output devices. For example, I/O interface **635** may receive the output of one or more sensors, and/or output control signals to one or more of the components of work machine **100** or steerable attachment **200**.

[0059] Controller **600** may comprise a communication interface **640**. Communication interface **640** allows signals, such as data and software, to be transferred between controller **600** and external devices, networks, or other information sources and/or destinations. For example, computer-executable code and/or data may be transferred to controller **600**, over one or more networks, from a network server via communication interface **640**. Examples of communication interface **640** include a built-in network adapter, network interface card (NIC), Personal Computer Memory Card International Association (PCMCIA) network card, card bus network adapter, wireless network adapter, Universal Serial Bus (USB) network adapter, modem, a wireless data card, a communications port, an infrared interface, an IEEE 1394 fire-wire, and any other device capable of interfacing controller **600** with a network or another computing device. Communication interface **640** preferably implements industry-promulgated protocol standards, such as Ethernet IEEE 802 standards, Fiber Channel, digital subscriber line (DSL), asynchronous digital subscriber line (ADSL), frame relay, asynchronous transfer mode (ATM), integrated digital services network (ISDN), personal communications services (PCS), transmission control protocol/Internet protocol (TCP/IP), serial line Internet protocol/point to point protocol (SLIP/PPP), and so on, but may also implement customized or non-standard interface protocols as well.

[0060] Software transferred via communication interface **640** is generally in the form of electrical communication signals **655**. These signals **655** may be provided to communication interface **640** via a communication channel **650** between communication interface **640** and an external system **645**. In an embodiment, communication channel **650** may be a wired or wireless network, or any variety of other communication links. Communication channel **650** carries signals **655** and can be implemented using a variety of wired or wireless communication means including wire or cable, fiber optics, conventional phone line, cellular phone link, wireless data communication link, radio frequency (“RF”) link, or infrared link, just to name a few.

[0061] Computer-executable code is stored in main memory **615** and/or secondary memory **620**. Computer-executable code can also be received from an external system **645** via communication interface **640** and stored in main memory **615** and/or secondary memory **620**. Such computer-executable code, when executed by processor(s) **610**, enable controller **600** to perform the various processes or functions disclosed herein, such as process **400** or **500**.

INDUSTRIAL APPLICABILITY

[0062] Traditionally, for certain grading tasks in which a motor grader is not suitable or available, a grader attachment, with caster wheels and a blade or moldboard, may be attached to a work machine **100**, such as a skid steer. However, such systems have difficulty operating on irregular terrains, in which lateral forces on blade **220** may cause the caster wheels to lose traction.

[0063] Accordingly, a steerable attachment **200** is disclosed with ground-engaging members **230** (e.g., wheels) that can be steered and/or driven via an attachment electronic module **250**, which is in communication with machine electronic control module **150** of work machine **100**. In particular, machine electronic control module **150** may process steering controls from machine control(s) **140**, and convert these into steering commands, which are then sent to attachment electronic control module **250**. Attachment electronic control module **250** then steers and/or drives ground-engaging members **230** according to these steering commands, and provides feedback about the steering radius of steerable attachment **200** to machine electronic control module **150**. Machine electronic control module **150** uses this feedback to match the steering radius of work machine **100** to the steering radius of steerable attachment **200**. In other words, steerable attachment **200** is controlled, in coordination with work machine **100**, using the same machine control(s) **140** on work machine **100**.

[0064] Steerable attachment **200** offers a variety of benefits, including improved steering and traction, higher mechanical advantage, higher machine load, and/or the like. In turn, these benefits improve the functionality of steerable attachment **200**. For example, by providing smooth coordinated movement of work machine **100** and steerable attachment **200**, work machine **100** is less likely to perturb the ground behind blade **220**, resulting in improved grading results. In addition, having motorized ground-engaging members **230** in front of blade **220** helps to counter the forces on blade **220**, which are otherwise borne entirely by ground-engaging members **130** of work machine **100**.

[0065] It will be understood that the benefits and advantages described above may relate to one embodiment or may relate to several embodiments. Aspects described in connection with one embodiment are intended to be able to be used with the other embodiments. Any explanation in connection with one embodiment applies to similar features of the other embodiments, and elements of multiple embodiments can be combined to form other embodiments. The embodiments are not limited to those that solve any or all of the stated problems or those that have any or all of the stated benefits and advantages.

[0066] The preceding detailed description is merely exemplary in nature and is not intended to limit the invention or the application and uses of the invention. The described embodiments are not limited to usage in conjunction with a particular type of industrial context or with a particular type of work machine. Hence, although the present embodiments are, for convenience of explanation, depicted and described as being implemented with construction equipment, it will be appreciated that it can be implemented for various other types of equipment, and in various other environments. Furthermore, there is no intention to be bound by any theory presented in any preceding section. It is also understood that the illustrations may include exaggerated dimensions and graphical representation to better illustrate the referenced items shown, and are not considered limiting unless expressly stated as such.

Claims

1. A steerable attachment comprising: an attachment body, wherein the attachment body comprises a fastening portion, and wherein the fastening portion is configured to attach to a work machine; a blade connected to the attachment body and configured to flatten a surface; at least one ground-engaging member; a steerable axle system connected to the attachment body and configured to steer and rotate the at least one ground-engaging member; and an attachment electronic control module configured to receive one or more steering commands from a machine electronic control module in the work machine, actuate the steerable axle system according to the one or more steering commands, measure a position of the steerable axle system, calculate a steering radius of the steerable axle system based on the measured position, and send the calculated steering radius to the machine electronic control module.

2. The steerable attachment of claim 1, wherein the blade is joined to the attachment body along a central axis, and configured to rotate around the central axis.

3. The steerable attachment of claim 1, wherein the steerable axle system comprises at least one all-wheel drive hub, and wherein the at least one ground-engaging member comprises a wheel that is driven by the at least one all-wheel drive hub.

4. The steerable attachment of claim 3, wherein the at least one all-wheel drive hub comprises at least two all-wheel drive hubs, wherein the steerable axle system comprises a rod extending between the at least two all-wheel drive hubs, and wherein each end of the rod is attached to a respective one of the at least two all-wheel drive hubs by a respective spindle.

5. The steerable attachment of claim 1, wherein the at least one ground-engaging member comprises at least two wheels, wherein the steerable axle system comprises a tie rod connected between at least two steering arms, and wherein each of the at least two steering arms is connected to a respective one of the at least two wheels.

6. The steerable attachment of claim 5, wherein the steerable axle system comprises at least two steering actuators, and wherein each of the at least two steering actuators is connected to a respective one of the at least two steering arms and configured to extend and retract.

7. The steerable attachment of claim 1, wherein the attachment electronic control module is configured to receive the one or more control parameters via a wired connection through the fastening portion.

8. The steerable attachment of claim 1, wherein the attachment electronic control module is configured to receive the one or more control parameters via wireless communication.

9. The steerable attachment of claim 1, wherein the one or more steering commands comprise one or both of a turn radius or a differential speed between the at least two wheels.

10. An assembly comprising: the work machine; and the steerable attachment of claim 1, attached to the work machine via the fastening portion.

11. The assembly of claim 10, wherein the work machine comprises: one or more machine controls; and a machine electronic control module configured to receive a steering control from the one or more machine controls, send the one or more steering commands to the attachment electronic control module based on the steering control, receive a steering radius from the attachment electronic control module, and match a steering radius of the work machine to the received steering radius.

12. The assembly of claim 11, wherein the work machine further comprises a pair of tracks, and wherein the steering radius of the work machine is a steering radius of the pair of tracks.

13. The assembly of claim 10, wherein the work machine is a skid steer.

14. The assembly of claim 10, wherein the work machine comprises a pair of loader arms, wherein the fastening portion comprises a pair of engagement members, and wherein each of the pair of engagement members is configured to connect to a respective one of the pair of loader arms.

15. A steerable attachment comprising: an attachment body, wherein the attachment body comprises a fastening portion, and wherein the fastening portion is configured to attach to a work machine; a blade connected to the attachment body and configured to flatten a surface, wherein the blade is joined to the attachment body along a central axis, and configured to rotate around the central axis; at least one ground-engaging member; a steerable axle system connected to the attachment body and configured to steer and rotate the at least one ground-engaging member, wherein the steerable axle system comprises at least one all-wheel drive hub, and wherein the at least one ground-engaging member is driven by the at least all-wheel drive hub; and an attachment electronic control module configured to receive one or more steering commands from a machine electronic control module in the work machine, actuate the steerable axle system according to the one or more steering commands, measure a position of the steerable axle system, calculate a steering radius of the steerable axle system based on the measured position, and send the calculated steering radius to the machine electronic control module.

16. The steerable attachment of claim 15, wherein the at least one all-wheel drive hub comprises at least two all-wheel drive hubs, wherein the steerable axle system comprises a rod extending between the at least two all-wheel drive hubs, and wherein each end of the rod is attached to a respective one of the at least two all-wheel drive hubs by a respective spindle.

17. The steerable attachment of claim 15, wherein the at least one ground-engaging member comprises at least two ground-engaging members, wherein the steerable axle system comprises a tie rod connected between at least two steering arms, wherein each of the at least two steering arms is connected to a respective one of the at least two ground-engaging members, wherein the steerable axle system comprises at least two steering actuators, and wherein each of the at least two steering actuators is connected to a respective one of the at least two steering arms and configured to extend and retract.

18. A method of controlling an steerable attachment that is attached to a work machine, the method comprising: by a machine electronic control module in the work machine, receiving a steering control from one or more machine controls in the work machine, sending one or more steering commands to an attachment electronic control module in the steerable attachment based on the steering control, receiving a steering radius from the attachment electronic control module, and matching a steering radius of the work machine to the received steering radius; and by the attachment electronic control module in the steerable attachment, receiving the one or more steering commands from the machine electronic control module, actuating a steerable axle system of the steerable attachment according to the one or more steering commands, measuring a position of the steerable axle system, calculating a steering radius of the steerable axle system based on the measured position, and sending the calculated steering radius to the machine electronic control module.

19. The method of claim 18, wherein the one or more steering commands comprise one or both of a turn radius or a differential speed between at least two wheels of the steerable attachment.

20. The method of claim 18, wherein the work machine comprises a pair of tracks, and wherein the steering radius of the work machine is a steering radius of the pair of tracks.